REAL-TIME YARD MANAGEMENT

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EXECUTIVE SUMMARY

This report is the first deliverable in Work package (WP) 2 ‘Real-time Yard Management’ of the Automated Rail Cargo Consortium (ARCC) project. In WP 2 research and innovation activities lead to the analysis, understanding and definition of efficient business processes and a common understanding of decision processes and their optimisation and automation potential, focused on Marshalling yards and the interaction between Network/line management and the operations management in Marshalling yards and Terminals.

In chapter 2 and 3 of this report the different types of nodes considered in the WP (Marshalling yards, Terminals) are classified. A general overview about typologies, operational procedures and organisation is given. Four case studies in large Yards/Terminals in Germany and Sweden have been carried out in order to develop a common understanding and description of operational procedures and rules and of the decision processes in these types of nodes.

In chapter 4 of the report differences with one or multiple rail operators in Marshalling yards and Terminals are described. As the Swedish and the German situations are actually different, current state in both countries were considered.

Chapter 5 deals with the automation/optimisation capabilities of a ‘Real-time Yard Management’ in Yards and Terminals and for the interaction with Network management. As agreed in the project scope, description of automation/optimisation potential is focused on Marshalling yards and the interaction between Network/line management and the operations management in Marshalling yards and Terminals.

It is summarised in chapter 6 that a system that pro-actively could inform about the consequences of potential decisions is currently not available in any of the yards. As a result of the case studies, the decision makers in the yards also consider the development/ provision of such a decision support system as very useful and very much appreciated.

It can be expected, that a Real-time Yard Management in combination with an interacting Real-time Network Management will contribute to automation and digitalisation of monitoring and decision processes along the freight rail supply chain. Based on an advanced simulation/optimisation approach the expected impacts shall lead to improved punctuality, system efficiency and competitiveness of freight rail transportation.

ABBREVIATIONS AND ACRONYMS

Abbreviation	Description
ADR	Accord européen relatif au transport international des marchandises dangereuses par voie de navigation intérieure Rhin
ARA	Antwerp, Rotterdam, Amsterdam
ARCC	Automated Rail Cargo Consortium
BLU	Betriebsleitsystem für Umschlagbahnhöfe
C4R	Capacity for Rail
CIM	Convention internationale concernant le transport des marchandises par chemin de fer
COTIF	Convention relative aux transports internationaux ferroviaires
DB	Deutsche Bahn
DUSS	Deutsche Umschlaggesellschaft Schiene-Strasse
ERTMS	European Rail Traffic Management System
ETA	Estimated Time of Arrival
FM	Frequency Modulation
FOC	(Rail) Freight Operating Company
GA	Grant Agreement
GoA4	Grade of Automation
IM	(Railway) Infrastructure Manager
ISO	International Organization for Standardization
IT	Information Technology
IP	Innovation Programme
LeiDis	Leitsystem (Netz) Disposition
MAAP	Multi Annual Action Plan
MY	Marshalling Yard
Rbf	Rangierbahnhof
RID	Réglement international concernant le transport des marchandises dan-gereuses par chemin de fer
RNE	RailNetEurope
RTYM	Real-time Yard Management
RU	Railway Undertaking
S2R JU	Shift2Rail Joint Undertaking
SERA	Single European Railway Area
SWL	Single Wagon Load
SMART	Smart Automation of Rail Transport
TAF/TSI	Telematics Applications for Freight / Technical Specifications for Interoperability
TD	Technical Demonstrator
TEU	Twenty-foot Equivalent Unit
TIS	Train Information System
TRL	Technology Readiness Level
TRV	Trafikverket
UIC	Union internationale des chemins de fer
WP	Work Package

GLOSSARY OF TERMS

Due to different use of terms of railway operation, the following clarification is given for using in this report:

- A railway network in UIC terms consists of ***nodes*** and ***lines*** (links between nodes)
- Although ***nodes*** represented an arbitrary location in a railway network, predominant nodes stand for extended station areas, in which lines are crossing and/or composition/decomposition of trains take place.
- In the rail freight transport business, some especial railway facilities are necessary to ensure end-to-end-logistics chains for wagonload and/or combined transport. This includes unique type of nodes at a terminus or at intermediate points of the rail freight supply chain for shunting, assembling, sorting and marshalling trains or loading/unloading and storing wagons. These types of nodes are frequently designated as "Terminals". On the other hand, the term "Terminal" is used mainly for facilities with a possibility to transfer loading units between different transport modes and/or means of transportation. In this document, the unique types of ***freight nodes*** will be referred to as ***Marshalling yards, Terminals*** and/or (industrial) ***Sidings.***
- The term ***"(Railway) network***" will in this document be used for the network consisting of lines and their links to above mentioned types of freight nodes
- Main processes of ***Marshalling yards*** focus on the aggregation and disaggregation of trains and the wagon connection performance (right wagon on right train).
- ***Terminals*** will be defined as places, equipped for the transhipment (Rail-Road, Rail-Waterway) and storage of loading units (Containers, semitrailers, swap-bodies).
- The term ***Sidings*** will be used for rail subsystems with the scope of loading/unloading, storing wagons, shunting and train building activities at a local operating level (mainly at industrial companies' sites).

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 CONTEXT AND MOTIVATION

The research and innovation activities within the work stream Real-time Yard Management will be conducted in line with the Shift2Rail Multi-Annual Action Plan [MAAP, 2014].

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.

Work package (WP) 2 'Real-time Yard Management' is a main topic of the Automated Rail Cargo Consortium (ARCC) project "Rail freight automation research activities to boost level of quality, efficiency and cost effectiveness in all area of rail freight operations". The ARCC-project is related to the Shift2Rail (S2R) Work Plan 2015, Call identifier: H2020-S2RJU-2015-01 Topic: Member Call S2R-CFM-IP5-02-2015: "Start-up activities for freight automation".

As automation and digitalisation are key innovation drivers for the future of rail freight as a whole, IP5 and the ARCC project address the research vision throughout the lifetime of the S2R programme.

Marshalling yards and Terminals are important kinds of freight nodes in the end-to-end-logistics chain of rail freight transport. They are very relevant subsystems and especially of vital importance for (single) wagon load and multimodal transport.

Both market segments are under particular pressure of the increasing road freight transport. As the lack of cost-efficiency and punctuality of rail freight services is a source of dissatisfaction among rail customers, automation/optimisation can generate a substantial contribution for increasing the cost-competitiveness of these rail freight segments.

In WP 2 of the ARCC project, research and innovation activities will lead to the analysis, understanding and definition of efficient business processes and a common understanding of decision processes and their optimisation and automation potential, focused on Marshalling yards and the interaction between Network/line management and the operations management in Marshalling yards and Terminals. The overall aim of the ARCC-project is to carry out an initial phase of rail freight automation research activities in order to boost levels of quality, efficiency and cost effectiveness in rail freight operations of the European railway sector.

1.2 Scope and Objectives

In large freight nodes, vast and complex yard operations are carried out to manage up to hundreds of incoming/outgoing trains and shunting operations for more than a thousand wagons per day. Large freight nodes consist of a complex infrastructure of tracks, switches, crossings and infrastructure service facilities. The daily operations management in this type of nodes requires multi-dimensional decisions, which are often too complex for manual solutions and causes inefficiencies in yard operations.

Furthermore, today planning at Yards and Terminals is not well coordinated with planning of the network operator, giving rise to costly last-minute changes of the timetable. Besides, also support for ad hoc changes in the operations management processes seems to be poor. The interaction between yard and Network management will be subject of Deliverable D2.2 “Description of business processes of a Network management system and the interactions/interfaces with a Real-time Yard Management System”.

Comparing freight traffic to passenger traffic, there is a larger need for flexibility and short term re-planning/new planning. For that reason and in frequent cases of delays and limited yard resources, static user-defined prioritisation rules cannot ensure that yard operations are performed per the right priorities.

Therefore, intelligent decision-making on a real-time basis will be required and become a strategic element of automation and optimisation in freight nodes. If decision support methods could deliver results in real-time, it would be possible to optimise these decisions and take global effects of operational decisions into account, which currently cannot be considered due to the complexity of network effects and the required decision speed. The decision processes in the project scope that are aimed at to be improved include real-time information of various stakeholders in the railway system.

It is assumed that decision processes with “real-time” decision support capabilities are mainly required in large freight nodes and in cases of deviations from regular plans. Consistently the **project focus** is on large freight nodes. Furthermore, development of regular plans is **not in scope** of the WP2.

The objective of the project is to analyse planning and operations management processes in order to clearly define the requirements, potential impact, and scope of innovation developed in the project.

1.3 Expected Results from this Deliverable

As described in the Grant Agreement (GA), Annex 1, the following **activities** will lead to expected results of the Deliverable D 2.1:

The task will start by classifying the different types of nodes considered in the WP (Marshalling yards, Terminals) and develop a common understanding and description both of operational procedures and rules in these types of nodes and of interactions between Yard and Network management. Furthermore, a common understanding of decision processes and their optimisation and automation potential will be developed and described.

This Deliverable D 2.1 aims to give an overview of the current situation in Marshalling yards and Terminals. Moreover, some of the results of the analysis are prerequisites for the upcoming Deliverable D 2.2.

Therefore, analysis of operational procedures, decision-making and rules within Marshalling yards and Terminals are carried out by the beneficiaries. Throughout the activities within WP 2 there will also be a link to the SMART consortium/Work stream ´Real-time Yard Management System´ of the Open Call 'S2R-OC-IP5-01-2015 - Freight automation on lines and in yards' to present the maximum possible level of synergies. Results of related previous projects are considered in this report [Capacity4Rail, 2015] [PLASA, 2017] [SMART, 2017/1] [SMART, 2017/2].

The start-up activities carried out in WP 2 form only the first step for a Real-time Yard Management System. In the framework of the Shift2Rail programme, a three-phase approach has been chosen. The first phase covered in this project will define the requirements for a Real-time Yard Management based on the state of the art in yard operations and the expectations of the operators. The result of this first phase is a clear definition of requirements for an IT solution for RTYM and the description of the technical demonstrator for an experimental proof of concept. The IT solution will then be implemented and tested in a phase 2 in order to be demonstrated in a real-world Marshalling yard in a third project phase.

Development of this solution will be based on techniques from the research fields of optimisation and simulation. The methods will capitalise on the increasing amount of digitalised and automatically collected data.

2 CHARACTERISTICS OF MARSHALLING YARDS

2.1 TYPOLOGIES

Marshalling yards and intermodal terminals are both nodes in rail freight transport chains. While the Marshalling yards are the railway's production facilities, intermodal terminals are its interface towards the surroundings.

In Marshalling yards, wagons from inbound trains are sorted into new outbound trains. The arrival and departure times of trains, the train composition, the time requirements of the shunting tasks, the tracks availability and the operational practice and planning determines the required work. New trains are formed – long-distance freight trains – that operate between the Marshalling yards. Over long distances, e.g. in international traffic, the wagons often need to pass through several intermediate Marshalling yards before they reach their destinations (Figure 1).

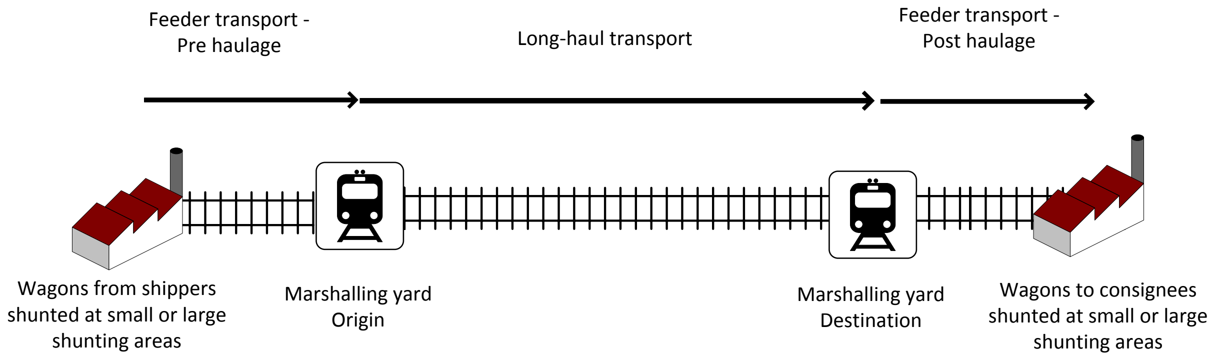


Figure 1: Common node configuration in Single Wagon Load (SWL)

In general, for Marshalling yards a distinction is drawn between [Pachl, 2012]:

- Flat yards (with or without humps) and
- gravity yards.

In a Marshalling yard with hump, the hump is located between the arrival and classification sections, onto which the wagons are shunted and then rolled down onto different tracks in the classification section.

In a flat yard without hump (also referred to as “shunting yard”) shunting locomotives are used for moving the wagons back and forth.

Typically, large Marshalling yards are hump yards, therefore analysis in this project focusses on this type of yards.

A complete Marshalling yard consists of an entry section R where the trains arrive (arrival or receiving yard), a classification section M (classification bowl or marshalling area) where the wagons are ordered, and an exit section D (departure yard) from where the trains depart (Figure 2).

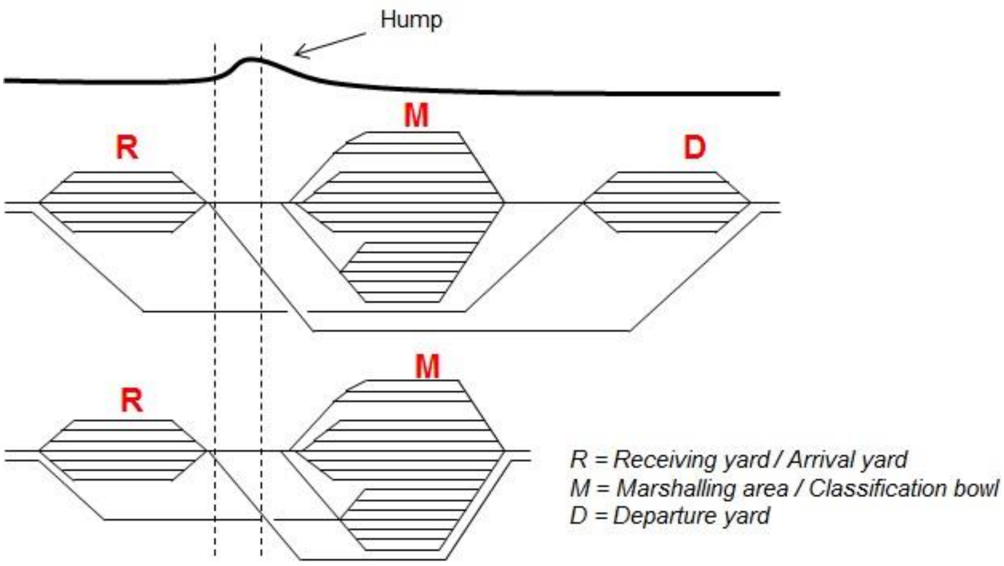


Figure 2: Typical layout for Marshalling yards

In large Marshalling yards, these three elements are sometimes duplicated so that wagons can flow through the Marshalling yard in both directions (“double yards”). In this kind of yard, the so-called “around the corner” traffic is limiting the performance. This refers to wagons which need to be transferred to a departure track which does not belong to the shunting system where the wagons have arrived.

Moreover, some Marshalling yards consist only of an arrival yard and a classification bowl [Gestrelius et al., 2017]. Inbound trains arrive at the arrival yard where their wagons are uncoupled and inspected. After that the wagons are then rolled over a hump into the classification bowl (a *roll-in*) where they are sorted into new outbound trains. Additional wagon sorting can be accomplished by pulling wagons in the classification bowl back to the arrival yard and pushing them over the hump once more (a *pull-back*).

If the trains should be sorted according to destination, an additional group of tracks should be available in connection to the departure yard.

2.2 OPERATIONAL PROCEDURES AND REQUIRED ASSETS

Marshalling yards are purpose-built yards that are used to sort trains and/or switch wagons between trains to build new trains. Sorting and grouping wagons are crucial activities for Single Wagon Load (SWL) transport, by which a wagon or a coupled group of wagons are shunted into the facilities of a shipper, and once loaded, they are marshalled to form full load trains (block trains) or trains with removal or addition of groups of wagons at intermediate stops, that run over longer distances.

Main operational procedures in Marshalling yards are the following:

Train split. Trains arrive in tracks of the arrival yard, where wagons and documents are checked. The train is split into groups of wagons, for their final destination. The line loco moves away, while the shunting loco takes place behind the groups of wagons to shunt.

Train build. Uncoupling of incoming trains' wagons 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 yard. 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 any external propulsion by following a downhill system of tracks and automated switches. Mostly they are braked using hump retarders placed along the tracks, where they cumulate to reach the critical size for a departing train.

Departure preparation. Finally, wagons are moved to tracks of the departure yard, where documents are commonly checked, the line locomotive is coupled to the wagons, the brakes are tested and the train is ready to depart.

If trains consist of two or more train sections with different next nodes (i.e. Marshalling yards, Terminals or Sidings), wagons must be sorted (grouped) by destination already during train formation, which sets certain requirements on the marshalling procedures. The advantage of such "**group trains**" is that trains can reach a high degree of fullness on long shared transportation distances without all the wagons needing to have the same destination. The stations should, however, lie in roughly the same direction/region to allow the flows to be coordinated. Among the drawbacks with group trains can be mentioned that the timetables for the different train sections cannot be structured independently of each other. Forming group trains requires relatively long permitted train lengths unless the train sections are to be extremely short, which in its turn would mean poor economy on those stretches where they travel alone.

Performing operational procedures requires **assets** as well as real-time information e.g. about the assets' utilisation, status and/or location.

Main assets that have to be considered are the following:

- Railway lines and their link to the network elements of the Marshalling yard
- Static elements of the Marshalling yard (Tracks, switches, hump)
- Incoming and outgoing trains and their composition
- Wagons, group of wagons
- Shunting locomotives
- Personnel for performing the yard operations
- Personnel for performing dispatching/disposition processes

2.3 ORGANISATION

In most European countries, there are different stakeholders for four functions in large freight nodes:

- the infrastructure owner
- the infrastructure manager
- the operator for marshalling and shunting in the yard
- the operator of incoming/outgoing trains

The ownership of the infrastructures refers to rail tracks and superstructures e.g. warehouses, cranes and reach stackers. The management of the infrastructures refers e.g. to the authorisation of signal-controlled shunting movements.

All four functions can in principle be handled by a single actor, if the actor that owns the infrastructure is also responsible for the operational activities. However, in deregulated freight markets and for public terminals, it is a common practice to split responsibilities for infrastructure and operations.

Thus, the infrastructure owner appoints an operator to serve one or multiple customers / users of the freight node. Operators at Marshalling yards are commonly Freight Operating Companies (FOC) as well, putting them in a delicate situation - as yard operators having to serve their competitors as FOC.

2.4 DIGITALISATION/AUTOMATION STATUS

A main driver behind this project is the increased digitalisation and automation throughout the railway sector. Increased digitalisation generates new data which in turn can be used to automate processes and make better decisions.

Digitalisation would be one of the last chances in this decade for the rail freight sector to compete in the race against other transport modes. Obstacles to success for digitalisation in railways are the incorporation of new technologies both in the existing assets and operations [BearingPoint, 2016].

The marshalling technology employed in Marshalling yards with humps varies depending on the importance of each yard and the traffic it serves. For example, the grade of automation is very high in certain large Marshalling yards where almost everything is automatic except the coupling and uncoupling operation. Although wagons with automatic coupling are on the market, they have yet to be adopted on a broad scale by the rail freight market. In an international context, e.g. in North-America, Australia and parts of Asia, automatic couplers have already been adopted on a broader scale, mainly for closed-system railways.

To prevent the wagons from collisions but also to avoid too large gaps forming between the wagons, their speed must be controlled, which was previously done manually (and at some older

Marshalling yards still is done) by means of brake shoes. In modern yards, this task is automated with dedicated brakes in the form of for example spiral brakes, push-rod brakes or piston brakes / retarder breaks, located on the grooves and remotely operated electrically or by compressed air, and sometimes computer-controlled (Figure 3 and Figure 4).

Figure 3: Ramp retarder in München-Nord [Source: jrschmidt-photos.de]

Figure 4: Automatic clasp (beam) retarder (left); Piston retarders in working position (right) [Source: wikipedia.org]

In large Marshalling yards, hump operations are fully automated and controlled by a sequence control computer system, i.e. regulation of the wagon speed (slope brakes, track brakes and retarders installed on the tracks), the pushing force and speed of a radio controlled shunting locomotive over the hump.

The grade of automation in smaller Marshalling yards differs very much, ranging from automated hump yards or yards where wagons are braked manually with brake shoes with a significant injury risk to the shunting personnel, to the smallest Satellite stations where wagons are shunted manually in a couple of parallel tracks.

Planning the operational procedures in a Marshalling yard is a very important and complex problem. Complexity increases by taking into account numerous cases of deviations from regular plans. In most cases, operation rescheduling is made manually by highly experienced dispatchers. As disposition/dispatching processes in Marshalling yards and Terminals, including interaction with the traffic management system, have a major impact in terms of reducing lead times and improving the punctuality and cost-efficiency of rail freight, case studies in different Marshalling yards have been conducted.

2.5 CASE STUDIES

2.5.1 Identification of case studies for selected Marshalling yards

As stated before, this project focus is on large freight nodes, particularly on large Marshalling yards.

Taking into account both influences from different types of Marshalling yards (double yard, single yard, gravity yard) and having to limit the number of case studies, Marshalling yards were chosen from the two countries, where the project partners come from.

Consequently, analysis was conducted at the Marshalling yards
- Mannheim/ Germany
- München-Nord/ Germany
- Hallsberg/ Sweden

All these Marshalling yards are situated on at least one of the European freight corridors (Figure 5).

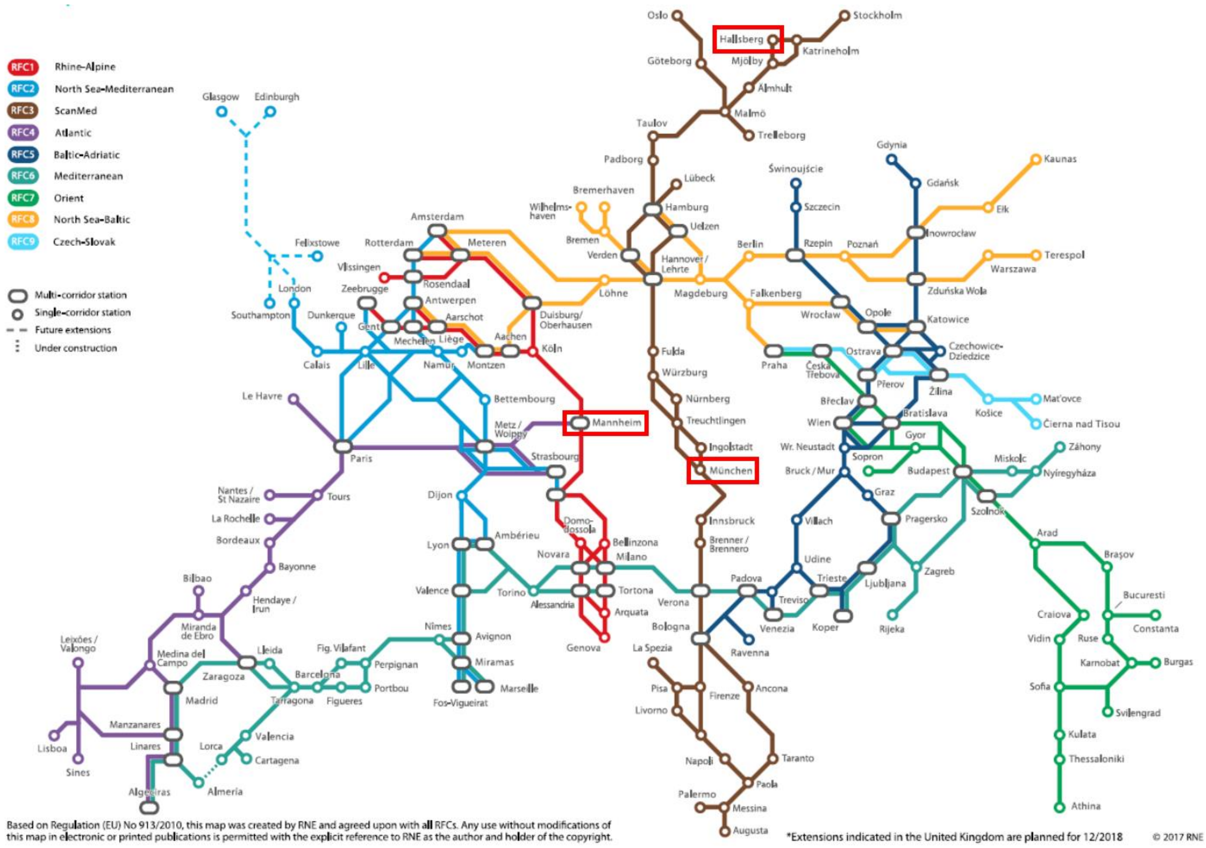


Figure 5: Location of the selected Marshalling yards on the European Rail Freight Corridors

Several selected outputs allow evaluating the challenges for automation in Marshalling yard:

- Classification/differentiating factors of Marshalling yards
- Processes, actors, decisions and data sources for decision-making
- Room for improvements

2.5.2 Case study: Mannheim Marshalling yard

2.5.2.1 Classification

Germany has several Marshalling yards where Mannheim is the second largest. The yard is most important for rail freight transport in the corridor from the ARA-harbours and from the north of Germany to the south/south to north of Germany and for transit to France, Switzerland and Italy (Figure 6).

Mannheim is a flat yard with two humps. All three sections (Arrival yard, classification bowl and departure yard) are duplicated ("System West/East" and "System East/West"), so that wagons can flow through the Marshalling yard in both directions ("double yard"). Daily up to 12 shunting runs ("Überführungsfahrten") in each direction are done to transfer wagons between the two parts of the Marshalling yard (Figure 7).

Hump operations are automated and controlled by a sequence of control computer system.

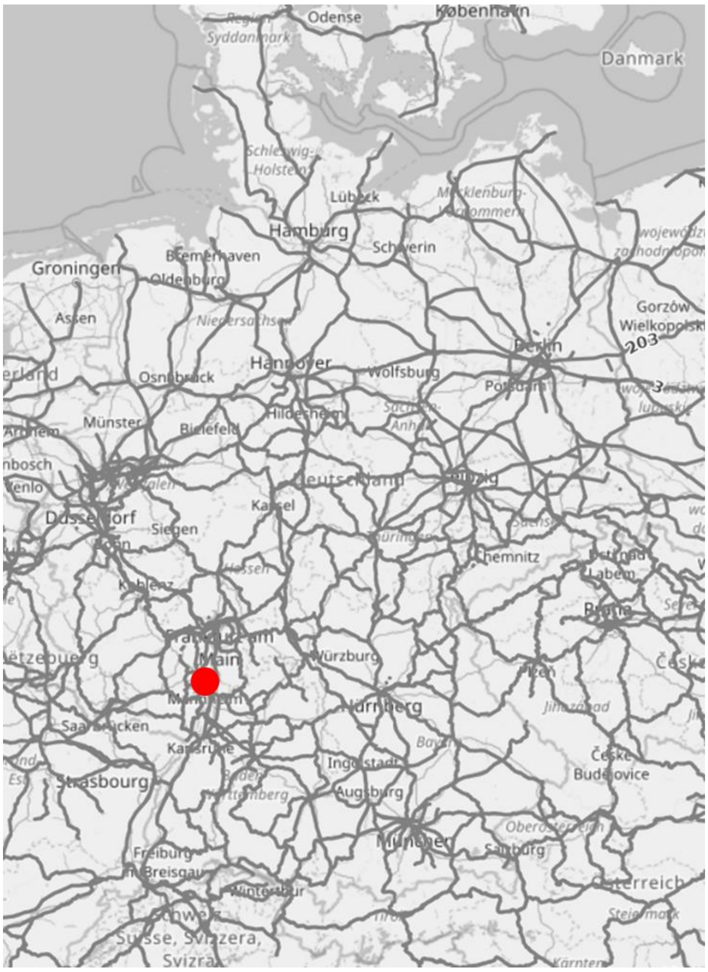


Figure 6: Location of the Mannheim Marshalling yard in the German railway network [Source: OpenRailwayMap]

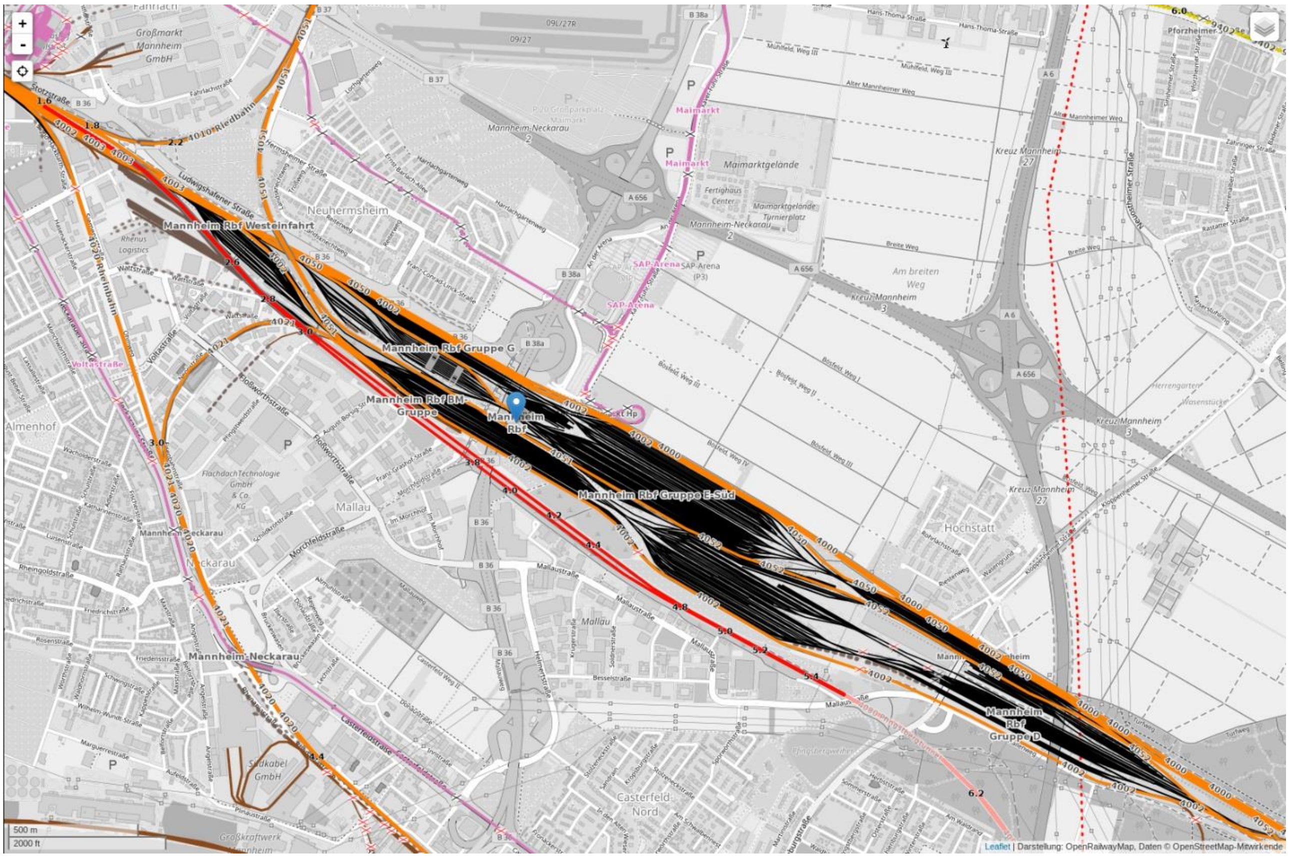


Figure 7: Layout of the Mannheim Marshalling yard [Source: OpenRailwayMap]

Main characteristics of the Mannheim Marshalling yard are (see also Table 1):

- Infrastructure Owner and Manager: DB Netz
- Yard Operator: DB Cargo
- FOC: DB Cargo
- Overall track length: 240 Kilometres
- Switches: 550
- Starting trains (March 2017): 2.261 trains per month
- Terminating trains (March 2017): 2.275 trains per month
- Trains in transit (March 2017): 352 trains per month (Remove or add wagons from/to the train in the yard)

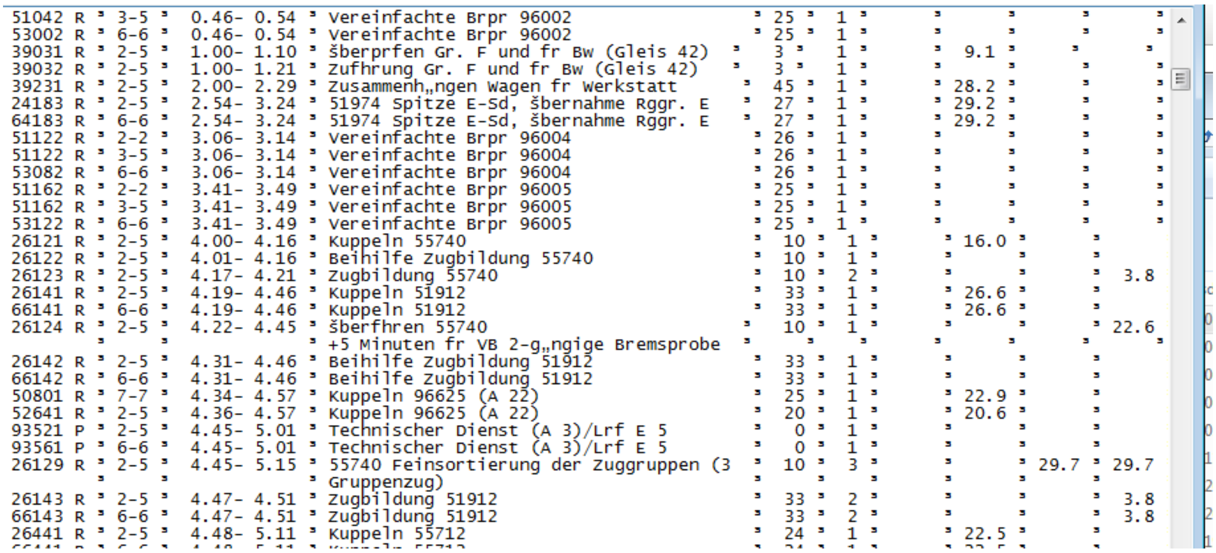
Table 1: Number of tracks and available marshalling capacity in Mannheim MY

	System West/East	System East/West
Receiving yard	15 tracks	12 tracks
Classification bowl	41 tracks	42 tracks
Departure yard	16 tracks	30 tracks
Available shunting capacity over the hump	150 wagons per hour	154 wagons per hour
Average of marshalling wagons over the hump	110 wagons per hour	110 wagons per hour

2.5.2.2 Operational procedures

Operational procedures of the Mannheim Marshalling yard correspond to the standard procedures of a double yard as described above.

Based on the timetables for incoming and outgoing trains, existing yard infrastructure, required process steps and available resources, the daily activities of the yard staff are planned in detail (Figure 8). This plan contains the sequence of the activities such as brake tests, coupling/uncoupling activities, transfer trains and support in train building processes (see text in the middle column). Detailed scheduling of the activities is listed with an order number (1st column) and the planned time on the left side of the daily plan. On the right side of the daily plan different information about expected duration of the activities appear.



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51042 R 3-5 0.46- 0.54 Vereinfachte Brpr 96002            25  1
53002 R 6-6 0.46- 0.54 Vereinfachte Brpr 96002            25  1
39031 R 2-5 1.00- 1.10 šberprfen Gr. F und fr Bw (Gleis 42)  3  1   9.1
39032 R 2-5 1.00- 1.21 Zufhrung Gr. F und fr Bw (Gleis 42)   3  1
39231 R 2-5 2.00- 2.29 Zusammenh„ngen Wagen fr Werkstatt  45  1  28.2
24183 R 2-5 2.54- 3.24 51974 Spitze E-Sd, šbernahme Rggr. E  27  1  29.2
64183 R 6-6 2.54- 3.24 51974 Spitze E-Sd, šbernahme Rggr. E  27  1  29.2
51122 R 2-2 3.06- 3.14 Vereinfachte Brpr 96004            26  1
51122 R 3-5 3.06- 3.14 Vereinfachte Brpr 96004            26  1
53082 R 6-6 3.06- 3.14 Vereinfachte Brpr 96004            26  1
51162 R 2-2 3.41- 3.49 Vereinfachte Brpr 96005            25  1
51162 R 3-5 3.41- 3.49 Vereinfachte Brpr 96005            25  1
53122 R 6-6 3.41- 3.49 Vereinfachte Brpr 96005            25  1
26121 R 2-5 4.00- 4.16 Kuppeln 55740                      10  1  16.0
26122 R 2-5 4.01- 4.16 Beihilfe Zugbildung 55740          10  1
26123 R 2-5 4.17- 4.21 Zugbildung 55740                   10  2              3.8
26141 R 2-5 4.19- 4.46 Kuppeln 51912                      33  1  26.6
66141 R 6-6 4.19- 4.46 Kuppeln 51912                      33  1  26.6
26124 R 2-5 4.22- 4.45 šberfhren 55740                    10  1             22.6
                       +5 Minuten fr VB 2-g„ngige Bremsprobe
26142 R 2-5 4.31- 4.46 Beihilfe Zugbildung 51912          33  1
66142 R 6-6 4.31- 4.46 Beihilfe Zugbildung 51912          33  1
50801 R 7-7 4.34- 4.57 Kuppeln 96625 (A 22)               25  1  22.9
52641 R 2-5 4.36- 4.57 Kuppeln 96625 (A 22)               20  1  20.6
93521 P 2-5 4.45- 5.01 Technischer Dienst (A 3)/Lrf E 5    0  1
93561 P 6-6 4.45- 5.01 Technischer Dienst (A 3)/Lrf E 5    0  1
26129 R 2-5 4.45- 5.15 55740 Feinsortierung der Zuggruppen (3  10  3   29.7  29.7
                       Gruppenzug)
26143 R 2-5 4.47- 4.51 Zugbildung 51912                   33  2              3.8
66143 R 6-6 4.47- 4.51 Zugbildung 51912                   33  2              3.8
26441 R 2-5 4.48- 5.11 Kuppeln 55712                      24  1  22.5
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Figure 8: Extract from daily plan of yard staff

Beside the daily plans of yard staff and their continuous monitoring (comparison of actual times and planned times), a lot of information for controlling and monitoring operational procedures comes from different IT-Applications (Table 2).

Table 2: IT-Applications used for controlling and monitoring operational procedures

IT-Application (Source of information)	Relevant Content	Owner
LeiDis - Leitsystem zur Netzdisposition	▪ Prenotification of incoming trains ▪ Monitoring of train runs ▪ Causes of train delays	DB Netz
TRACE – Train Control Europe	▪ Overview of planned outgoing trains ▪ Timetable deviations of national and international train runs ▪ Overview of parked trains ▪ Overview of causes for train delays	DB Cargo
PVG - Produktionsverfahren Güterverkehr	▪ Information about trains approaching the yard ▪ Administration of timetable and shipment information ▪ Train decomposition and wagon transfer/interchange ▪ Data interchange with the sequence control computer system of the hump ▪ Support of wagon inspection activities ▪ Information about wagons on tracks ▪ Treatment of outgoing trains	DB Cargo
TOM – Train Order Management	▪ Planning of border-crossing special trains ▪ Cancellation and modification of international trains	DB Cargo
WIS – Wageninformationssystem	▪ Wagon database	DB Cargo
IPL- Integriertes Planungssystem	▪ Timetable of trains ▪ Trip plan for each wagon	DB Cargo
EDITH- Ereignisgesteuerte Personaldisposition im Transportbereich	▪ Roster for yard staff ▪ Actual quantity taken for yard staff	DB Cargo
CDIF- Cargo-Disposition für Fahrzeuge	▪ Operational schedule for locomotives	DB Cargo

IT-Application (Source of information)	Relevant Content	Owner
Tf-Info - Triebfahrzeugführer-Informationssystem	▪ Information about train driver assignment	DB Cargo

2.5.2.3 Yard staff and their roles/responsibilities

Operational procedures are performed by yard staff. Most of the activities are conducted during 3-shift operations.

In Table 3, an overview about yard staff and their tasks is given.

Table 3: Staff at Mannheim MY and their tasks

Yard role (German name)	Tasks
Disponent DB Netz	Announcements of incoming/outgoing trains; Interaction with the network managers; Decision about sequence of incoming trains
Fahrdienstleiter/DB Netz	Authorisation of signal-controlled train and shunting movements
Disponent Rbf gesamt	Overall responsibility for yard operations management; Final ad-hoc decision making
Disponent West/Ost	Responsible for train decomposition activities
Disponent Ost/West	Responsible for train formation activities
Zugvorbereiter	Preliminary activities for outgoing trains
Zugabfertiger	Commercial services for incoming/outgoing trains
Grenzabfertiger	Activities for international trains, that terminate or start at the yard
Bergmeister	Controlling of decomposition/uncoupling and marshalling wagons over the hump
Langmacher	Responsible for uncoupling activities

Yard role (German name)	Tasks
Kuppler/Bremshelfer	Conduct of brake test for outgoing trains Coupling of wagons
Rangiermeister	Controlling shunting activities in the arrival and/or departure yard
Disponent Wagenmeister	Responsible for planning activities of wagon inspectors
Schichtführer Wagenmeister	Shift foreman for operating train and wagon inspection
Wagenmeister	Conduct wagon inspections
Wagentechnischer Sonderdienst	Conduct wagon inspection out of regular plans
Lokrangierführer	Shunting engine driver

2.5.2.4 Decision processes in the Yard

As daily activities of the yard staff are planned in detail in advance, there should usually be only a minor need for decisions on changes of existing plans to control operational procedures at the yard.

In practice, due to the location of the Mannheim MY in the production network of DB Cargo, disturbances as well as deviations of regular plans appear frequently, which require ad hoc decisions and changes/adaptions of planned activities. As shown in Table 4, disturbances appear frequently both in the line network and within the Marshalling yard. Some of the table entries summarise multiple events, therefore the number of individual events is even higher than the indicated numbers.

Decision-makers at the Marshalling yard for controlling and monitoring operational procedures and for ad hoc decision-making use both information from existing IT-Applications (see Table 2) and from yard staff. If additional resources are required or disturbances occur, which have consequences beyond the local region, the superordinated control instances of DB Cargo are involved in the decision making process.

The overarching goal is to limit the consequences of an event on quality and punctuality and optimally use the available resources. This includes the capability to cover additional trains. No dedicated quantitative performance indicators are being used for ad hoc decision making.

Table 5 shows an overview of the most occurred decisions caused of deviations from regular plans.

Table 4: Overview of deviations at Mannheim MY

Kind of deviations	Potential causes	Frequency
Delay of incoming trains	▪ Disturbances along the lines (infrastructure based) ▪ Loco and wagon damages ▪ Lack/sickness of train driver	middle
Delay of outgoing trains	▪ Braking percentage not sufficient	middle
Delay of outgoing trains	▪ Train weight exceeded	middle
Delay of outgoing trains	▪ Outage of loco for outgoing train	middle
Lack of personnel resources	▪ Short-term sickness of train driver ▪ Short-term sickness of staff for conducting shunting activities ▪ Outage of train driver for outgoing trains due to late incoming trains	low low high

Table 5: Overview of most occurred decisions caused of deviations

Decisions required	Potential causes	Decision-maker
Obtain approval from infrastructure manager to run trains with non-regular train parameter	▪ Braking percentage not sufficient ▪ Train weight exceeded	DB Netz/DB Cargo Überregionaler Disponent
Ad-hoc changing sequence/ prioritisation of yard operations	▪ Delay of incoming trains ▪ Lack of personnel resources	DB Cargo Disposition
Ad-hoc additional planning/running of special trains	▪ Delay of incoming trains ▪ Delay of outgoing trains ▪ Lack of personnel resources	DB Cargo Disposition
Prioritisation of outgoing trains	▪ Delay of incoming trains ▪ Delay of outgoing trains ▪ Lack of personnel resources	DB Cargo Disposition/DB Netz

All decisions are based on information from the different IT-Applications as well as on communications with different DB Cargo traffic control levels and dispatchers from DB Netz. The dispatchers in Mannheim MY take their decisions (how to continue operations after a disturbance) based on their individual knowledge and local knowledge. The available IT-Applications are used for illustrating the actual situation, but the dispatcher depends mainly on his knowledge of the yard, the wagon transfers and the capacity of the part of the yard for which he or she is responsible.

A system that pro-actively could inform about the consequences of potential decisions is currently not available at DB Cargo. The decision makers in Mannheim MY consider the development/ provision of such a decision support system as very useful and very much appreciated.

2.5.3 Case study: München-Nord Marshalling yard

2.5.3.1 Classification

Among the Marshalling yards in Germany, München-Nord is a medium-sized yard. The yard is most important for rail freight transport in the corridor to Austria, Czech Republic and Italy as well as in the Greater Munich area (Figure 9).

München-Nord is a flat yard with one hump (Figure 10).

Hump operations are highly automated and controlled by a sequence control computer system.

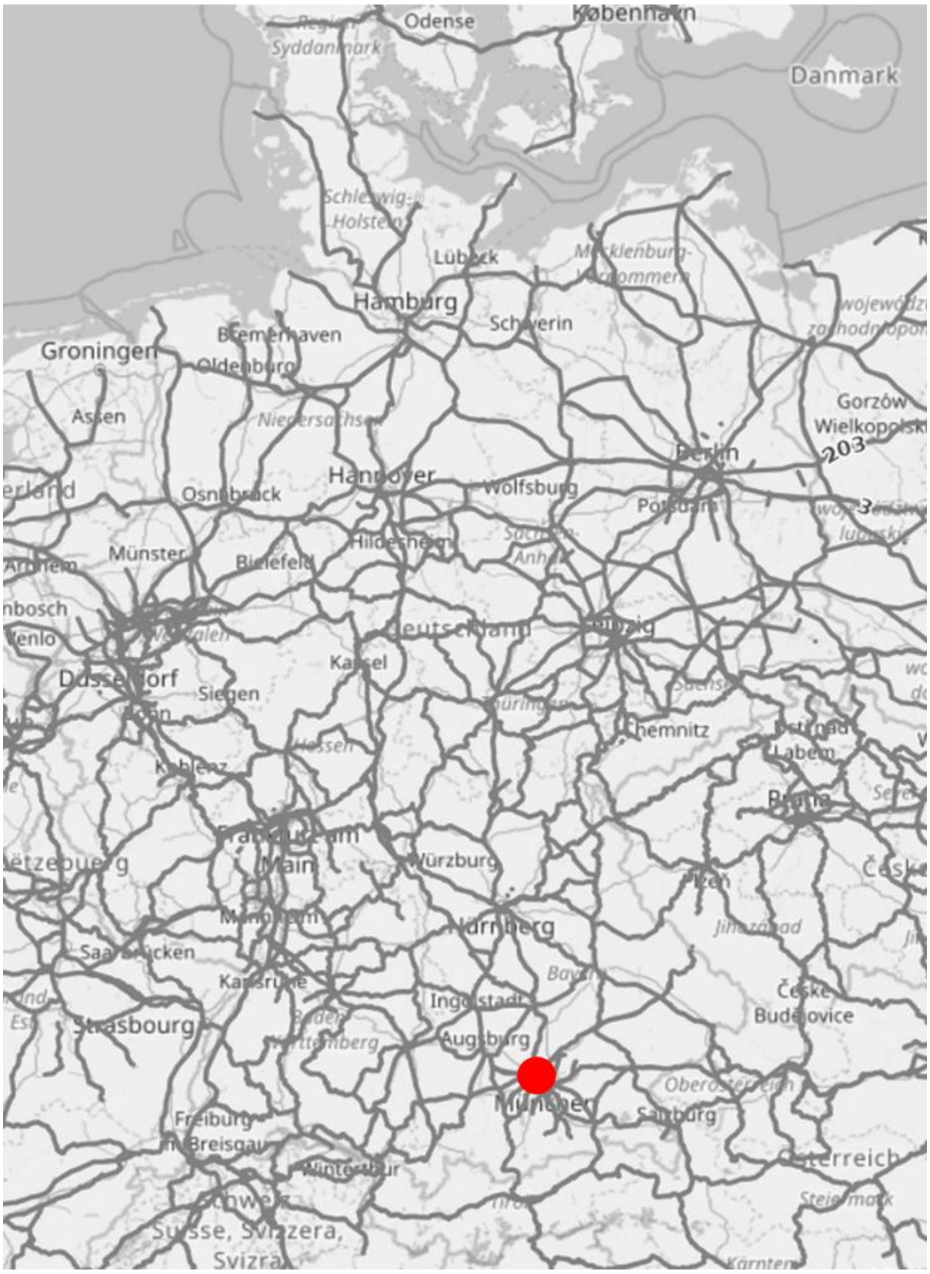

Figure 9: Location of the München-Nord Marshalling yard in the German railway network

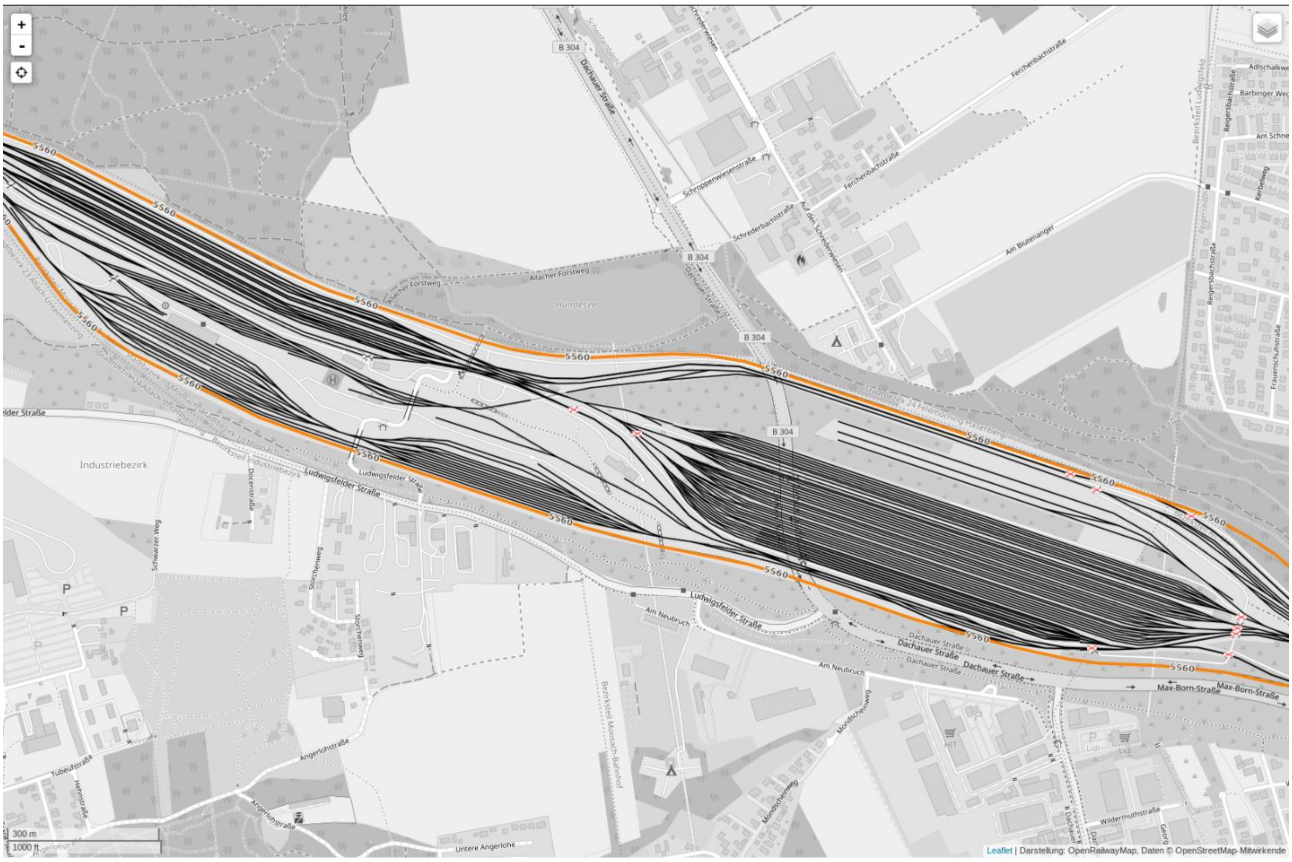

Figure 10: Layout of the München-Nord Marshalling yard [Source: OpenRailwayMap]

Main characteristics of the München-Nord Marshalling yard are (see also Table 6):

- Infrastructure Owner and Manager: DB Netz
- Yard Operator: DB Cargo
- FOC: DB Cargo, ARS Altmann, Lokomotion, RBH
- Overall track length: 120 Kilometre
- Switches: 356
- Starting trains (March 2017): 1.379 trains per month
- Terminating trains (March 2017): 1.441 trains per month
- Trains in transit (March 2017): 504 trains per month (Remove or add wagons from/to the train in the yard)

Table 6: Number of tracks and available marshalling capacity in München-Nord MY

	München-Nord MY
Receiving yard	14 tracks
Classification bowl	40 tracks
Departure yard	13 tracks
Available marshalling capacity over the hump	250 wagons per hour
Currently average of humped wagons	110 wagons per hour

2.5.3.2 Operational procedures

As the München-Nord Marshalling yard is a flat yard with one hump, operational procedures appear like already described above.

Based on the timetables for incoming and outgoing trains, existing yard infrastructure, required process steps and available resources daily activities of the yard staff are also planned in detail in advance similar to Mannheim.

Beside the daily plans of yard staff and their continuous monitoring (comparison of actual times and planned times) employees of München-Nord Marshalling yard for controlling and monitoring operational procedures use the same IT-Applications as described in Table 2 for the Mannheim MY.

2.5.3.3 Yard staff and their roles/responsibilities

Operational procedures are performed by yard staff. Most of the activities are conducted during 3-shift operations. Most of the roles of staff in München-Nord Marshalling yard is similar to Mannheim MY.

In Table 7 an overview about yard staff and their tasks is given.

Table 7: Staff of München-Nord MY and their tasks

Yard staff	**Tasks**
Disponent DB Netz	Announcements of incoming/outgoing trains; Interaction with the network managers; Decision about sequence of incoming trains
Fahrdienstleiter/DB Netz	Authorization of signal-controlled train and shunting movements; Decision about track in the receiving yard for incoming trains
Disponent Rbf gesamt	Overall responsibility for yard operations management; Final ad-hoc decision making

Yard staff	Tasks
Disponent Rbf	Responsible for performing operational yard operations
Rangierarbeiter Einfahrgruppe	Preparation of wagons of incoming trains for pushing over the hump
Rangierbegleiter Einfahrt	Performing shunting operations at arriving yard
Rangierbegleiter Ausfahrt	Performing shunting operations at departure yard
Rangierarbeiter Richtung	Performing coupling activities mainly at classification bowl
Zugabfertiger	Commercial services for incoming/outgoing trains; Preliminary activities for outgoing trains (Checking paper work, brake test)
Mitarbeiter Zugbildungsabteilung	Activities to compose outgoing trains
Bergmeister/ DB Netz	Controlling of marshalling wagons over the hump
Wagenmeister	Conduct wagon inspections
Lokrangierführer	Shunting engine driver

2.5.3.4 Decision processes in the Yard

As daily activities of the yard staff are planned in detail in advance, there should be usually only a minor need for decisions on changes of existing plans to control operational procedures at the yard.

In practice, due to the location of the München-Nord MY in the production network of DB Cargo, disturbances as well as deviations of regular plans often appear, which require ad hoc decisions and changes/adaptions of planned activities.

The kind of deviations from regular plan, potential causes for deviations and required decisions are very similar to those mentioned for Mannheim MY (see section 2.5.2).

All decisions are based on information from the different IT system as well as on communications with different DB Cargo traffic control levels and dispatchers from DB Netz. The dispatchers in München-Nord MY take their decisions (how to continue operations after a disturbance) based on their individual knowledge and local knowledge. The available tools are used for figuring out the consequences of the decisions, but the dispatcher depends mainly on his knowledge of the yard, the wagon transfers and the capacity of the part of the yard for which he or she is responsible.

A system that pro-actively could inform about the consequences of potential decisions is currently not available at DB Cargo. The decision makers in München-Nord MY consider the development/ provision of such a decision support system as very useful and very much appreciated.

2.5.4 Case study: Hallsberg Marshalling yard

2.5.4.1 Classification

Sweden has several Marshalling yards, where Hallsberg is the biggest and the most important one, considering the number of trains handled. It is located in the centre of the Swedish rail network as a main node in the north-south freight corridor and it is the main production site for rail freight traffic in Sweden. Through its geographical location, Hallsberg's Marshalling yard has a strategic location in Sweden's freight flows and forms an important hub of Swedish rail freight.

International freight traffic with destinations in for example Germany and Italy passes Hallsberg on the way to the connections from the southern part of Sweden to Europe via the Öresund Bridge to Denmark or via the port terminals in Trelleborg and Ystad. Moreover, the western main line connecting the two largest cities in Sweden, Stockholm-Gothenburg, passes the Marshalling yard (Figure 11 and Figure 12).

Figure 11: Location of the Hallsberg Marshalling yard in the Swedish railway network [Source: Trafikverket Network Statement]

Figure 12: Layout of the Hallsberg Marshalling yard

As illustrated by Figure 13, Hallsberg Marshalling yard is built similar to a gravity yard as there is a through-going slope for the whole yard. Moreover, albeit there are also two humps in the yard (or to be more specific, two tracks over the same hump), due to safety constraints and track layout, only one hump can be used at a time [Trafikverket, 2015a].

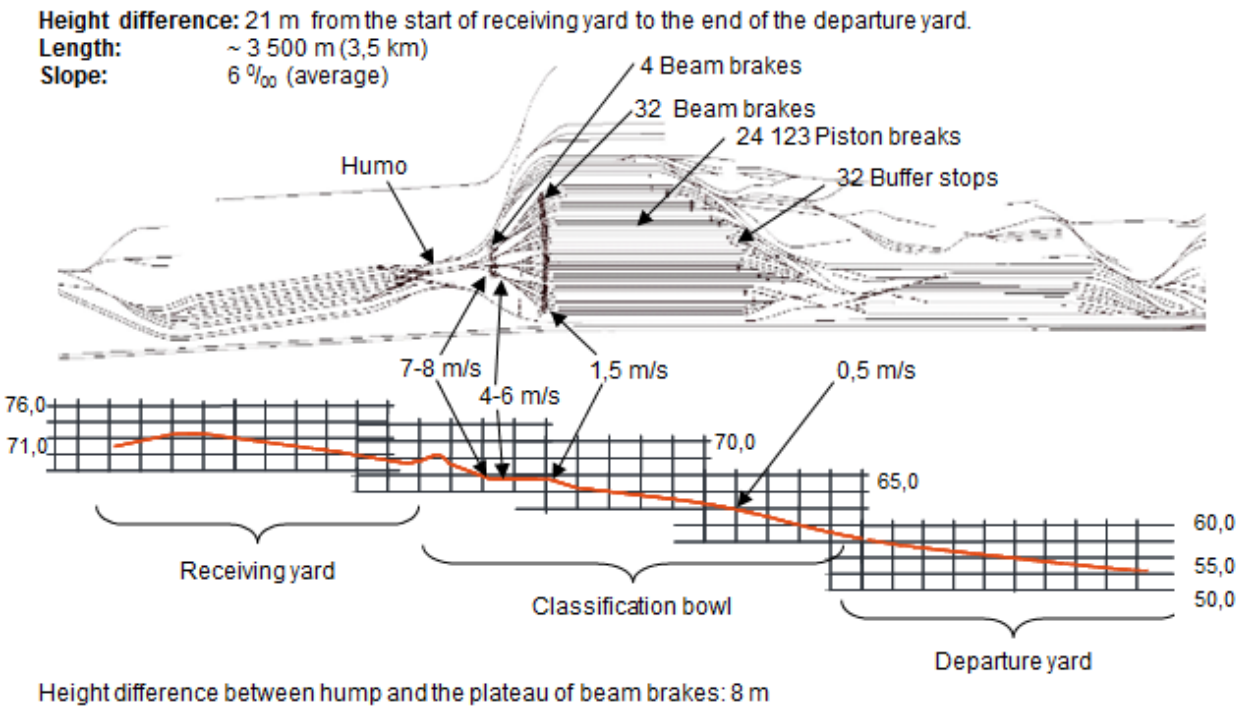

Figure 13: Hallsberg Marshalling yard – a gravity yard with hump [Trafikverket, 2015b]

Main characteristics of the Hallsberg Marshalling yard are:

- Infrastructure Owner and Manager: Swedish Transport Administration (Trafikverket)
- Yard Operator: Green Cargo
- FOC: Green Cargo, Hector Rail
- Overall track length: 60 km
- Switches: 170
- Capacity: 500 000 wagons / year
- Shunted volume: 305 000 wagons / year
- Beginning trains T16[1] (364 days in period): 13928
- Terminating trains T16: 14361
- Trains in transit T16: 2848

Data considering the number of trains are taken from the 2016 annual working timetable at the time for finalization in September 2015.That is, ad-hoc trains and changes to the working timetable have not been accounted for. Trains in transit are train planned to pass the arrival yard and/or departure yard, with some activity, i.e. the activity data field in the train database is not empty.

[1] "T16" is the timetable used for 2016, valid for 52 weeks which equals 364 days

Activities are e.g. remove or add wagons, but also driver change, engine change or other reason for being at the yard. The included trains have freight load/off load at other locations than Hallsberg, i.e. they are not service trains.

Table 8: Number of tracks and available marshalling capacity in Hallsberg MY

	Hallsberg
Receiving yard	8 tracks
Classification bowl	32 tracks
Departure yard	12 tracks
Available marshalling capacity over the hump	167 wagons per hour
Average of marshalling wagons over the hump	102 wagons per hour

2.5.4.2 Operational procedures

The operations of Hallsberg MY, as any Marshalling yard with hump, can be categorised within the following activity groups;

1. Train arrival
2. Hump operations
3. Classification
4. Train departure

Each of these activity groups contains a number of operational steps.

Table 9 states the measured time for each step within the four activity groups.

Table 10 states the IT-applications used for controlling and monitoring operational procedures at Hallsberg MY.

Table 9: Operational steps in Hallsberg MY [Trafikverket, 2015a]

Steps	**Time (s)**	**Time (min)**
Train arrival		
Reserve time (based on braking prior to the signal)	14	0,23
Driving	157	2,62
Securing wagons and uncoupling them from locomotive	30	0,5
Arrival inspection (1 min per wagon)	1920	32
Coupling to the shunting locomotive	5	0,08
Towing, releasing brakes, waiting for signal	60	1

Steps	**Time (s)**	**Time (min)**
Pushing wagons towards the hump (230+40 m with 1.2 m/s)	225	3,75
Pushing over the hump	465	7,75
Sum (train arrival)	*2876*	*47,93*
Hump operations		
Pushing wagons towards the hump (230+40 m with 1.2 m/s)	225	3,75
Pushing over the hump (32 wagons - 18 meters long and 1,2 m/s)	465	7,75
Sum per train	*690*	*11,5*
Classification		
Coupling wagons and brakes (100 m/min + 10 s/wagon)	750	12.50
Time for filling the brake system with air	900	15.00
Testing the brake system	60	1.00
Refilling the brake systems after the test	20	0.33
Brake test, hitting the brakes, controlling each wagon	180	3.00
Releasing brakes	120	2.00
Controlling that all brakes have been released	180	3.00
Release buffer stops	15	0.25
Activate brakes	5	0.08
Time for driving the locomotive to the wagons and coupling it	10	0.17
Releasing brakes	120	2.00
Simple brake test	60	1.00
Time for departure including path reservation	150	2.50
Time for activating buffer stops, relays, reaction time	60	1.00
Sum (classification time)	*2630*	*43.83*
Train departure		
Driving	96	1.6
Uncoupling from the shunting locomotive	60	1
Driving the shunting locomotive away	12	0.2
Driving the line locomotive to wagons	12	0.2
Coupling to the line locomotive	10	0.17
Charging the brake pressure	300	5
Simple brake tests	60	1
Waiting for the signal	120	2
Departing	120	2
Sum (*Train departure)*	*790*	*13.17*

Table 10: IT-Applications used for controlling and monitoring operational procedures at Hallsberg MY

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

IT-Application (Source of information)	Relevant Content	Owner
Platå	▪ Operational schedule for locomotives and train drivers	Green Cargo AB
OP	▪ Optimization and information about train driver assignment	Green Cargo AB

2.5.4.3 Yard staff and their roles/responsibilities

Operational procedures are performed by yard staff. Most of the activities are conducted during 3-shift operations, but from during Saturday night when there is no personnel in the yard. The staffing of the shifts differ depending on work load and type of activities that are to be carried out.

Planners and dispatchers are stationed in the control tower. They allocate tracks to trains and ensure safe marshalling operations.

There are also yard personnel who are responsible for wagon inspection, coupling/uncoupling and brake tests. Further, there are three shunting locomotives at the yard; two of them work in the arrival yard and the other one is assigned to the classification and departure yards.

The manoeuvring of switches and points of the classification zone is done by a computerised control system enabling full automation. Albeit the manual task of the uncoupling of wagons still prevails. Also, the speed control of the wagons is computer controlled and achieved by using beam brakes and brake piston.

Table 11 presents an overview of yard staff and their tasks.

Table 11: Staff at Hallsberg Marshalling yard and their tasks

Yard role (Swedish name)	Tasks	
Rangeroperatör	Authorization of signal-controlled shunting movements; Interaction with the line train dispatchers; Interaction with the shunting engine driver Controlling of decomposition/uncoupling and marshalling wagons over the hump (*Växlingsledare*).	Green Cargo AB
Rangerledare	Planning of yard movements; Decision about track allocation	Green Cargo AB
Bangårdspersonal/ avkopplare	Wagon inspection; Coupling and uncoupling activities; Brake-test.	Green Cargo AB
Skiftesledare	Shift foreman	Green Cargo AB
Rangerlokförare	Shunting engine driver	Green Cargo AB

Yard role (Swedish name)	Tasks	
Tågklarerare	Train dispatcher; Authorization of signal-controlled arrival yard movements and outgoing trains; Jointly plan arrival yard with *Rangeroperatör*. Responsible for safety work on tracks in the whole yard	Trafikverket
Tågplanerare	Allocation of train paths to/from the yard	Trafikverket

2.5.4.4 Decision processes in the Yard

It should be noted that Sweden is one of the few countries that use a booking system for assigning wagons to trains for the whole transport in Sweden before a wagon starts its journey. This implies certain pre-requites on the marshalling procedures. The implementation of the booking system 'BRAVO' means that the departing train of the wagon (from the yard) has already been determined before the wagon arrives at the Marshalling yard. Booking systems give the freight operators better control over their fleet and, in particular, better control of the arrival time of each wagon. In rail networks without booking system, operators can assign the wagon to the earliest departing train heading towards the wagon destination. In contrast, when a booking system is used, operators have to send each wagon to its predetermined departing train even if there is another suitable train departing earlier. This drawback can be counter-acted by re-booking wagons where it is suitable, but this has to be done carefully since re-booking might violate agreements with the customers, and might also cause problems in receiving Marshalling yards [Khoshniyat, 2012].

The planning procedure at Hallsberg is based on experienced planners and dispatchers who are stationed in the control tower where they plan the track allocations for the departing trains approximately one day prior to the departure.

The operational tasks are usually planned in the morning when the utilisation of the yard is on a relatively low level. The planned composition of the trains changes as the departure approaches. In fact, new orders from customers might cause the composition of trains to change as late as two hours before the departure time of a train [Koshniyat, 2012]. This complicates planning as the preconditions are constantly changing and deviations from the planned operations occur frequently. Table 12 states the main operational situations where decisions are required by the marshalling operator at Hallsberg MY. The recommendations are from the report [Trafikverket, 2015a].

Table 12: Overview of most occurred decisions at Hallsberg MY [Trafikverket, 2015a]

Decisions required	Situation	Potential decisions
Path selection for delayed incoming trains to the receiving yard	Early / late in relation to the departure times of the wagons	• If the train: (1) is so delayed that the wagons have missed their planned departure, and (2) is early with regards to the departure time of the wagons, and (3) will prevent other on-time trains if it enters the receiving area, then park the train somewhere else. Re-book wagons for outgoing trains.
		• If the train does not disturb any on-time trains, let it enter the receiving area.
Track selection for incoming trains	Train arrives from south or north	Select tracks 1-6 for trains arriving from north and track 5-8 for trains from south. Tracks should be selected so that an alternating marshalling sequence is possible. Select tracks near the centre of the receiving area, track 5 or 6, if possible.
Roll-in sequence	Trains on the receiving yard are ready to be rolled into the classification bowl. All wagons of an outbound train must have been rolled from the receiving yard to the classification bowl before the outbound train can be moved to the departure yard. Moving an outbound train from the classification bowl to the departure yard requires yard staff and a shunting engine. The roll-in sequence should therefore, if possible, distribute the times when the outbound trains are ready to be rolled to the departure yard over time.	• Recommendation 1: If the departing trains have wagons from all or many of the arriving trains: The recommendation is to start marshalling the arriving train with the most mixed destinations.
		• Recommendation 2: If the departing trains contain wagons from only some of the arriving trains: The recommendation is to start marshalling the arriving trains with few destinations.
Handling of damaged wagons	Train with damaged wagons is detected at the arrival inspection	Try to separate damaged wagons without interfering with other marshalling activities.
Movement planning in receiving yard	Other train movements may block the entrance to receiving area for an arriving train	Ensure that less time-critical train movements do not delay the access of the train to the receiving area. When there are staff available to inspect and clear an arriving train for marshalling, its access to the receiving area should not be delayed by other train movements.

Decisions required	Situation	Potential decisions
Approval from infrastructure manager to run outbound trains with non-regular parameters	Outbound train with non-regular train parameter e.g.: - Train weight exceeded - Brake weight percentage not sufficient	Reconfiguration of outbound trains if approval is not obtained.

2.6 Summary of results from the analysis

As stated in the conducted analysis of Marshalling yards, large freight nodes consist of a complex infrastructure of tracks, switches, crossings and infrastructure service facilities such as gravity humps, workshops, wagon weighbridges and connected loading points.

In the analysis, operational procedures, necessary staff and deviations from regular plans and kind of decisions in three Marshalling yards were analysed and a summarised.

Due to different infrastructure, system elements, level of digitalisation/automation and their location in the production network of the RU, different operational procedures are applied in different Marshalling yards.

As daily activities of the yard are planned in regular plans in advance, there should be usually only a minor need for decisions on changes of existing plans to control operational procedures at the yard.

In practice, a lot of disturbances as well as deviations of regular plans appear and cause ad hoc decisions and changes/adaptions of planned activities. As analysed, in these cases, dispatching of assets and personnel is mainly based on experience of planners and dispatchers. For example, at Hallsberg MY planners and dispatchers plan the shunting of wagons for the departing trains approximately one day prior to the departure**.** The operational tasks are usually planned in the morning when the utilisation of the yard is on a relatively low level. The composition of the trains changes as the operation date approaches. In fact, new orders from customers might cause the composition of trains to change as late as two hours before the departure time of a train. This complicates planning as the preconditions and constraints are constantly changing.

The main goals of dispatching in yards can be summarised as follows:

- Try to minimise consequences of delay on quality/punctuality
- Use the available resources in an optimal way, such that some spare capacity remains, e.g. to operate exceptional trains

For planning and steering of transit wagons through the yards, a complex target system exists for punctual fulfilment of operational requirements, e.g. wagon transfer/interchange from incoming to outgoing trains. In Sweden, the implementation of a booking system means that the departing train of the wagon (from the yard) has already been determined before the wagon arrives at the Marshalling yard.

During analysis, however it was not possible to identify a standard set of KPIs that is applied in ad hoc decisions to help quantify decision alternatives.

As described above, all decisions are based on information from the different IT systems.

As analysed in the German Marshalling yards regarding decision-making, the available IT systems are used for illustrating the actual situation, but the dispatcher depends mainly on his knowledge of the yard, the wagon transfers and the capacity of the part of the yard for which he or she is responsible.

In the analysis, operational procedures, necessary staff and deviations from regular plans and kind of decisions in three Marshalling yards were analysed and summarised.

3 CHARACTERISTICS OF TERMINALS

3.1 TYPOLOGIES

Intermodal terminals can in the most general definition of the term be categorised as Inland intermodal terminals or as Port terminals [Capacity4Rail, 2015].

Inland intermodal terminals

Inland intermodal terminals are nodes on a railway network where you handle, store and transfer goods between different transportation modes to the final customer; it is normally equipped with costly technology demanding a high degree of coordination and resource utilisation. Therefore, great effort is required to find an optimal configuration of infrastructure to exploit extensively technical resources and to organise technological procedures. Generally, Terminals can be classified by location in the logistics chain (e.g. Hub and Spoke, Gate terminal), by dimensions (large, medium and small) or transfer mode (Vertical or Horizontal).

Port terminals

Ports are the interface between land based and water based systems. While the maritime domain can involve vast geographical coverage, the land domain relates to the port's region and site location. Ports handle the largest amounts of goods by accommodating transhipment activities and modern container ports commonly act as pioneers in automation and innovation of terminal operations. Moreover, in comparison with land based terminals, the operation and the information flows are more complex: in port terminals, the intermodal unit loads are transhipped at least twice (ship-to-shore and shore to train). Ship-to-shore cranes, portal cranes, straddle carriers, reach stackers and empty container trucks are the main equipment used for handling containers at both port and connected inland terminals.

Based on these definitions, different types of intermodal terminals can be categorised as:

- Port terminals
- Large intermodal terminals
- Medium intermodal terminals
- Small intermodal terminals
- Industrial intermodal terminals for a single shipper

As nodes in transport chains, intermodal terminals (as well as Marshalling yards) are part of socio-technical systems where organisational, infrastructural, technological as well as market related aspects all have to be considered in order to obtain a full description. The various types of yards and intermodal terminals have different functions and operational pre-requisites and their description from a system perspective can be categorised as follows:

1. Operational procedures
2. Organisation
3. Infrastructure
4. System elements

3.2 Operational procedures

The operational procedures associated with the **basic functions** of an intermodal terminal are the following [Cosmos, 2017]:

- Transhipment of unit loads between modes of rail and road.
- Sequencing of operations; rail and truck disposition for loading and unloading, disposition of transhipments, internal terminal movements and intermediate buffering.
- Administrative functions, e.g. document control, security and damages of unit loads and documents for handling of dangerous goods.
- Ingoing and outgoing train check, e.g. braking test.
- Local shunting by rail

Moreover, there are **additional functions** that intermodal terminals may offer based on existing demand such as:

- Storage services
- Bundling services
- Forwarder function for rail and road operators
- Customs handling
- Trucking / pre- and post-haulage
- Maintenance, repair, cleaning of unit loads
- Handling of temperature sensitive goods

The **capacity and productivity** of an intermodal terminal can in turn be determined by a range of factors, where the primary influencing ones are:

- transhipment demand
- the position of the Terminal within the rail and road network
- the size and shape of the terminal area
- the length of the handling tracks and
- the number and capabilities of the utilised transhipment equipment

Operational capacity and **key performance indicators (KPI)** for intermodal terminals are commonly presented in the form of number of handled tonnage or unit loads, commonly expressed in TEUs. In order to establish the operational productivity, a number of KPI's can be measured, e.g.:

- Transhipment volume
- Utilisation rate of transhipment equipment
- Total Terminal costs per unit load
- Transhipment costs per unit load
- Energy consumption per unit load

3.3 Organisation

In most European countries, the organisation of large intermodal terminals differentiates between two functions; the **ownership** of the terminal infrastructure- and superstructure and the **management and operations** of the Terminal.

The ownership relates to the ownership of the infrastructures e.g. rail tracks and superstructures e.g. warehouses, cranes and reach stackers. These functions can in principle be handled by single actor, if the actor that owns the Terminal is also responsible for the operational activities. However, in deregulated freight markets and for public terminals, it is a common practice to appoint the most suitable operator through a tender. The following principles commonly prevail for large public intermodal terminals:

- Non-discriminative access to Terminals for shippers and operators
- Rail access for all licensed railway operators
- Road access for all road operators
- Transparent capacity allocation and pricing

3.4 Infrastructure

Large intermodal terminals are commonly located adjacent to consumption and production areas, where the demand for freight transportation is high or where it is expected to increase. The Terminals constitute an important link between the modes and enables bridges between production and consumption areas. When considering the localisation of an intermodal terminal, the following pre-requisites are critical for the Terminal’s long-term competitiveness:

- Good localisation in relation to the rail network
- Good localisation in relation to the road network
- Vicinity to freight transport markets
- Sufficient space for current operations and future expansion

Logistics clusters emerge as land use and other infrastructure are managed in such a way that transportation-intensive, warehousing and industrial activities are located in vicinity of each other in a limited geographical area. Large intermodal terminals are commonly parts of logistic clusters, incorporating large areas for handling unit loads and industrial sidings connecting it to warehouses.

3.5 System elements

The structure of the system elements of an intermodal terminal relates to the types and amount of goods that a specific type of Terminal is designed for and operationally handles. The type of technology used for transhipment plays an essential role for the efficiency of the Terminal. Intermodal terminals are commonly capital intensive, where conventional transhipment technologies used for transferring unit loads between modes are cranes as well as reach-stackers. These types of Terminals require relatively high investment costs and utilisation rate in order to achieve efficiency and as the transhipment cost is not proportional to the total transport distance in an intermodal transport chain, they constitute a contributing factor that restricts intermodal transports' competitiveness to long distance and high-volume operations i.e. mostly suitable for large scale intermodal terminals and end-point relations.

Figure 14: The reach stacker, a conventional technology commonly used for transhipment of unit loads at large intermodal terminals [Source: Coop]

A number of other transhipment technologies have been developed in order to streamline the transhipment process; however, when deviating from the conventional technologies the transport system commonly is transformed into a closed system as many of the novel technologies require customisation on railcars, chassis or unit loads, thus making the system unusable or not easily accessible for all operators and shippers. Regarding smaller unit loads (≤ 20 foot) that are equipped with tunnels for forklift handling, heavy forklift trucks is a common, simple and cost-effective alternative for transhipment.

Furthermore, in intermodal terminals several tracks are commonly required to be able to park the wagons while they wait to be loaded and unloaded. Hence, large intermodal terminals are cost- and space intensive and the cost per unit load is relatively high even with large freight volumes. However, their handling capacity is very high and electrified cranes commonly have lower emissions generated than technologies using fossil fuels e.g. reach stackers running on diesel.

Non-electrified terminal tracks are required by vertical transhipment equipment which implies that trains must be shunted with a diesel locomotive. Dual powered (hybrid) shunting locomotives running on both diesel and electricity offer opportunities for overcoming this challenge.

A straddle carrier (Figure 15) is used for stacking containers on top of each other and thus save storage area in the terminal. Terminal tractors are used for long distance movements of unit loads within the terminal area.

Figure 15: Straddle carriers used for stacking containers [Source: Kalmar industries]

A rail mounted gantry (RMG) crane (Figure 16) is a type of gantry crane in which the crane is allowed to move along the rail to the position of the unit loads. Another type of crane which is common at large intermodal terminals is the rubber tired gantry (RTG) crane (Figure 17), which is a mobile gantry crane used for loading and unloading of railcars and trucks and for stacking containers. Several tracks can be covered simultaneously and containers can be stored at the side of tracks. Cranes are most effective when high numbers of railcars are handled systematically and can be moved between rail and yard operations. However, when higher flexibility is required; reach stackers are the preferred transhipment technology in large intermodal terminals.

Figure 16: Rail mounted gantry crane a conventional technology used for transhipment and stacking of unit loads units at ports and large intermodal terminals [Source: Liebherr]

Figure 17: Rubber tired gantry crane used for transhipment and stacking of containers [Source: Liebherr]

3.6 CASE STUDIES

3.6.1 Case study: Stockholm Årsta Intermodal Terminal

As Stockholm Årsta Intermodal Terminal is located only six kilometres south of Stockholm city centre, it can be regarded as a gate terminal into the city for northbound trains and for city distribution in the Stockholm region. The terminal is also located along the western main line, which is the rail line connecting Sweden's two largest cities; Stockholm and Gothenburg. There are also a number of larger ports within a relatively short distance, and Arlanda airport in the northern parts of Stockholm [Jernhusen, 2015]. Thus, Årsta is in the middle of a large and important logistics region. On the other hand, due to the number of port and inland intermodal terminals in the vicinity of the terminal, stiff competition exists between these terminals for the incoming freight volumes on rail to the region. The outgoing volumes are significantly lower, as there is an imbalance between production and consumption in the region, similar to many other urban regions.

Table 13 illustrates the productivity of the ten largest intermodal Terminals in Sweden considering the number of handled TEUs. It should be noted that data was not available for all intermodal terminals in Sweden, for example the large port Terminals Port of Gothenburg and Port of Stockholm (Frihamnen) are not included in the table. A rough estimation entails that large intermodal terminals handle around 50 000 TEUs or more and medium sized Terminals handles between 20 000 - 50 000 TEUs/year. The numbers vary between different European countries as they are dependent on the total cargo handled in each country and the overall number of available intermodal Terminals in the country. In 2015, Årsta Terminal handled around 27 000 TEU/year (reduced from 48 000 in 2013, as illustrated by Table 13), but the capacity is almost three times higher – 80 000 TEU/year.

Table 13: The ten largest intermodal terminals in Sweden in 2013 [Transportnytt, 2014]

Ranking	Terminal	City	TEUs in 2013
1	Nässjö intermodal terminal	Nässjö	90 000
2	Port of Gävle Granudden	Gävle	80 000
3	Eskilstuna intermodal terminal	Eskilstuna	77 200
4	Gothenburg intermodal terminal	Gothenburg	75 000
5	Port of Helsingborg	Helsingborg	75 000
6	Årsta intermodal terminal	Stockholm	48 000
7	Vaggeryd intermodal terminal	Skillingaryd	34 000
8	Logent Hallsberg terminal	Hallsberg	21 000
9	Pampus container terminal	Norrköping	20 000
10	Sundsvalls intermodal terminal	Sundsvall	20 000

3.6.1.1 Organisation

The investor and owner of the intermodal terminal is Jernhusen, which is a Swedish state-owned company that owns, develops and manages properties and Terminals along the Swedish railway. The company “Väte Trafik” is the main terminal operator and “Kyl & Frysexpressen” is the second largest operator in the terminal; responsible for the refrigerated cross-dock operations at the Terminal. The terminal operator takes a fee for every transhipment that is carried out by the cranes of which Jernhusen also charges a certain percentage and the terminal operator also charges rail operators a fee for every train-set that is shunted into terminal tracks. Therefore, there is an incentive to increase the number of transhipments carried out at the Terminal.

As of January 1st, 2017, Väte Trafik is the main terminal operator, previously they have only been providing shunting services for the terminal but as the previous terminal operator “Carrier Transport AB” revoked their contract last year, Väte Trafik was tendered by Jernhusen as the new terminal operator [Jernhusen, 2017]. As the company still provides the shunting services for the terminal, they ought to have a more advantageous business model as a terminal operator than their predecessors.

A local firm called ‘Kyl & Frysexpressen’ (‘fridge and freeze express’) manages the entire refrigerated cross-dock warehouse (Cross-dock B in Figure 18) in the logistics facility of Årsta. Kyl & Frysexpressen is also the distributor for the largest wholesaler ICA in Sweden to the inner city and the south of Sweden. The total area dedicated for the refrigerated cross dock is 9 500 m2, and the other cross-dock (Cross-dock A) is 5 500 m2, non-refrigerated and operated by another company ‘Mertz’ and a large Swedish grocery supplier ‘Pågen’.

The main rail operator that currently uses the terminal is Green Cargo.

Figure 18: Stockholm Årsta Intermodal Terminal [Source: Jernhusen]

3.6.1.2 Operational procedures

On weekdays, about three to four trains arrive daily. One train arrives during the night at 01:30, and is then reloaded rather quickly and departures again at 04:00 a.m. i.e. prior to the opening of the other activities at the terminal at 05:00 a.m. During this time, certain functions of the terminal i.e. gate entrance, transhipment and shunting in, are opened only for handling that specific train.

Later in the morning another two trains arrive which are handled at the Terminal throughout the day. Since it is very costly to operate the terminal on weekends due to the high costs of labour, the terminal is not open during weekends.

When the trains arrive at the terminal, the company “Väte Trafik” assists with the shunting in and out of the area. When the train is inside the terminal and located on the right track, the unloading procedure takes place. The gantry cranes lift the unit loads off the trains and onto the parking lots. The reverse procedure occurs when the trains are loaded. When the train is reloaded it departures and the same process follows the consecutive train.

The following are the standard and additional services coupled to the main operational procedures at Årsta Intermodal Terminal:

Standard services:

- Transhipment of containers, tank containers, semi-trailers and swap bodies
- Shunting
- Gate in / out inspection
- Brake test
- Storage of cargo carriers, less than 48 hours

Additional services:

- Additional storage beyond the basic setup
- Storing of refrigerated or heated units loads
- Handling of hazardous goods
- Cross-dock
- Sealing of unit loads
- Repairs and maintenance of unit loads

3.6.1.3 Systems elements

Jernhusen has invested an additional 400 million SEK in the Terminal when it officially reopened in May in 2014. In Årsta they have invested in two cross-dock buildings and two rail mounted gantry cranes, accompanied with a small yard for storage of unit loads and parking of trucks. There are around 100 parking lots for semi-trailers along the tracks. The main reason for the renovation was to make the terminal more modern and efficient so that more goods could be handled in shorter amount of time [Jernhusen, 2015].

The intermodal terminal mostly handles semi-trailers - about 80 % of all incoming units - and only a small number of containers and tanks, about 20 % of all incoming units. The terminal is relatively small compared to other Terminals that mainly handle containerised freight. Due to this fact and the fact that there is no stacking equipment available such as straddle carriers for stacking multiple containers on top of each other, the terminal cannot handle any large amounts of freight that has to be stored in the terminal area for a longer period of time. The containers can be stacked on one level i.e. two units vertically.

The facility consists of four tracks that are 520-540 meters long. Hence a Swedish full length intermodal train of approximately 630 meters cannot be handled on one track but has to be to split up into approximately 13 and 5 twin wagons on two tracks. Furthermore, as European cross-border trains often exceed 700 meters, the Terminal cannot handle the easily hence imports are impeded. The main reason behind the short track lengths is that the IM Trafikverket could not make more land available in the surroundings of the terminal area when Jernhusen modernised the terminal area in 2014.

The terminal operator uses an IT-system that is implemented at the majority of Jernhusen’s Terminals in order to gather information about the shippers, unit load and cargo characteristics etc. The system has integrated several previous systems, thereby intending to create an IT standard for Swedish intermodal traffic. However, regarding the interface towards the system, rail operators use different systems of their own for reporting their arrivals and what they are carrying, where the latter in turn depends on the shippers’ routines for information exchange.

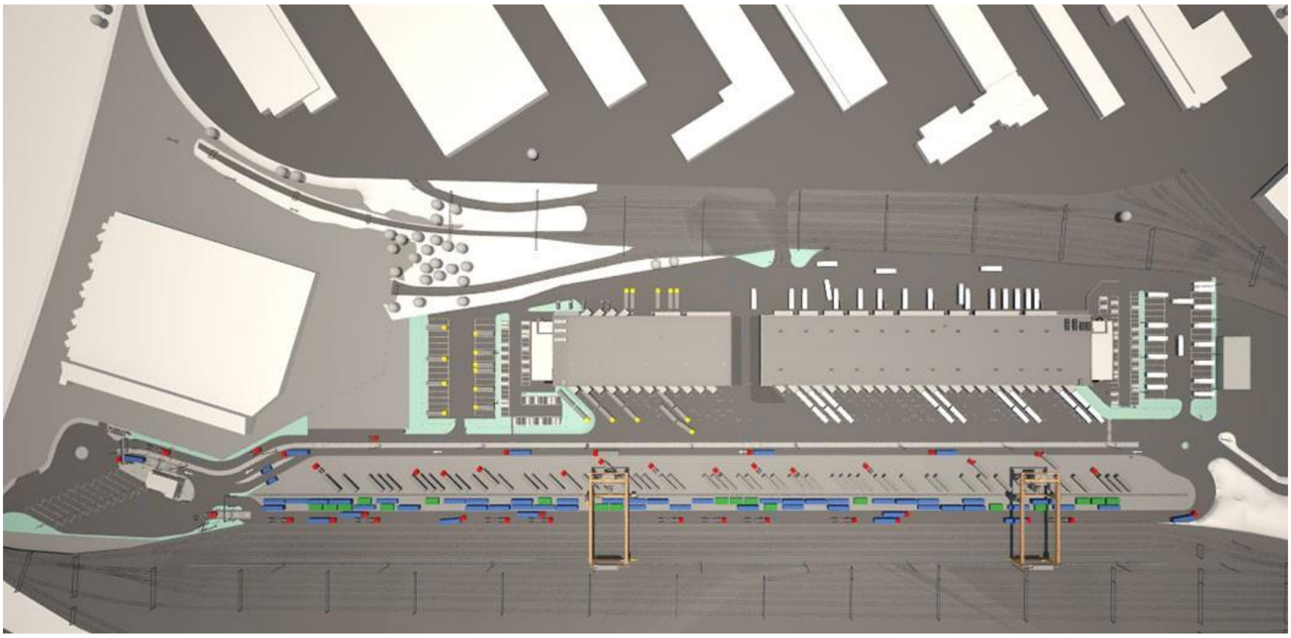

Figure 19: Layout of Stockholm Årsta Intermodal Terminal [Source: Jernhusen, 2015]

3.6.1.4 Digitalisation status and decision processes in the Terminal

For both incoming and outgoing freight from the terminal, there is currently limited digital information exchange between the main stakeholders involved, i.e. rail operators, road hauliers and the terminal operator. This implies that the terminal operator cannot accurately know the exact ETA (Expected Arrival Time) of neither freight trains nor trucks. Albeit there is normally an ETA for arriving freight trains, it is not automatically provided further by the terminal operator to road hauliers and trucks arrive at the Terminal without any pre-arrival notification in case of deviations [Jacobsson et al., 2017].

The standard procedure is that road truck hauliers are informed by the rail operator in case of train delays. If the information flow is broken, trucks will experience idle times at the Terminal or empty returns. The terminal operator only informs truck hauliers that are in the terminal area or who contact the terminal operator themselves.

Regarding deviations on the ETA of incoming trains, according to dispatchers at the terminal, they receive information from the Swedish Transport Administration (Trafikverket) regarding the train's current position, based on the specific line the train is located, not its precise location. As a result, secondary delays might be difficult to foresee. Nevertheless, the terminal operator makes an estimation based on their experience on when the train might arrive. If the information of deviations regarding the ETA of incoming freight trains would be more accessible and accurate, the planners at both the terminal operator and road hauliers could plan their resources more efficiently, mainly regarding the number of trucks that are forced to wait at the Terminal or return empty [Jacobsson et al., 2017].

Moreover, due to the various IT-systems and analogue routines for information exchange among shippers, truck hauliers and rail operators - the terminal operator cannot always be informed in advance regarding the sequence of unit loads on the trains, thus making the decisions regarding the planning of transhipments and pick-ups cumbersome.

As stated in the system elements in previous chapter, the facility consists of two heavy gantry cranes and four tracks that are 520-540 meters long, thus each track cannot hold a Swedish full-length freight intermodal train consisting of 18 twin wagons, approximately 630 meters. The train is then divided into two parts and put on different tracks - typically 13 wagons on one and 5 on the other. A main implication of this splitting of trains is that the terminal tracks are occupied and a fewer incoming trains can be accepted.

Hence, there is an overcapacity regarding the number of arriving trains that the Terminals serve on a daily basis with respect to the available transhipment and labour capabilities, implying that the operational procedures in the Terminal are stable and function well. According to the terminal operator, more than 90% of the delayed trains out from the Terminal are caused by the rail operator; either due to missing engine driver or due to missing train assignment.

Table 14 provides an overview of the most occurred decisions caused by deviations in Årsta Intermodal Terminal.

Table 14: Overview of most occurred decisions caused by deviations at Årsta Intermodal Terminal

Decisions required	Kind of deviations	Potential decisions	Decision maker
Local shunting into the Terminal	Multiple trains arrive simultaneously	Prioritise on-time trains. If both trains are late, prioritise shunting movements with best production characteristics and least impact on other activities.	Shunting operator (Väte Trafik)
Local shunting into the Terminal	Length of incoming trains exceeds track capacity.	If incoming train exceeds track length or if tracks are partly occupied, the train is divided into two parts and put on different tracks: ~ 13 wagons on one track and 5 on the other.	Shunting operator (Väte Trafik)
Local shunting into the Terminal	Train with damaged wagons is detected at the arriving inspection.	Try to separate damaged wagons with minimal impact on other operations.	Shunting operator (Väte Trafik)
Ad-hoc positioning of transhipment equipment	- Delay of incoming trains - Delay of outgoing trains - Delay of trucks - Lack of personnel resources	Prioritisation and sequencing regarding transhipments of unit loads between rail and road.	Terminal operator (Väte Trafik)

Decisions required	Kind of deviations	Potential decisions	Decision maker
Ad-hoc positioning of trucks	- Delay of incoming trains - Delay of outgoing trains	- In case of delays for incoming and outgoing trains - inform truck hauliers that are in the terminal area or who contact the terminal operator. - The standard procedure consists of truck hauliers being informed by the rail operator in case of train delays. If this information is not passed further, trucks will experience idle times at the Terminal or empty returns from the Terminal.	- Terminal operator (Väte Trafik) - Rail operator
Ad-hoc internal movement of unit loads	- Delay of incoming trains - Delay of outgoing trains - Delay of trucks - Lack of storage capacity - Damaged unit load detected at entry inspection or during transhipment.	- Internal storage - Transhipment between road and rail - Damaged unit load sent to the workshop for repairs	Terminal operator (Väte Trafik)
Approval from infrastructure manager to run outgoing trains with non-regular parameters	Outgoing train with non-regular train parameter e.g.: - Train weight exceeded - Brake weight percentage not sufficient	Reconfiguration of outgoing trains if approval is not obtained.	- Infrastructure manager (Trafikverket) - Shunting operator (Väte Trafik) - Terminal operator (Väte Trafik) - Rail operator

3.6.2 Case study: DUSS-Terminal München-Riem

The Terminal München-Riem is located in the east of Munich and was put into operation in 1992. Due to its geographical location, Munich has a significant strategic value as gateway terminal on the north-south transport axis and is a central hub in Germany between Northern and Southern Europe. Feeder trains with intermodal cargo from all over Germany and the neighbouring countries arriving to the Terminal, are sorted here and transhipped onto connecting trains mainly to Italy and vice versa. Those handlings make about 25% of the total transhipment throughput. Furthermore, München-Riem is highly valuable for maritime hinterland traffic [DUSS, 2017].

The Terminal has direct rail connections to main lines in all directions. The location just off the motorway A94 Munich-Passau and the motorway junction A99 Munich-East enables easy access to Salzburg / Kufstein, Lindau, Garmisch, Stuttgart and Nuremberg. The new Munich trade fair –

considered one of the largest exhibition centres in Germany – is located in immediate vicinity of the terminal.

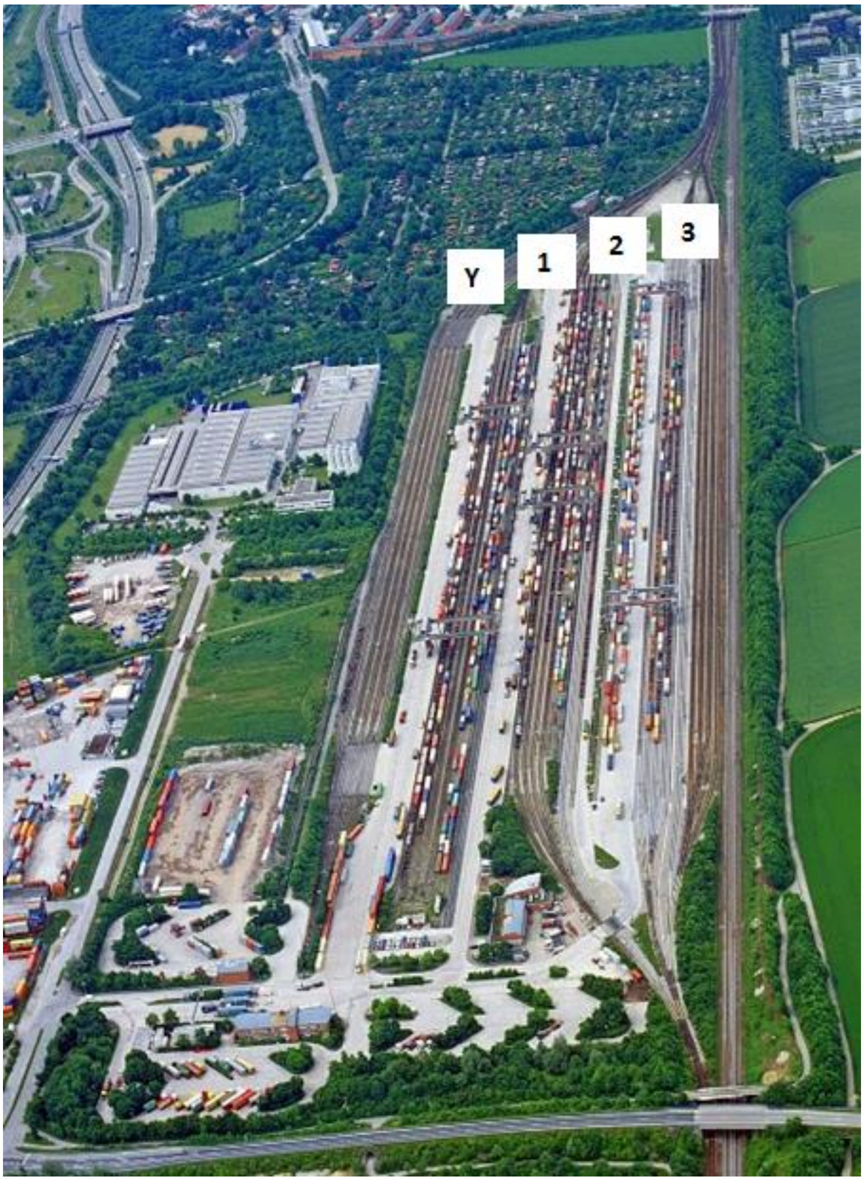

Figure 20: DUSS-Terminal München-Riem [Source: DB Netz]

3.6.2.1 Organisation

The owner of the intermodal terminal München-Riem is DB Netz AG, which is a state owned German company that owns, develops and manages railway infrastructure in Germany. DUSS, a subsidiary of DB Netz AG (75% ownership) is the terminal operator and also the operator of all intermodal terminals belonging to DB Netz AG. The minority owners of DUSS are Kombiverkehr (12,5%) and DB Cargo (12,5%). DUSS pays an annual fee for renting the terminal infrastructure of DB Netz.

Other main stakeholders involved in the terminal process are the following:

- Railway undertakings e.g. DB Cargo - provide the transport service by rail
- Railway operators e.g. Kombiverkehr and Hupac - develop, organise and market Europe-wide networks for rail-road combined transport
- Forwarders - constitute the interface towards shippers similar to railway operators, except their services go beyond combined transports as services of other modes are also offered
- Shunting operators – handle the local shunting in and out from the terminal area

3.6.2.2 Operational procedures

When trains arrive to the entrance of terminal area, they are shunted into the terminal area by the shunting operator after receiving an approval from the terminal operator that they can accept the incoming train. The shunting activities are carried out in the area labelled as the letter Y in Figure 20. The responsibility of the DUSS is not engaged until a train has been shunted into the transhipment yard area (within the terminal) by the shunting operator.

When the train is inside the terminal and located on the right track, the unloading procedure takes place. The gantry cranes lift the unit loads off the trains and directly on the truck or onto the parking lots/storage area. The reverse procedure occurs when the trains are loaded. When the train is reloaded, it departures and the same process follows the consecutive train.

Selected service information [DUSS, 2017]:

- Approved loading units: ISO-Containers 20' – 45', Swap bodies, trailers
- Electrified transhipment tracks (access)
- Brake test facility
- 24-hour operation
- Dangerous goods handling (RID/ADR)
- RID/ADR leakage place
- Reefer plugs (temperature-controlled units)
- Customs office

3.6.2.3 Systems elements

The terminal München-Riem was put into operation with two transhipment modules in 1992, modules 1 and 2 in Figure 20 and extended to a third module in 2011, module 3 in Figure 20. Since January 2016, the terminal has an additional storage area to increase intermediate storage capacities [DUSS, 2017].

There are no longer any expansion possibilities for the terminal due to the boundaries set by its surrounding and the projected scenario considers a new intermodal terminal being implemented in Munich when future demand exceeds the terminal's capacity. Table 15 states the main data regarding the infrastructure and operational resources at the terminal.

Table 15: Selected data considering the main infrastructure and operational resources at the terminal [DUSS, 2017]

Number of rail-mounted gantry cranes	6
Number of reach stackers	2
Max. lifting height above rail head	12 m (relative to top of unit)
Max. cargo-carrying capacity	41 t
Modes of operation	twistlock, grapple arms
Max. length of grapple arms	3.600 mm
Max. ground storage capacity (unstacked)	590 TEU (in the module), 350 TEU (separate storage area)
Max. terminal handling capacity	360.000 units p.a.
Transhipment tracks, operational length - Module 1	5 x 700 m
- Module 2	5 x 700 m
- Module 3	4 x 700 m
Total number of tracks	14
Total usable length of transhipment tracks	9800 m
Interim storage	Capacity: 1000 TEU

Besides the Terminal Operating System (called BLU) for the internal terminal operations, the terminal operator uses two applications which enable monitoring trains when running on the main line:

(1) LeiDis: The system offered/ managed by the national rail infrastructure manager DB Netz and covering train movement on the DB Netz-Network
(2) Train Information System (TIS): Web-based application management by RailNetEurope (RNE) in Vienna. The system delivers real-time train data concerning international passenger and freight trains. The relevant data is obtained from the respective national infrastructure Managers' systems. [TIS, 2017] The IT system is on a European level and thus considered suitable for the operator as the terminal to great extent handles cross border trains (about 25% of the total transhipment throughput is connected to Italy).

3.6.2.4 Digitalisation status and decision processes in the Terminal

As stated above the terminal operator uses two applications in order to obtain real-time train data. However, similar to the case of Årsta intermodal terminal, for both incoming and outgoing trains there are currently limited digital information exchange between the main stakeholders involved, i.e. IM, RU, railway operators, road hauliers and the shunting operators. Thus, the information flow between all relevant stakeholders is either disrupted or occurs in a manual way (telephone, email, etc.). Furthermore, it has to be noted that ETA available in the current system is hardly viable for the shunting service provider and terminal managers. As a result and considering the whole transport chain, it is very complicated to steer the incoming road hauliers and trucks in case of deviation.

Regarding deviations on the ETA of incoming trains, the two IT applications provide the train's current position, but do not provide an ETA taking into account real traffic conditions during the train run (possession works, change of locomotive and staff, etc.). In addition, TIS does not cover the last mile from the main track to the terminal infrastructure. Therefore, secondary delays might be difficult to foresee. For instance, a train might be on time on time when entering the shunting area but delayed when entering the terminal area. Moreover, in the case of delayed incoming trains, the current procedure for information exchange might be long as several stakeholders need to be informed (Railway undertaking, combined transport operator, road hauliers).

As described, the information chain is long and the digitalisation status is still on a low level and the information exchange is mainly performed manually (via telephones and e-mails). When the information flow is disrupted, trucks experience ether idle times at the Terminal or empty returns. With DUSS being aware of this issue, they are currently working on an IT-application set to be ready (test Version) by the end of 2017, where information regarding the status of a specific loading unit (and especially the time for picking it up in the terminal) can be obtained via a mobile application by the relevant stakeholder.

In combined transport, a significant potential for productivity improvements exist if existing obstacles (disrupted information flow, unclear legal issues regarding data sharing and corporate rights) could be resolved. The planed application by DUSS might be one step forward.

Table 16 provides an overview of the most occurred decisions caused by deviations in the München-Riem Intermodal Terminal.

Table 16: Overview of most occurred decisions caused by deviations at München-Riem Intermodal Terminal

Decisions required	Kind of deviations	Potential decisions	Decision maker
Local shunting into the Terminal	Multiple trains arrive simultaneously	Which train should be approved first for entering the terminal area? Prioritise on-time trains and those with best production characteristics and least impact on other activities low	Terminal operator (Established coordination procedure with all relevant stakeholders)
Local shunting into the Terminal	Damaged wagons are detected at the arriving inspection.	Try to separate damaged wagons with minimal impact on other operations	Shunting operator
Ad-hoc positioning of transhipment equipment	- Delay of incoming trains - Delay of outgoing trains - Delay of trucks - Lack of personnel resources	Prioritisation and sequencing regarding transhipments of unit loads between rail and road	Terminal operator (together with relevant stakeholders)
Ad-hoc positioning of trucks	- Delay of incoming trains - Delay of outgoing trains	In case of delays for incoming and outgoing trains the standard procedure consists of contacting the railway undertaking who contacts the rail operator who in turn contacts the road hauliers and the ETAs for pick-ups or deliveries are updated.	- Terminal operator - Rail undertakings - Rail operator

Decisions required	Kind of deviations	Potential decisions	Decision maker
Ad-hoc internal movement of unit loads	- Delay of incoming trains - Delay of outgoing trains - Delay of trucks - Lack of storage capacity - Damaged unit load detected at entry inspection or during transhipment	- Internal storage - Transhipment between road and rail - Damaged unit load sent to the workshop for repairs	- Terminal operator
Approval from infrastructure manager to run outgoing trains with non-regular parameters	Outgoing train with non-regular train parameter e.g.: - Train weight exceeded - Brake weight percentage not sufficient	Reconfiguration of outgoing trains if approval is not obtained.	- Infrastructure manager - Shunting operator - Terminal operator - Rail operator

3.7 Summary of results from the analysis

As stated in the introduction of this chapter, intermodal terminals acting as nodes in transport chains are parts of socio-technical systems where operational, organisational, infrastructural and technological as well as market related aspects all have to be considered in order to obtain a full description. Various types of intermodal terminals have different functions and operational pre-requisites and a description from a system perspective, which has been applied in this analysis, has been categorised accordingly:

1. Operational procedures
2. Organisation
3. Infrastructure
4. System elements

To summarise, the basic operational procedures associated with an intermodal terminal are the following:

- Ingoing and outgoing train check e.g. braking test.
- Local shunting by rail
- Transhipment of unit loads
- Sequencing of operations
- Administrative functions

As for the organisation, in many European countries large intermodal terminals differentiate between two functions - the ownership of the Terminal and the management and operations of the Terminal. In the case of Årsta Intermodal Terminal in Sweden, it is owned by the state-owned company 'Jernhusen' which has tendered the operations to a private company, 'Väte Trafik'. In the case of Germany, a similar organisational structured is in place as the state-owned company DB Netz owns the terminal and DUSS handles the terminal operations. However, there are some differences in this structure as DUSS is also public company and owned to 75% by DB Netz. Thus DUSS is considered as a public infrastructure manager whereas the operators of Jernhusen intermodal terminals in Sweden are private terminal operators.

Regarding infrastructural parameters, large intermodal terminals are commonly located adjacent to relatively large consumption and/or production areas, where the demand for freight transportation is high or where it is expected to increase. When considering the localisation of an intermodal terminal, the following pre-requisites are critical for the Terminal's long-term competitiveness:

- Localisation in relation to the rail network
- Localisation in relation to the road network
- Vicinity to freight transport markets
- Sufficient space for current operations and future expansion

In both the case of Årsta Intermodal Terminal and the one of DUSS München-Riem, it is evident that all of these pre-requisites are fulfilled except the latter i.e. sufficient space for current operations and future expansion. As for many city terminals, the land on which the Terminal is built upon is highly valued and expansion possibilities are limited.

In the case of the Årsta terminal, there are four transhipment tracks that are 520-540 meters long; hence a Swedish full length intermodal train of approximately 630 meters cannot be handled on one track but has to be to split up into two groups with approximately 13 and 5 twin wagons on two tracks. Moreover, as European cross-border trains are often even longer – imports to the Terminal are impeded. A main reason behind the short track lengths is that the IM Trafikverket could not make more land available in the surroundings of the terminal area. The unit loads are only stacked one level due to the lack of standardised stacking equipment such as straddle carriers commonly used at large intermodal and port Terminals, as well due to terminal design; thus, the operations are concentrated on handling semi-trailers rather than containers which can be stacked multiple levels upon each other, thus offering a better utilisation of the available space.

Continuing with the systems elements, both terminals use rail mounted gantry cranes as the main transhipment technology, thus offering high capabilities for fast transhipments albeit also requiring high utilisation rates.

Another main system element is the capabilities for handling information and communication between the main stakeholders i.e. the infrastructure manager, rail operators, road hauliers and the terminal operator. Today the automation and digitalisation level, discussed further in chapter five, is very low, which for instance implies that that the terminal operator cannot know accurate ETA's of neither freight trains nor trucks.

Furthermore, it has to be noted that ETA available in the current systems are hardly viable for terminal operators - considering the whole transport chain, it is very complicated to steer the incoming road hauliers and trucks in case of deviation. Regarding deviations on the ETA of incoming trains, the IT applications provide the trains' current position, but do not provide an ETA taking into account real traffic conditions during the train run (possession works, change of locomotive and staff, etc.). In addition, TIS does not cover the last mile from the main track to the terminal infrastructure. Hence, secondary delays might be difficult to foresee for the terminal operators.

Moreover, in regard to delayed incoming trains, the current procedure for information exchange might be long as several stakeholders need to be informed (Railway undertaking, combined transport operator, road hauliers). The standard procedure is that road hauliers should be informed by the involved rail operator or railway undertaking. Due to the various non-standardised IT-systems and manual routines for information exchange (telephone, email, etc.) among the involved stakeholders, the terminal operator cannot always be informed in advance regarding the sequence of unit loads on the trains, thus making the decisions regarding the planning of transhipments and pick-ups cumbersome. As the information chain is long and the digitalisation status is on a low level, the information flow is prone to disruptions and when it is disrupted trucks will experience idle times at the terminal or empty returns from the terminal.

The terminal operator in Årsta only informs truck hauliers that are in the terminal area or who contact the terminal operator themselves. Nevertheless, as there is only one rail operator currently using the terminal in Årsta, the information exchange there functions rather well according to the terminal operator, except for wagon-load trains that experience last minute wagon cancelation.

DUSS on the other hand are currently working on an IT-application, where information regarding the status of a specific unit loads (and especially the time for picking it up in the terminal) can be obtained via a mobile application by the relevant stakeholder.

In intermodal transport chains, the lack of information commonly also applies to unit loads containing goods from multiple shippers, where the sequence of the different shipments is not known in advance, thus making it challenging for the cross-dock operators and distributors to optimise their procedures.

4 DESCRIPTION OF DIFFERENCES WITH ONE OR MULTIPLE RAIL OPERATORS IN MARSHALLING YARDS AND TERMINALS AND OF THE INTERACTION WITH NETWORK MANAGEMENT

4.1 THE SWEDISH SITUATION

4.1.1 Marshalling yards

As stated previously, Marshalling yards are the railway's production facilities. A consequence of the deregulation of the railway market is that many freight operators may wish to use the same Marshalling yard, i.e. the same production facility. This calls for different rail operators to share marshalling tracks and technical equipment, and raises questions on the responsibilities and rights of the different parties. In Sweden, the infrastructure manager owns the marshalling tracks and infrastructure equipment, and is responsible for track maintenance and, to some extent, capacity allocation. However, the infrastructure manager is not responsible for operating the marshalling yard. This responsibility falls on the rail operators wishing to use the marshalling yard, or on a marshalling service provider.

Marshalling is a complex process, and making the most appropriate capacity allocation and prioritisation decisions is hard. If there is only one rail company using the yard, all decision processes and operations will be internal, but when multiple operators share the yard, some sort of cooperation or delimitation agreement must exist between the different companies. Further, economic barriers make it hard for small companies to operate a Marshalling yard themselves. Therefore, small companies can only use the Marshalling yard if they can buy a reasonably priced marshalling service.

Currently railway operators (or more correctly, authorised applicants) apply to the Swedish IM Trafikverket for access to Marshalling yards. The Marshalling yard access service includes access to the tracks and facilities within the marshalling yard. However, the actual marshalling tasks, such as e.g. arrival control, uncoupling, shunting, coupling and brake tests, are not included in the access service provided by the infrastructure manager. This means that a railway operator that applies for, and receives, a train path to or from a Marshalling yard must either have authorised marshalling personnel that can carry out the marshalling, or buy the marshalling service from a service provider.

All railway operators are allowed to use the technical equipment at Marshalling yards, as long as their personnel have appropriate training. Notably, it is the responsibility of the Marshalling yard personnel to guarantee safe dispatching at the yard, as many Marshalling yard tracks are not dispatched by the infrastructure manager. Figure 21 shows the tracks of Hallsberg Marshalling yard (top picture) and the tracks and signals controlled by the infrastructure manager's traffic managers (bottom picture). To guarantee safe dispatching, the personnel in the control tower have to cooperate closely with the IM traffic managers. It's the railway operator's responsibility to ensure that all marshalling personnel have received appropriate training, and the Swedish Transport Agency (Transportstyrelsen) is the supervising authority. As can be seen, the arrival yard and departure yard, but not the classification bowl (encircled), are controlled by the IM. The classification bowl is controlled by the marshalling personnel in the control tower.

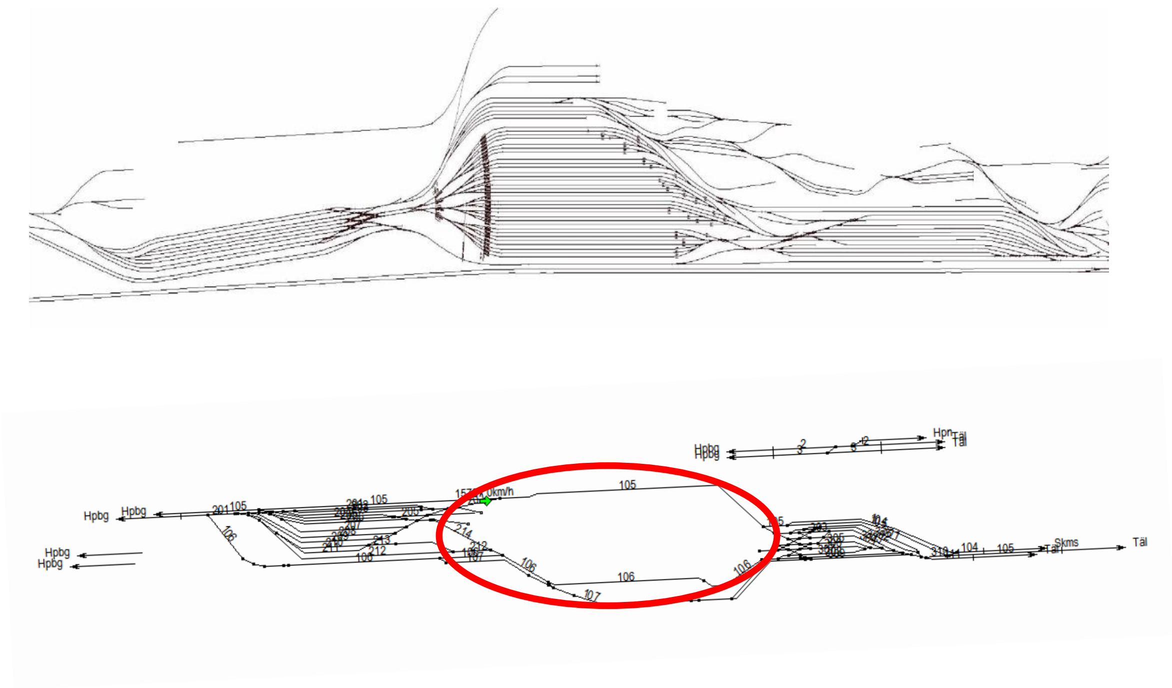

Figure 21: Control sections of Hallsberg MY

A marshalling service provider has to respect laws (civil law and contract law). Further, the SERA directive includes rules for service providers:

- European Parliament and Council directive 2012/34/EU [EU, 2012] and
- European Parliament and Council directive 2016/2370/EU [EU, 2016]

The Swedish infrastructure manager is not responsible for overseeing the competitive neutrality of Marshalling yard service providers. Rather, this falls under the responsibility of the Swedish Transport Authority and sometimes the Swedish Competition Authority.

Currently, only Green Cargo AB has trained marshalling personnel in Sweden, and Green Cargo also has the mandatorship for marshalling. Green Cargo is the main user of Swedish Marshalling yards, and operates over 99% of all marshalled wagons. Other operators may pay Green Cargo to marshal their wagons, but in general these wagons either come from or go to Green Cargo trains. Importantly, Green Cargo does not provide nor sell a specific well-defined marshalling service, and has not expressed an interest in becoming a fully-fledged marshalling service provider. All wagons that are to be marshalled (both Green Cargo's and other companies') must be entered into Green Cargo's wagon planning system BRAVO. This is because BRAVO provides data required to ensure safe marshalling. Entering, and later deleting, other operators' wagons from BRAVO requires some administration work on Green Cargo's part.

If wagon failure is discovered during the arrival inspection, the wagon is sent to a repair track. The repair service is provided by a separate company, independent of the Marshalling yard operator.

There are no legal obstacles preventing other railway operators, or a specialised marshalling service provider company, from carrying out marshalling services. However, as the vast majority of marshalled wagons belong to Green Cargo, it would be hard for any other company to make a profit from marshalling. Due to the non-competitive situation, the Swedish infrastructure manager recently investigated the question of how the marshalling service should be operated. The conclusion was that preventing Green Cargo from being the main marshalling operator would result in major risks. From a capacity point of view, it would be sub-optimal to assign different actors to the same track capacity but at different times of the day or week. From a more technical point of view, Green Cargo owns many FM frequencies used for e.g. remote locomotive and switch steering, and there may not be enough FM frequencies available for another company to provide a marshalling service. However, the Swedish infrastructure manager has asked Green Cargo to release some FM frequencies. If Green Cargo in the future stops marshalling other operators' wagons, or if a new railway operator with large marshalling volumes enters the Swedish railway market, then the Swedish infrastructure manager has strong reasons to re-evaluate how the marshalling service should be operated.

Another aspect when it comes to Marshalling yards and many operators is that traffic can be, and is often, redirected from one yard to another. If different operators are allocated to different yards this flexibility may be lost. The flexibility also means that if e.g. some regulation forced Green Cargo to stop marshalling at a specific yard, they may re-plan their wagon-trips to avoid using that yard, thereby removing the customer base from the new marshalling service provider.

Sometimes, there are discussions on the impartiality and fairness of the capacity allocation at marshalling yards. There are also sometimes discussions on the prioritisation of wagons and trains during traffic disturbances and disruptions. In an interview with the infrastructure planning manager at Green Cargo, he argued that it would be preferable if the infrastructure manager had specialised marshalling planning personnel that could help settle these discussions. Further, he stated that it would be good if IM personnel were responsible for safe dispatching in the Marshalling yard.

4.1.2 Intermodal terminals

Regarding the intermodal terminals, the situation differs from that of the Marshalling yards in Sweden. One main difference is that for intermodal terminals, there are two infrastructure managers involved; Trafikverket who is responsible for the traffic on the line and Jernhusen who owns the transhipment facilities and terminal area. The facilities are tendered to a terminal operator who is obliged to offer non-discriminative access for all licensed railway and road operators, based on transparent capacity allocation and pricing.

It should be noted that the business model of the state own company 'Jernhusen' is that they should generate an annual profit and thus they charge the terminal operator a fee for each transhipment.

Moreover, there are no terminal operators who simultaneously act as rail operators as well, hence the same situation as for Marshalling yards do not occur where rail operators have to acquire the marshalling services of the competitors. On the other hand, many terminal operators are also active as road hauliers thus competing with local hauliers which they also serve as a terminal operator.

4.2 THE GERMAN SITUATION

As a consequence of the deregulation of the railway market, in Germany like in most other European countries, several private railway undertakings operate freight trains. Most of these RUs focus on the operation of train load trains, combined transport and the operation of shunting services on sidings.

Wagon load train (Single wagon) are operated almost only by DB Cargo, however there are a few private operators offering this kind of traffic, but either on a very limited set of relations or on a non-regular basis.

DB Cargo offers wagon load trains all over Germany and throughout Europe, including many long-distance relations. This includes collecting and distributing customer loads from (industrial) sidings.

The use of Marshalling yards in Germany is regulated by the infrastructure manager DB Netz. The users of Marshalling yards are granted the usage rights for all necessary tracks and service facilities in the yards by the IM. Usage charges are described in the Network Statement for Service Facilities, which is publicly available on the internet.

All service facilities and signalling appliances in Marshalling yards in Germany are also operated by the IM DB Netz.

In Germany, actually all tracks and service facilities in Marshalling yards are rented to DB Cargo. After agreement with DB Netz, shunting operations of other operators can be carried out on these DB Cargo tracks such that mutual influences are avoided.

5 AUTOMATION/OPTIMISATION CAPABILITIES OF A "REAL-TIME YARD MANAGEMENT SYSTEM" IN YARDS, TERMINALS AND FOR THE INTERACTION WITH NETWORK MANAGEMENT

5.1 MARSHALLING YARDS

As described in the use cases, Marshalling yards manage a multitude of complex and time-critical tasks. In three Marshalling yards operational procedures, necessary staff, deviations from regular plans and kind of decisions were analysed.

As daily activities of the yards are planned in regular plans in advance, there should usually be only a minor need for decisions on changes of existing plans to control operational procedures at the yard. In practice, a lot of disturbances as well as deviations of regular plans appear and cause ad hoc decisions and changes/adaptions of planned activities.

For planning and steering of transit wagons through the yards, a complex target system exists for punctual fulfilment of operational requirements, e.g. wagon transfer/interchange from incoming to outgoing trains. During analysis, however it was not possible to identify a standard set of KPIs that is applied in ad hoc decisions to help quantify decision alternatives.

As analysed in the German Marshalling yards, available IT systems are used for illustrating the actual situation, but the dispatcher´s decision-making depends mainly on his knowledge of the yard, the wagon transfers and the capacity of the part of the yard for which he or she is responsible.

A system that pro-actively could inform about the consequences of potential decisions is currently not available in any of the yards. The decision makers in the yards consider the development/ provision of such a decision support system as very useful and very much appreciated.

As marshalling is a complex process, making the most appropriate capacity allocation and prioritisation decisions is hard. If there is only one rail company using the yard, all decision processes and operations will be internal, but when multiple operators share the yard, some sort of cooperation or delimitation agreement must exist between the different companies.

Automatic and optimising decision support systems that can inform about the consequences of potential decisions are a good foundation for achieving enhanced yard capacity and efficiency and for the cooperation required at Marshalling yards. These decision support systems will rely on pre-defined rules. If appropriate and well-defined rules have been agreed upon by the involved actors or decided by the infrastructure manager, then these rules can be used in computerised decision processes. This would provide the actors with a clear cooperation foundation, and also discussions on individual employee's decisions could be reduced. Also, the efficiency of the Marshalling yard operations is likely to be increased if good optimising planning software is used, which would decrease the capacity problems of shared resources.

Optimisation module and algorithms must be proven for large and complex yard infrastructures. Furthermore, they must integrate well with the existing IT environment and with activities toward yard automation, e.g. intelligent assets and automated shunting in yards.

In the future, management and control of rail operations will be able to benefit from much larger volumes of more timely data and this will offer great opportunities for better managing operations with a "Real-time Yard Management System".

5.2 Intermodal Terminals

As derived from the description of the intermodal terminals and illustrated by the case studies, there is still a high potential for improvement regarding the automation and optimisation capabilities of intermodal terminals as well as for their interaction with the Network management.

The capabilities for automatic information exchange and communication between the main stakeholders i.e. the IM, RU, road hauliers and terminal operators – and the corresponding digitalisation level are currently on a very low level. This implies that in the case of deviations the terminal operator cannot know accurate ETA's of neither freight trains nor trucks. Albeit there is normally an ETA for arriving freight trains, it is not automatically provided further by the terminal operator to road hauliers and trucks arrive at the Terminal without any pre-arrival notification in case of deviations.

Moreover, in regard to delayed incoming trains, the current procedure for information exchange might be long as several stakeholders need to be informed. The standard procedure is that road hauliers are informed by the involved rail operator or railway undertaking. Due to the various non-standardised IT-systems and manual routines for information exchange (telephone, email, etc.) among the involved stakeholders, the terminal operator cannot always be informed in advance regarding the sequence of unit loads on the trains, thus making the decisions regarding the planning of transhipments and pick-ups cumbersome. As the information chain is long and the digitalisation status is on a low level, the information flow is prone to disruptions and when it is disrupted trucks will experience idle times at the Terminal or empty returns from the Terminal.

Nevertheless, the terminal operator makes an estimation based on their experience on when the train might arrive. If the information of deviations regarding the ETA of incoming freight trains would be more accessible and accurate, the planners at both the terminal operator and road hauliers could plan their resources more efficiently, where one of the main benefits would be a reduced number of trucks that are forced to wait at the Terminal or return empty.

DUSS on the other hand are currently working on an IT-application, where information regarding the status of a specific unit loads (and especially the time for pick-ups in the terminal) can be obtained via a mobile application by the relevant stakeholder. In addition, the IT system 'TIS' used by the terminal operator for monitoring cross-border trains does not cover the last mile from the main track to the terminal infrastructure. Hence, delays from the shunting operator are difficult to foresee.

5.3 INTERACTION BETWEEN YARDS, TERMINALS AND NETWORK MANAGEMENT

This section is introduced by an example of a situation caused by a lack of coordination between yards and Network management, followed by a description of optimisation capabilities. There are certainly other complementing scenarios for improvement in the interaction between Yards, Terminals and the Network management, and the whole area will be further explored in Deliverable D 2.2, together with details about the background and decision processes related to the presented scenario.

In actual traffic situations, it is quite common that freight trains depart from Marshalling yards outside the planned timetable slots. Actually, many freight trains depart before their scheduled departure time and also plenty of trains depart after the scheduled time. This causes trains to run outside the planned timetable slots, and therefore many aspects of the transport have to be re-planned in the operational setting. As a consequence, there is a risk that the operational planning cannot be made in the same holistic planning perspective as the original tactical planning had been, leading to inefficient resource utilisation of infrastructure, vehicles and personnel. In particular, it occurs that when the freight trains approach the destination Marshalling yard (or Terminal), this yard is not yet able to handle the arriving train due to limited arrival capacity. Then the freight train has to stop at some side track along the line, hindering other trains to use this side track, thus reducing the capacity of the rail line network. When the yard has the free capacity to handle the arriving train, the train is allowed to approach the yard. Thus, the departures outside the planned timetable slots cause the line to be less efficiently utilised and that yards are congested so that they cannot handle the arriving trains, which in turn cause the line network to be less efficiently used.

In order to reduce the negative consequences of having trains running outside planned timetable slots, there are at least two approaches. One approach is to forbid trains to run outside the slots, forbidding trains to departure too early and possible penalize trains departing too late. However, operational experience with forbidding too early departures has shown that it is very hard, and may even have increased negative consequences [Trafikverket, 2015].

Another approach is to improve the preparedness of the trains that do run outside the planned timetable slots, which is the cornerstone of proposed development scenario. The scenario for improved coordination between line and Yard/Terminal planning and operation includes the following aspects:

- As soon as the RU knows that it needs to operate a train outside the planned timetable slot, the RU reports this to the IM.
- Before departure for trains running outside the original timetable slot, a new, conflict regulated, operational timetable slot should be created that secures that the train does not create and is not exposed to any unforeseen problems along the way to its destination.
- The new timetable slot should be the best possible, given the operational situation of the day and the allowed adjustments on other trains' timetable slots.
- Before departure, the arrival capacity of the receiving Yard/Terminal should be secured so that the trains should never have unplanned waiting time along the line, caused by limited arrival capacity of the yard.

The changes that are needed to enable the scenario include:

- Earlier and clearer communication between RU and IM about foreseen deviations in departure times – regarding departures that are moved forward as well as backward in time.
- Better coordinated decisions regarding deviating departure times and its consequences, both within the RU and within the IM (so that it is not just an agreement between the train driver and the local train dispatcher).
- When changing a departure time, the consequences of this on the line all the way from departure to destination should be analysed and understood.
- Better understanding of the consequences of the changed departure time also at the arrival Yard/Terminal.
- The risk of unplanned waiting along the line caused by limited arrival capacity at the arrival yard should be reduced.
- Better coordination and prioritisation of the RU's trains.
- Better coordination of the dispatching process at IM.

Actually, the description above applies both to Marshalling yards and to intermodal Terminals. However, often (at least according to our observations) the problems are more accentuated at the Marshalling yards. Thus, the Marshalling yards will be in focus in developing the scenario, even though the basic concepts should be valid also for Terminals.

To conclude, there is a great potential for better coordination and making better informed decisions regarding the operational departure times for freight trains from Yards and Terminals. The development scenario includes both automation – mostly regarding information processing and communication – and optimisation/simulation – primarily regarding timetable calculation, Yard/Terminal capacity calculation and handling time estimation. The benefits from the improved scenario would be shared by both the freight operating companies, the infrastructure manager and the railway system as a whole.

In forthcoming deliverables of the ARCC WP2 (D2.2, D2.3, D2.4), this scenario and its possibilities and challenges will be further explored.

6 CONCLUSIONS

Yard and Network management are key components for guaranteeing on-time delivery and efficiency in particular in single wagon transport. For building a successful Yard Management System, it is important to provide a consistent set of data describing the processes in the yard and the surrounding railway networks in real-time.

The interaction between the Yards, Terminals and Network management have a significant improvement potential, where optimisation, automation and advanced decision support tools can also make an important contribution in ad-hoc timetable planning and operational process that connects freight traffic in Yards and Terminals with available timetable slots in the network. Yard and Network management can be automated by improved decision support.

A main challenge would be to model these data management processes in an appropriate software system and lead to algorithm optimisation. The following tasks should have been fulfilled:

- Definition and selection of suitable methods for data analytics and data management leading to algorithms optimisation.
- Description of methods and algorithms that can improve decision support and increase automation.
- Design and selection of a suitable software environment for Real-time Yard Management in Marshalling yards.
- Detailed functional and technical specification of selected environment including interfaces to Real-time Management and IT Production Fulfilment Systems.
- Adaptation of an existing software system according to result of specification.
- Installation of the Real-time Yard Management System in a production-like test and training environment.
- Feasibility proof for Real-time abilities of the software system according to defined test cases.

The tasks are expected to contribute to automation and digitalisation of monitoring and decision processes along the supply chain of single wagon transport (wagon load system). Based on an advanced simulation/optimisation approach the expected impacts of a Real-time Yard Management in combination with an interacting Real-time Network Management shall lead to improved punctuality, system efficiency and competitiveness of single wagon load transport.

It is intended, that a Real-time Yard Management System can optimise resource-allocation and connect with external systems to improve network planning.

By implementing automatic and optimising planning systems, the discussions on unfairness during capacity allocation and operations could be limited. If the marshalling plans are generated using computers, mathematics, and strict rules, the human factor can be reduced and any potential intended unfairness eliminated. In ARCC WP2 it is foreseen, to contribute to this aim by studying the possibility for automatic re-planning of shunting yards during operations, especially in combination with train path re-planning.

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