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Smart Automation of Rail Transport
(Project reference – 730836)

Deliverable D4.1
Identification of relevant information about train classification process and marshalling yard sorting methods

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## Abbreviations and Acronyms

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<tr>
<td>ARCC</td>
<td>Automated Rail Cargo Consortium</td>
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<tr>
<td>ERTMS</td>
<td>European Rail Traffic Management System</td>
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<tr>
<td>GoA4</td>
<td>Grade of Automation</td>
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<tr>
<td>IP</td>
<td>Innovation Programme</td>
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<tr>
<td>MAAP</td>
<td>Multi Annual Action Plan</td>
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<tr>
<td>RTMYM</td>
<td>Real Time Marshalling Yard Management</td>
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<tr>
<td>S2R JU</td>
<td>Shift2Rail Joint Undertaking</td>
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<tr>
<td>SL</td>
<td>Single Wagon</td>
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<tr>
<td>SMART</td>
<td>Smart Automation of Rail Transport</td>
</tr>
<tr>
<td>TAF/TSI</td>
<td>Telematics Applications for Freight / Technical Specifications for Interoperability</td>
</tr>
<tr>
<td>TD</td>
<td>Technical Demonstrator</td>
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<tr>
<td>TRL</td>
<td>Technology Readiness Level</td>
</tr>
<tr>
<td>UIC GB</td>
<td>International Union of Railways</td>
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<td>WP</td>
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1. **ABSTRACT**

Deliverable D4.1 Identification of relevant information about train classification process and marshalling yard sorting methods includes the analysis of the classification and sorting process performed in order to produce outbound trains with single-stage and multistage sorting modes of operation for shunting yards. The main goal of SMART project is to increase the quality of rail freight, as well as its effectiveness and capacity, through the contribution to automation of railway cargo haul at European railways. Two SMART working streams are:

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

The SMART prototype solution for obstacle detection will provide prototype hardware and software algorithms for obstacle detection, as well as standardized interfaces for integration into ATO module. The system will combine two night vision technologies, thermal camera and image intensifier, with multi stereo vision system and laser scanner in order to create fusion system for short (up to 20 m) and long range (up to 1000 m) obstacle detection during day and night operation, as well as during operation in impaired visibility. By this planned fusion of sensors, the system will be capable, beside reliable detection of obstacles up to 1000 m, to provide short range (< 200 m) wagon recognition for shunting operations.

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

Deliverable 4.1 is the introductory report to the second working stream - Development of a real-time marshalling yard management system and one of two Deliverables of WP4 - Analysis, requirements and specification of a real-time marshalling yard management system.

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

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

- Visual representation module
- Module for marshalling process planning

In order to provide necessary specification and to define main processes for designing information system as start-up activities, analysis of real marshalling yards is needed. Furthermore, analysis of marshalling yard sorting methods is necessary for future work on optimization of available resources and planning of marshalling operations.
2. EXECUTIVE SUMMARY AND REPORT SCOPE

This report is the first deliverable of the Work Package 4 within the Real Time Marshalling Yard Management working stream of SMART project.

The aim of this deliverable is to identify relevant information about train classification process in marshalling yard and about marshalling yard sorting methods. This report includes introductory analysis of the classification and sorting process performed in order to produce outbound trains with single-stage and multistage sorting modes of operation for shunting yards.

This deliverable D4.1 gives general overview of the Real Time Marshalling Yard Management problem and sorting methods. D4.1 is the part of the results of activities in task T4.1 (Analysis of the marshalling yard management problem) and task T4.2 (Analysis of train classification process in marshalling yard).

An introduction is given in Chapter 3, followed by Marshalling Yards presented in Chapter 4. This includes sections about marshalling yard infrastructure and main operations in marshalling yards. General information and importance of marshalling yards are also given in this chapter.

In order to do performance analysis of different operations of the marshalling yard, two real marshalling yards were selected and described in this report. The analysis of the marshalling yard management problem was done by analyzing Real Marshalling Yards: Niš Ranžirna – Popovac, Serbia and Karnobat, Bulgaria. Detailed analysis of above mentioned marshalling yards is the basis for making the initial conclusions for defining an overall framework architecture of the yard management problem, based on the operational research techniques that cover simulation based rules, heuristic, dynamic programming with problem decomposition and mathematical programming, which represents the results to be described in D4.2 Deliverable (the second deliverable of WP4).

Detailed analysis of above mentioned marshalling yards is given in Chapter 5 and Chapter 6. The structures of these chapters are almost the same and they are in line with joint discussion and common conclusions of future collaboration with partners of ARCC project. At the beginning of chapters there is general overview of Serbian and Bulgarian railways. After that, in next two sections general information and marshalling yard infrastructure are given for both selected marshalling yards. At the end of these chapters, last section describes the main processes in the marshalling yard divided in 4 subsections. It includes shunting operations, planning and organization of shunting operations and documents for regular operations management. In the final subsection some problems in the marshalling yard are addressed.

Chapter 7 focuses on real time marshalling yard management problem. First section gives relevant information about train classification process and some criteria for train classification process. As nowadays marshalling processes mainly involve manual planning and make decision process are very important for potential decreasing of train transport time, second section gives information about types of decisions, subject of decisions and decision maker. The last section of this chapter briefly describes parameters for marshalling yard management problem. Here, it is given just as start-up overview in contrast with more detailed analysis and list of requirements that will be given in next deliverable D4.2.

Chapter 8 describes marshalling yard sorting methods and gives state of the art for methods for formation of multi group trains. After introduction in the first section, second section describes methods for consecutive forming of multi group trains and methods for simultaneous formation of multi group trains, divided in two subsections. Then, in next two sections, analysis of methods and parameters for simultaneous formation of multigroup trains is given and some remarks for heuristic approach for simultaneous formation of multigroup trains. Finally, there is a separate conclusion for this chapter.

Chapter 9 concludes the D4.1.
3. INTRODUCTION

In this introductory chapter, we present a motivation for a framework for focusing on the relevant domain knowledge prerequisites of SMART requirements regarding real time marshalling yard working stream. We give a global framework for analysis done in this deliverable D4.1. At the end, we conclude this chapter by targeting some activities that will be done at the end of WP 4 and at the end of whole SMART project.

In order to understand goal of SMART project regarding marshalling yard working stream, observation of global perspectives of transport with special attention to rail transport has to be done.

European transport strategy 2011-2021 (Roadmap to a Single European Transport Area - Towards a competitive and resource efficient transport system) sets the goals of increasing the quality of rail freight, as well its effectiveness and capacity. The noted transport strategy envisions significant reduction of Europe's dependence on imported oil and reduction of transport carbon emissions by 60% till 2050. Initiatives proposed have a goal to shift 30% of road freight over 300 km to other transport modes such as rail or waterborne transport by 2030, and more than 50% by 2050. In order to achieve such vision, developing of new infrastructure will be necessary, as well as increasing of efficiency and throughput of the existing infrastructure.

One of the ways to increase efficiency of existing infrastructure is to automate the cargo haul. Trains are more suited for autonomous operation than other types of vehicles (especially road vehicles) as they are moving on a fixed and known track. Nevertheless, most of the innovation in autonomous vehicles is occurring on the road due to lack of innovation in railway automation as a consequence of railway heavy regulation. Noted regulations and safety focus hampers the implementation of recent innovations in autonomous driving and pushes cargo transport to road with much higher risks and casualty levels.

On the other hand, the European rail freight doesn’t have growth in parallel with the European economy. The industry's stagnation can partly be explained by the existence of legal barriers restricting competition (including the infrastructure access regime, taxation, etc.), but also by problems of operational and technical nature, which impact the overall capacity and performance of the railway sector. In addition, economic growth of European countries is not the same. There are significant differences between EU countries in volume of railway freight transport. The volume of freight railway transport in 2014 (tkm) is shown in Fig. 3.1, and national, international and transit transport are indicated. Volume of national transport depends on development of domestic industry.

![Figure 3.1 The volumes of railway freight transport in EU](data Eurostat 2014)
Thirdly, there are big differences in European railway network regarding technological level of equipment and automation. Differences are more visible when comparing between EU and non EU countries is done. Table 3.1 gives data about the number of inhabitants, length of national railway lines and freight transportation in 2014 for Germany, Sweden, Bulgaria and Serbia. These four countries are selected for comparing because the facts that SMART partners are from Germany, Bulgaria and Serbia and two partners of the complementary ARCC project are from Germany and Sweden.

<table>
<thead>
<tr>
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<th>Number of inhabitants</th>
<th>Length of railway line</th>
<th>Rail freight transport (million tkm)</th>
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<tr>
<td>Germany</td>
<td>81,200,000</td>
<td>33.426 km</td>
<td>112.629</td>
</tr>
<tr>
<td>Sweden</td>
<td>9,750,000</td>
<td>9.689 km</td>
<td>21.296</td>
</tr>
<tr>
<td>Bulgaria</td>
<td>7,185,000</td>
<td>4.159 km</td>
<td>3.439</td>
</tr>
<tr>
<td>Serbia</td>
<td>7,103,000</td>
<td>3.808 km</td>
<td>2.988</td>
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For European rail freight to become more attractive, the rail freight sector must provide customer tailored services to its clients and be more effectively integrated in the logistics value chain. Reliability, lead times, deliveries on-time and in full, frequencies and cost must meet customer requirements for different goods segments.

In order to compare the relative importance of rail transport between the countries, the data can be normalized by presenting the level of freight traffic related to population, as shown in Fig. 3.2.

In last 25 years there was the decline in traffic volume in Bulgaria and Serbia. Volumes of railway freight transport in Serbia and Bulgaria in period 1990-2014 are presented in Fig. 3.3.
Serbian and Bulgarian railways are the part of Pan-European Corridor X, which passes through Austria, Slovenia, Croatia, Serbia, Macedonia and Greece, shown in Fig. 3.4. It has four branches: Xa, Xb, Xc andXd.

Corridor X: Salzburg - Ljubljana - Zagreb - Belgrade - Niš - Skopje - Veles - Thessaloniki.
Branch A: Graz - Maribor - Zagreb
Branch B: Budapest - Novi Sad - Belgrade
Branch C: Niš - Sofia - Plovdiv - Edirne - Istanbul via Corridor IV
Branch D: Veles - Prilep - Bitola - Florina - Igoumenitsa (Via Egnatia)

Bulgarian railways are also the part of Pan-European Corridor IV, which passes through Germany, Czech, Austria, Slovakia, Hungary, Romania, Bulgaria and Turkey.

Corridor IV: Dresden / Nuremberg - Prague - Vienna - Bratislava - Győr - Budapest - Arad - Bucharest - Constanța / Craiova - Sofia - Thessaloniki / Plovdiv - Istanbul.

Figure 3.4 Pan-European Corridor X

Marshalling yards are one of the most important parts of every railway infrastructure along the European corridors. Marshalling yards have a decisive impact on accuracy, availability and cost efficiency of rail freight services.

The cost competitiveness and the reliability of freight services need to be considerably improved so that rail freight can be in a position to offer a cost-effective, attractive service to shippers that helps to take freight away from the already-congested road network. In order to provide customer tailored services mentioned above, marshalling yards are inevitable for doing some improvements and optimization.

Therefore, the objective is to achieve the same level of flexibility and accessibility as the other means of continental intermodal transport and to achieve even better reliability improvement of planning and operation of marshalling yards needs to be done. In that sense, an efficient and effective operation of marshalling yards is at the heart of the future single wagonload (SWL) freight service in Europe and close connected with modern real time marshalling yard management system.

In line with the targets of the MAAP TD5.2 and within the scope of digitalization for future rail freight, the objective of TD5.2 is to optimize processes in nodes/local hubs and for real-time network
management. Among the various ways of automating processes in nodes, the automation of disposition/dispatching processes in marshalling yards and terminals, including interaction with the traffic management system, has a major impact in terms of reducing lead times and improving the punctuality and cost-efficiency of rail freight.

In large nodes, vast and complex yard operations are carried out that require advanced technology to manage hundreds of incoming/outgoing trains and shunting operations for more than a thousand wagons per day. In the case of delays and limited yard resources, static user-defined prioritization rules cannot ensure that yard operations are performed according to the priorities of each wagon-based customer-driven trip plan. Therefore intelligent decision-making on a real-time basis will be required and become a strategic element of automation and optimization in yards.

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

The diagram of SMART real time marshalling yard management system is shown in Fig. 3.5.

![Figure 3.5 SMART real time marshalling yard management system](image)

Main limitation factors of freight transport on marshalling yards [MAAP] are:

- long- and unreliable lead-time in marshalling yards accompanied with high operational costs
- missing electrification of freight wagons to benefit from intelligent sensors and communication systems
- low reliability and high operational cost due to manual handling processes and resource planning based on experience or stand-alone IT systems
- low level of automation of the operational processes

From perspective of developing real-time marshalling yard management system, there are some issues needed for consideration:

- marshalling processes still involve much manual planning and improved decision support tools and analysis tools have shown to have a great potential
- all the attempts are done with stand alone applications
D4.1 Identification of relevant information about train classification process and marshalling yard sorting methods

- they are not based on real-time information

The SMART real time marshalling yard management (RTMYM) system has to be compatible for testing and implementation on every marshalling yard, from the smallest one to the largest one.

Regarding the issues mentioned above, and MAAP Task 5.2.2 New Single Wagon Load and real time management system, all necessary operational procedures and the necessary data for simulation have to be analyzed. For the simulation, not only master data e.g. yard infrastructure and shunting fleet, but also dynamic data e.g. fostered personnel resources and actual data of incoming trains are required.

It means that providing relevant real data from marshalling yard and availability for testing, evaluation and initial implementation are very crucial for designing respectable information system.

In order to fulfill demands from Task 5.2.2 [MAAP], two real marshalling yards were selected for analysis and specifications. The first one is Marshalling yard Niš – Ranžirna Popovac, Serbia and the second one is Marshalling Yard Karnobat, Bulgaria. This marshalling yard selection is based on the following reasons and principles:

- close cooperation with Serbian and Bulgarian Railways – the presence of their representatives in SMART Advisory Board is a guarantee for good collaboration
- availability of marshalling yard for technical visits, recording and interviewing
  - Marshalling yard Niš – Ranžirna Popovac is located in Niš, Serbia where the member of SMART Consortium for RTMYM working stream - UNI is also situated
  - Marshalling Yard Karnobat is located in Bulgaria where the member of SMART Consortium for RTMYM working stream - TUS is also situated
- the strategic importance of Marshalling Yard Niš – located on Corridor X (this marshalling yard is on the official list of European marshalling yards)
- the short distance of Marshalling Yard Karnobat from Burgas port
- the size of Marshalling Yard Niš – large enough to be appropriate for analysis
- Marshalling Yard Karnobat is mixed station – providing freight and passenger services to be appropriate for different simulation scenarios
- availability of getting real historical data from both selected yards
- availability of initial testing, evaluation and real time simulation on the selected yards

Beside data and information gathered from selected marshalling yards, the collaboration with ARCC project is also very important for overall project realization. As it was defined in project proposal and project call, in line with the targets of the MAAP TD5.2 and within the scope of digitalization for future rail freight, SMART established close cooperation in project realization and information exchange with the complementary S2R project ARCC-Automated Rail Cargo Consortium) and with project stakeholders.

As one of the results of collaboration for time duration of both projects, it will be possible to check some data and processes comparing relevant information with selected ARCC real marshalling yard (from Germany and Sweden) and opposite.

The second important result bringing compatibility, unification and universal implementation of achieved results and goals in future is agreement for defining the same structure for analysis all selected marshalling yards of both projects (Germany, Sweden, Serbia and Bulgaria).

From the global perspective, it is important to point out that design and implementation of real time marshalling yard management system is just phase I on road to provide cost effective, transport time reliable and energy friendly freight service.

The second phase is to get European marshalling yard network capable to be reliable and punctual in planning and offering freight services and to become more client friendly oriented type of transport. There is a diagram of 2 phases in optimization marshalling yards, shown in Fig. 3.6.
Figure 3.6 2-phase diagram of marshalling yard optimization
4. MARSHALLING YARDS

Marshalling or shunting yards play important role in freight railway transport. The efficient use of shunting yards has a deep impact on the efficiency and reliability of rail freight services due to reduction of transportation cost and increasing reliability and punctuality. Main processes of marshalling yards focus on the disaggregation and forming composition of trains according the freight cars destination.

Specifically, inbound trains are disassembled or humped, and the railcars are then reorganized to generate outbound trains via a system of tracks and switches. Using this consolidation and redistribution procedure, railcars can be sent through the network efficiently without providing a large number of end-to-end services. In practice, the processing time of freight railcars in a railroad yard represents a large proportion of the total railroad end-to-end transportation or trip time, so continuously improving the efficiency of railroad yard operations has received significant attention by decision makers and operations researchers in the rail industry.

4.1 General information and importance

The main task of optimization of the rail freight transport process is reflected in the transport plan i.e. time table which includes a plan of shunting/sorting work. Transport plan of freight trains should provide a fast delivery of goods to the recipient, more efficient use of the wagons, that is reduce their total transit time, optimal distribution of marshalling operation on transport line, as well as reducing the shunting operations on marshalling yards. Due to this fact, the tendency is to form direct (block) trains, i.e. trains carrying the load without changing its composition from baseline to end station. The basic condition for the organization of direct trains is the existence of mass commodity flows.

The basic elements that define the quality of transport are transport time and transport costs. It means that the optimal transport of goods may be provided by minimizing the time and cost of transport. Transport time of freight depends on the wagon retention on commodity operations (loading and unloading), the speed of the trains on main lines and retention in freight yard. The organization of shunting operations directly causes spent time of wagons at the freight yards and thus significantly affect the overall transport time.

Traffic regulations and guidelines indicate that safety must be taken into account first during shunting. Shunting is done in such a way to achieve maximum efficiency in the work and price is a key factor in shunting.

The usual practice on marshalling stations indicates that an important factor is the number of maneuvers and that the goal is with the least possible number of maneuvers to achieve greater result. Marshaling yards represent freight station, in which are partially or completely dismantling incoming freight trains, shunting of wagons per directions and station on their direction and formation of new freight trains. In marshalling yards is carried out and passing of trains that are not processed (i.e. the transit trains) but only performs change of locomotives and staff if that is necessary. In addition, the there is performed the repair of the wagons, servicing trains, cargo and other operations.

Marshalling yard is usually found in the context of large railway nodes, which are close to industrial or commercial transport centres, mining and metallurgical companies, distribution centers or major sea or river ports.

The main tasks of marshalling yard are dismantling trains, coming from local boundary stations, industrial zones, after that sorting wagons and forming a new trains (collection, direct or block trains). Collecting trains are delivered to the neighboring yards, while direct freight trains wagon shipped to neighboring or marshalling yards without intermediate changes in its composition.
4.2 Marshalling yard infrastructure

Marshalling yards are railway yards placed at some freight train stations where railway freight cars (wagons) are separated in order to collect them into trains according to their transport destinations. There are three types of marshalling yards: flat, gravity and hump yard.

Flat yards are constructed on flat ground, or on a gentle slope and freight cars are pushed by means of locomotive and reach to their required location.

Hump yard is the largest and the most effective classification yard, with the largest shunting capacity. Main part of this yard is the hump on a small hill over where a locomotive pushes the cars. Single cars or a block of coupled cars roll by gravity onto their destination tracks.

Operating in gravity yard is similar as in hump yard, and whole yard is set up on a continuous falling gradient. Almost all gravity yards have been equipped with humps and are worked as hump yards.

The typical layout of a marshalling yard, shown in Fig. 4.1, consists of a receiving yard where incoming trains arrive, a classification group of tracks where they are sorted, and a departure yard where outgoing trains are formed.

![Figure 4.1 Common marshalling yard with receiving yard, hump, classification bowl, and departure yard](image)

A typical classification bowl (classification group of tracks) is shown in Fig. 4.2a, in which the classification tracks are connected to the departure yard at the end opposite the hump. Not all yards have receiving and departure tracks; some have single-ended classification bowls as in Fig. 4.2b, while others have a secondary hump at their opposite end as in Fig. 4.2c. However, almost all yards have the layout of Figure 4.2b as a substructure.

![Figure 4.2 Some common classification bowl layouts. (a) double-ended yard, (b) single-ended yard, (c) advanced layout](image)

Two marshaling yards have been chosen as examples of real marshaling yard for this deliverable D4.1. One of them is Marshaling yard Niš in Serbia on Corridor X and Marshaling yard Karnobat in Bulgaria on the Corridor VIII.

Marshaling yard Niš is marshalling yard with a parallel arrangement of tracks located in the city of Niš - Popovac. Marshaling yard Niš has special importance while in Niš intersect three magistral railway...
D4.1 Identification of relevant information about train classification process and marshalling yard sorting methods

lines which are the parts of pan-European Corridor X (Subotica-Beograd-Niš; Sofija-Dimitrovgrad-Niš; Skoplje-Prešev-Niš) and two regional (Prahovo-Zaječar-Niš; Kosovska Mitrovica-Kuršumlija-Niš).

Total number of tracks in Marshalling yard Niš is 36 and they are divided into four groups:

* Receiving-departure group of tracks from 2 to 9
* Shunting-dispatch group of track from 10 to 28
* Station group of tracks from track from 29 to 36
* Bypass track-first, with track 1a and 1b

Figure 4.3 shows the layout of Marshalling yard Niš.

![Figure 4.3 Layout of Marshaling yard Niš](image)

Shunting operations in marshalling yard Niš are performed by shunting diesel locomotive which pushes the freight cars to required tracks.

Karnobat station is marshaling yard that serves the passenger and cargo movement and performs decomposition and composition of the freight trains. It has parallel arrangement of tracks with two individual regions with 35 tracks. Tracks at Marshalling yard Karnobat is divided into three groups:

* Receiving-departure group of tracks from 1 to 5 and 21 to 27
* Shunting-dispatch group of track from 6 to 17 and 29 to 35
* Carriage tracks from track 18 and 28

Figure 4.4 shows the layout of Marshalling yard Karnobat.
4.3 Main operations

Main operations in marshalling yards are:

- Prenotification of incoming and outgoing trains
- Arriving and checking incoming trains
- Disaggregating/aggregating trains
- Wagon shunting within the yard
- Throwing wagon using the hump and/or the locomotive
- Checking and departure outgoing trains.

Trains, that are going to be processed, are going on shunting-dispatch group of track. There is carried out commercial and technical inspection of wagons, checking the composition of the train, preparing for disassembling and eventually preparation for removal of some minor technical and commercial faults.

Transit trains, ie. trains that are not going to be processed in the yard, are arriving at the receiving-departure group of tracks. There is also carried out commercial and technical inspection of wagons, checking train composition and removing of some possibly minor technical and commercial faults. By transit trains can be done change of locomotive and train crew if that is necessary.

Technical inspection performed by inspector (examiner) immediately after the arrival of the train at the station, but the goal is the identification and elimination of defects that endanger traffic safety. In the case of a minor defect, correction is performed without uncoupling the wagon of the train. In case of malfunction due to technically unfunctionality/not able to run, the examiner prescribed labels affixed to the wagon and inform the movements inspector. Based on this information occur change in the shunting list.

Commercial checks carried out by goods porter and guard with the aim of identifying and removing defects with the goods or cargo accessories that endanger the safety of the goods themselves or traffic. A review of the completed commercial notify the movemants inspector.

Technical and commercial review of the train is done immediately after the arrival of the train at the station, as well as before the dispatch of the train if it is formed in the station.
Within the usual treatment of transit trains are performed the following operations:

- Prior to the arrival of the train to collect information on the composition and arrival time of the train, and workers go to the arrival track;
- After the arrival of the train are performed the following activities:
  - Uncoupling and departure of train locomotive that hauled the train (if you change the locomotive)
  - Handover of documents
  - Check and coupling to the other driving locomotives (if changing locomotives)
  - Commercial inspection of the train
  - Technical inspection of the train
  - Dispatches from the marshaling yard.

The technology of processing trains that are processed in the marshaling yard consists of the following operations:

- Uncoupling and departure of train locomotive that hauled the train (if you change the locomotive)
- Determining the exact composition of the train;
- Commercial inspection of the train
- Technical inspection of the train
- Creating shunting lists;
- Preparation of composition for maneuver (releasing air from the main brake line, decoupling of couplings for air line and uncoupling).

In order to form a train that should be dispatched to the final destination, sorting is performed done accumulated wagons. This is done in the marshaling group of tracks. Shunting of wagons is done with maneuvering locomotive that pulls and/or pushes a group of trains or through the release of the wagon group over hump. Marshalling process is performed by employees of the infrastructure, based on the shunting schedule, i.e. shunting list that is compiled by operated, i.e. carrier.

Movements inspector monitors shunting wagons on shunting tracks group and when the train is formed for dispatch, he inform the staff of commercial services and shunter. This is how begins the commence activities on the formation and dispatch of the train from the station.

Within dispatch a train that is assembled in marshaling yard perform are the following operations:

- Arrival and coupling of train locomotives
- Commercial inspection of the train
- Technical inspection of the train
- Forming a journey report and its annexes that are submitted to the train staff
- Dispatches from the train station.
5. ANALYSIS OF MARSHALLING YARD NIŠ-RANŽIRNA, SERBIA

5.1 Introduction - Short review of Serbian railways

The Serbian railway network is shown in Fig. 5.1. Corridor X railway line in Serbia is specially marked in Fig. 5.1a, and stations and marshalling yards are shown in Fig. 5.1b.

![Figure 5.1 Railway network in Serbia a) and b) [2]](image)

Total length of the railway network:
- Total length 3,808.7 km
- Single railway lines 3,533.2 km
- Double railway lines 275.5 km
- Narrow gauge railway lines 21.7 km
- Non-electrified railway line 2,612.7 km
- Electrified railway line 1,196.1 km

Since August 2015, Serbian Railways have been organized into three stock companies: the joint stock company for management of railway infrastructure "Infrastructure Railways of Serbia", the joint stock company for rail transport of goods "Serbia Cargo" and the joint stock company for passenger railway transport "Srbija Voz". Before this transformation, Serbian Railway was unique company.

In the Republic of Serbia in respect of the ownership and management of a network of railway lines, there is only one railway network owned by state and managed by company "Infrastructure Railways of Serbia". The network of railways of the Republic of Serbia is connected with the railway networks of seven countries, namely: Croatia, Hungary, Romania, Bulgaria, Macedonia, Montenegro and Bosnia and Herzegovina.

On all lines in Serbia for international traffic is logged loading gauge UIC GB. Railway lines in Serbia are not coded for combined transport profile in accordance with the publication of UIC 596-6. However, performed measurements show that it is possible to transport wagons loaded with cargo units combined transport such as HCC (high cube container) containers, semi-trailers and full road
D4.1 Identification of relevant information about train classification process and marshalling yard sorting methods

vehicles. Transport of these shipments is possible under special security conditions in the regime of order shipment.

The period 1990-2000 is extremely difficult for Serbian society and economy, including the railway. Railway freight transportation was declining from 1990 to 2000, but after that there was a certain growth. The scope of freight transport fell from $7.22 \times 10^9$ ntkm in 1990 to $1.92 \times 10^9$ ntkm in 2000. The large decline in the national economy is the biggest reason for the decline in the transport of goods.

Volume of railway freight transport in period 2000-2014 is presented in Fig. 5.2.

![Figure 5.2 Volume of rail freight transport in Serbia 2000-2014](image)

The volume of rail freight transport is the highest at Corridor X and it is smaller on regional and local railway lines. At Figure 5.3 is shown the volume of rail freight transport in Serbia for year 2004, where the line thickness represents the volume of rail freight transport in tones.

![Figure 5.3 Volume of railway freight transport performed in 2004 on the lines in Serbia](image)

In year 2015, 11.9 million tons were transported and 2.738 million ntkm was performed on Serbian railway.

In year 2015, 5,521,000 t of goods in 149,000 wagons were loaded on the Serbian railway network, mostly building materials, metal products, coal, ore, oil and others. In the same year, 5,566,000 t of goods from 151,000 wagons were unloaded.

During 2015, at border crossings there were received a total of 119,250 wagons with goods from 4,390,000 t, and handed over 142,700 of loaded wagons.
Today railway freight transport in Serbia is performed by Joint Stock Company for Freight Railway Transport „Srbija Kargo“. Besides this company, there are few smaller operators such as „Kombinovani prevoz“, „AB prevoz“, „Trans Cargo Logistics“, ZGOP Novi Sad, JP Nikola Tesla Obrenovac and Eurorail Logistics, which also can perform freight transport on Serbian railway lines.

Exchange of train, respectively wagon, between „Srbija Kargo“ and neighboring freight railway transport operators is carried out in border stations Subotica, Sid, Bogojevo, Kikinda, Vrsac, Dimitrovgrad, Tabanovci, Bijelo Polje and Brasina, in line with national agreements (conventions) and agreements between operators. Technological processes work regarding the exchange of trains or wagons, the border stations are based on the implementation of the Convention on International Carriage by Rail (COTIF) and the provisions of general rules that apply on the territory of Serbia.

### 5.2 General information and importance

Marshaling yard Niš (Figure 5.4) is a marshalling yard with a parallel arrangement of tracks and located in the city of Niš - Popovac. The station is open for cargo transportation in domestic and international traffic. The station has one platform for the reception of passenger trains but regular passenger transport is not performed. Scheme of Nis railway node is given in Fig. 5.5.

![Figure 5.4 Photo of Marshaling yard Niš-Ranžirna in Popovac](image)

Marshaling yard Niš is the freight station which receives and dispatches of a freight trains to the following stations:

- Marshaling yard Niš - Lapovo
- Marshaling yard Niš - Preševo
- Marshaling yard Niš - Dimitrovgrad
- Marshaling yard Niš - Zajecar
- Marshaling yard Niš - Kuršumlija, as well as trains in the node Niš.
5.2.1 Volume of work and the importance of Marshalling yard Niš in railway freight transport

Marshaling yard Niš has special importance while in Niš intersect three magistral railway lines (Subotica-Beograd-Niš; Sofija-Dimitrovgrad-Niš; Skoplje-Preševo-Niš) and two regional (Prahovo-Zaječar-Niš; Kosovska Mitrovica-Kuršumlija-Niš). Niš railway node is, after Belgrade railway node, the most important in the frame of railway network in Serbia. Due to this, marshalling yard Niš has a special significance in the transport of goods in domestic and international traffic Serbia.

In Fig. 5.6 a graph of processed wagons in marshaling yard Niš in 2015 by month is presented.
During 2015, in Marshalling yard Niš has arrived daily 11 trains (average), and dispatched 11 trains (average), which had average 21 wagons and had an average weight per 848 t. There were daily processed about 470 wagons both received and dispatched. The average spent time of shunting wagons was 18.19 hours, in the transition average spent time was 3.97 hours, and the average repair time of the wagon was 23.85 hours.

5.2.2 Ownership and organizational structure

In performing the duties in marshalling yard involved are actors working in the two companies, as well as technical means belonging to these two companies. One is "Infrastructure Railways of Serbia", and second is "Serbia Cargo".

Tracks, switches, signal conditioners, weighbridge and other facilities are the property of "Infrastructure Railways of Serbia". Shunting locomotives, workshops for the repair of wagons and wagon stock are owned by "Serbia Cargo".

5.3 Marshalling yard infrastructure

5.3.1 Infrastructure and equipment

Tracks at Marshalling yard Niš is divided into four groups:
- Receiving-departure tracks of 2 to 9
- Shunting-dispatch tracks of 10 to 28
- Station group tracks from track 29 to 36
- Bypass track-first, with track 1a and 1b

In addition to the above-mentioned plants of track, the station has two turnout tracks, which are in operation, namely:
- Turnout tracks No. 2 in the area of labor LP-3
- Turnout tracks "Niš" in the area of labor LP-3.

Area shunting signal box of area P-1 (main cellular signal box) all admissions shipping and shipping-shunting tracks i.e. 1-28. track.

Area maneuver area of local signal box LP-3 are all receiving and dispatching tracks, station group tracks, tracks for the current car repairs (wagon repair workshop) and point’s area puller.

Figure 5.7 shows the layout of Marshalling yard Niš.
Usable length of tracks is given in Table 5.1.

**Table 5.1 Usable length of tracks in Marshaling yard Niš**

<table>
<thead>
<tr>
<th>Track number</th>
<th>Usable length To Medurovo</th>
<th>To Trupale</th>
<th>Maximal train length From Medurovo</th>
<th>To Trupale</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>693</td>
<td>692</td>
<td>657</td>
<td>658</td>
<td>Bypass track</td>
</tr>
<tr>
<td>1a</td>
<td>152</td>
<td>152</td>
<td>-</td>
<td>-</td>
<td>For passenger train</td>
</tr>
<tr>
<td>1b</td>
<td>121</td>
<td>126</td>
<td>-</td>
<td>-</td>
<td>For locomotive</td>
</tr>
<tr>
<td>2</td>
<td>687</td>
<td>681</td>
<td>646</td>
<td>652</td>
<td>Receiving track</td>
</tr>
<tr>
<td>3</td>
<td>638</td>
<td>640</td>
<td>605</td>
<td>603</td>
<td>Receiving track</td>
</tr>
<tr>
<td>4</td>
<td>640</td>
<td>638</td>
<td>603</td>
<td>605</td>
<td>Receiving track</td>
</tr>
<tr>
<td>5</td>
<td>675</td>
<td>675</td>
<td>640</td>
<td>667</td>
<td>Receiving track</td>
</tr>
<tr>
<td>6</td>
<td>721</td>
<td>719</td>
<td>684</td>
<td>686</td>
<td>Receiving track</td>
</tr>
<tr>
<td>7</td>
<td>767</td>
<td>765</td>
<td>730</td>
<td>732</td>
<td>Receiving track</td>
</tr>
<tr>
<td>8</td>
<td>811</td>
<td>768</td>
<td>733</td>
<td>776</td>
<td>Receiving track</td>
</tr>
<tr>
<td>9</td>
<td>920</td>
<td>884</td>
<td>849</td>
<td>885</td>
<td>Receiving track</td>
</tr>
<tr>
<td>10</td>
<td>852</td>
<td>838</td>
<td>803</td>
<td>817</td>
<td>Shunt-dispatch track</td>
</tr>
<tr>
<td>11</td>
<td>759</td>
<td>759</td>
<td>724</td>
<td>724</td>
<td>Shunt-dispatch track</td>
</tr>
<tr>
<td>12</td>
<td>714</td>
<td>708</td>
<td>673</td>
<td>679</td>
<td>Shunt-dispatch track</td>
</tr>
<tr>
<td>13</td>
<td>757</td>
<td>751</td>
<td>716</td>
<td>722</td>
<td>Shunt-dispatch track</td>
</tr>
<tr>
<td>14</td>
<td>806</td>
<td>803</td>
<td>768</td>
<td>771</td>
<td>Shunt-dispatch track</td>
</tr>
<tr>
<td>15</td>
<td>710</td>
<td>702</td>
<td>667</td>
<td>675</td>
<td>Shunt-dispatch track</td>
</tr>
<tr>
<td>16</td>
<td>710</td>
<td>702</td>
<td>667</td>
<td>675</td>
<td>Shunt-dispatch track</td>
</tr>
<tr>
<td>17</td>
<td>743</td>
<td>733</td>
<td>698</td>
<td>708</td>
<td>Shunt-dispatch track</td>
</tr>
<tr>
<td>18</td>
<td>610</td>
<td>606</td>
<td>571</td>
<td>575</td>
<td>Shunt-dispatch track</td>
</tr>
<tr>
<td>19</td>
<td>598</td>
<td>594</td>
<td>489</td>
<td>563</td>
<td>Shunt-dispatch track</td>
</tr>
<tr>
<td>20</td>
<td>633</td>
<td>636</td>
<td>601</td>
<td>598</td>
<td>Shunt-dispatch track</td>
</tr>
<tr>
<td>21</td>
<td>712</td>
<td>705</td>
<td>670</td>
<td>677</td>
<td>Shunt-dispatch track</td>
</tr>
<tr>
<td>22</td>
<td>604</td>
<td>600</td>
<td>567</td>
<td>569</td>
<td>Shunt-dispatch track</td>
</tr>
<tr>
<td>23</td>
<td>633</td>
<td>637</td>
<td>597</td>
<td>598</td>
<td>Shunt-dispatch track</td>
</tr>
<tr>
<td>24</td>
<td>580</td>
<td>571</td>
<td>536</td>
<td>545</td>
<td>Shunt-dispatch track</td>
</tr>
<tr>
<td>25</td>
<td>513</td>
<td>506</td>
<td>471</td>
<td>478</td>
<td>Shunt-dispatch track</td>
</tr>
<tr>
<td>26</td>
<td>539</td>
<td>544</td>
<td>509</td>
<td>504</td>
<td>Shunt-dispatch track</td>
</tr>
<tr>
<td>27</td>
<td>672</td>
<td>596</td>
<td>556</td>
<td>558</td>
<td>Shunt-dispatch track</td>
</tr>
<tr>
<td>28</td>
<td>-</td>
<td>676</td>
<td>641</td>
<td>637</td>
<td>Shunt-dispatch track</td>
</tr>
<tr>
<td>29</td>
<td>-</td>
<td>136</td>
<td>-</td>
<td>-</td>
<td>Station group</td>
</tr>
<tr>
<td>30</td>
<td>-</td>
<td>134</td>
<td>-</td>
<td>-</td>
<td>Dead-end track</td>
</tr>
<tr>
<td>31</td>
<td>-</td>
<td>133</td>
<td>-</td>
<td>-</td>
<td>Dead-end track</td>
</tr>
<tr>
<td>32</td>
<td>-</td>
<td>173</td>
<td>-</td>
<td>-</td>
<td>Dead-end track</td>
</tr>
<tr>
<td>33</td>
<td>-</td>
<td>172</td>
<td>-</td>
<td>-</td>
<td>Dead-end track</td>
</tr>
<tr>
<td>34</td>
<td>-</td>
<td>218</td>
<td>-</td>
<td>-</td>
<td>Dead-end track</td>
</tr>
<tr>
<td>35</td>
<td>-</td>
<td>294</td>
<td>-</td>
<td>-</td>
<td>Dead-end track</td>
</tr>
<tr>
<td>36</td>
<td>-</td>
<td>290</td>
<td>-</td>
<td>-</td>
<td>Dead-end track</td>
</tr>
</tbody>
</table>
Tracks 29 to 36 are single-puller associated with the turnout tracks 2 in block 2 and on the opposite side there are dead-end tracks secured by buffer stop. The purpose of these tracks is determined by technological process of the station.

In addition to the foregoing, track systems for rail station also have facilities for shunting as follows:

- Turnout tracks number 2 on the block 2 has a usable length of 234 meters
- Turnout tracks "Niš" on the block 2 has a usable length of 277 meters

In addition to the above, track plants for the receipt and dispatch of trains, splitting and forming the same, in the area of Marshaling yard Niš there is a group of tracks for the wagon current repair and a group of tracks of locomotive depot.

This group consists of track rails:

- Track TK-1 usable length of 364 meters
- Track TK-2 usable length of 308 meters
- Track TK-3 usable length of 308 meters

On the tracks for the current repair, setting up and pulling wagons shall be done with shunting locomotives with a maximum permitted speed of 10 km/h.

![Figure 5.8 Photo of Marshalling yard Niš](image)

Among other station systems, this station has weighbridge with maximal load capacity of 100 t and usable length of 20m.

The station is secured with an electro-relay interlocking equipment system "Siemens-EI". All the tracks in the receiving group (2-9) and tracks 1, 1a and 1b are isolated and occupation of land is controlled on command control device.

In the area of Marshaling yard Niš are located 68 switches that are in use. All points on the area of the station, except of the switch number 46, are included in the electrical relay station security system.

Marshalling yard Niš has one PC-TTY. In the area of marshaling yard three telecommunications panels are in use. To make phone connections with movement’s inspector or other executives whose location is in the main station building or signal boxes P-1 and LP-3 are used automatically phones that are connected with central in marshaling yard. There are eight phones in the station.

In addition to telephone, intercom connections and public address systems to communicate with each other workers during technological processes and on the Marshaling yard Niš there is also radio connections.

Radios providing radio links are:

- Fixed radio station "Telecar 9- AEG"
- Portable (portable radio) "Teleport 9-AEG"
Portable "Motorola" GP 340

The radio link is used in the process of organization of work where internal movement’s inspector and yardmasters use the fixed station, and the outer movement’s inspector, foreman shunter and laborers using portable station.

Fixed radio stations that are used in the process of execution of the previous operation (marking of arriving trains) and finishing operations (marking of outgoing trains) are placed in a room on the operator terminal. For the completion of these operations in addition to the fixed station are used three portable.

For communication in the process of train disaggregation, fixed phone is located on the LP-3, while foreman shunter, yardman and shunter.

For each communication, executors on the same individual operations are equipped with a number of automatic telephones connected to the railway switchboard (ŽAT).

For communication between the movements inspector and operator on signal box signal from the field except platform phone station of Marshaling yard Niš has also intercom network.

5.4 Main processes in the marshalling yard

Marshalling yards are freight stations, in which are performed partially or completely disaggregating of incoming freight trains, shunting of wagons per directions and for stations on their direction and aggregating of new freight trains. In marshalling yard is carried out and passing through of trains that are not processed (i.e. the transit trains) but only performs change of locomotives and crew if that is necessary. In addition, there are performed a repair of the wagons, trains and cargo servicing and other operations.

Marshalling yard is usually found in the context of large railway nodes, which are close to industrial or commercial transport centers, mining and metallurgical companies, distribution centers or major sea or river ports.

The main task of marshalling yard consists of arriving and checking incoming trains, disaggregating and aggregating trains, wagon shunting within the yard, throwing wagon using the hump and/or the locomotive and checking and departure outgoing trains.

Trains coming to receive treatment are going on arriving-shipping tracks. There is carried out commercial and technical inspection of wagons, checking the composition of the train, preparing for disassembling and possibly removal of some minor technical and commercial faults.

Transit trains, i.e. trains that are not processed in the marshaling yard, are received at the arriving-shipping tracks. There is also carried out commercial and technical inspection of wagons, checking train composition and possibly removal of some minor technical and commercial faults. Transit trains can have the change of locomotives, driving and train crew.

Technical inspection performed by inspector (examiner) immediately after the arrival of the train at the station, with the goal of identification and elimination of defects that endanger road safety. In the case of a minor defect correction is performed without uncoupling the wagon of the train. In case of malfunction due to ride is not technically correct or able to run, the examiner prescribed labels affixed to the wagon and inform the movements inspector. Based on this information is done the change in the shunting list.

Commercial checks carried out by goods porter foreman (checker) and guard with the aim of identifying and removing defects with the goods or cargo accessories that endanger the safety of the goods themselves or traffic. A review of the completed commercial notifies the movement’s inspector.

Technical and commercial review of the train is done immediately after the arrival of the train at the station, as well as before shipping train when it is formed in the yard.

Technological chart of processing transit train for the classic conditions is shown in Fig. 5.9.
D4.1 Identification of relevant information about train classification process and marshalling yard sorting methods

<table>
<thead>
<tr>
<th>No.</th>
<th>Operation</th>
<th>Operation duration (min)</th>
<th>Performer/ Company</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Before train arrive</td>
<td>After train arrive</td>
</tr>
<tr>
<td>1.</td>
<td>Collecting information about the train</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Informing technical and commercial staff about number of trains, time and number of arriving track</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Arrive of workers at arriving track</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Decoupling and departure of locomotive</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Removing and adoption of the final signal</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>Handover of documents</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>Commercial inspection of train and composition</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>Arriving and coupling of locomotive</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>9.</td>
<td>Technical inspection of train and probe of brakes</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>10.</td>
<td>Removing and adoption of the final signal</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>11.</td>
<td>Departure of train</td>
<td>13</td>
<td></td>
</tr>
</tbody>
</table>

Total duration of the train treatment: 38 minutes

Figure 5.9 Graph of processing technology of the transit train without processing

The technology of processing trains in the station consists of the following operations:
- uncoupling and departure of locomotive;
- removing and adoption of the final signal;
- determining the exact composition of the train;
- commercial and technical inspection of the train;
- preparation of the shunting list;
- preparation of compositions for maneuver (releasing air from the main brake line, decoupling of air line and easing clutch).

Chart of processing technology of the train disassembled in the yard is shown in Fig. 5.10.
### D4.1 Identification of relevant information about train classification process and marshalling yard sorting methods

<table>
<thead>
<tr>
<th>no.</th>
<th>Operation</th>
<th>Operation duration (min)</th>
<th>Performer/Company</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Before train arrive</td>
<td>After train arrive</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>1.</td>
<td>Collecting information about the train</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>2.</td>
<td>Informing technical and commercial staff about number of trains, time and</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>number of arriving track</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Decoupling and departure of locomotive</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>5.</td>
<td>Removing and adoption of the final signal</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>9.</td>
<td>Settling of documents with defined composition of the train</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>10.</td>
<td>Making of shunting list</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>11.</td>
<td>Processing and sorting of wagon documents</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>13.</td>
<td>Delivery of shunting list</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Total duration of the train treatment</td>
<td>53 minutes</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 5.10 Chart of processing technology train that is disassembling in the station**

In order to form a train that should be departure to the next destination, sorting is performed to buildup the wagons. This is done on shunting-dispatch track from 10 to 28. Figure 5.11 gives a graph of the execution of major shunting operations. In Marshalling yard Niš wagons shunting is realizing by dragging and/pushing-off the group of trains with maneuver locomotive.
In marshalling yard, at the shunting-dispatch track group, there is the accumulation of wagons to form a train for further dispatch. Movement’s inspector monitors the accumulation of wagons on shunting-dispatch tracks and when the sufficient number of wagons for one train, he notifies the commercial service, the shunter. In Fig. 5.12 a graph of processing technology train formed in the station is shown.
### 5.4.1 Planning and organization of shunting operations

Shunting work at Marshaling yard Niš is permanent and is carried out by maneuver diesel locomotives. The main tasks in the execution of shunting operations in the area of receiving group of tracks are disassembling and assembling trains and eventually exclusion of wagon from the transit trains.

Time-table of traffic in Marshaling yard Niš is determined according to the annual freight transport time-table in Serbian railway. Chart of arrivals and departures of trains in Marshaling yard Niš in 2016 is shown in Fig. 5.13. This chart presents the basis for organization of shunting operations and plan of engagement of human and equipment resources.

![Figure 5.13 Railway freight traffic in Marshaling yard Niš according to Time-table for 2016](image-url)

**Figure 5.12 Graph of processing technology of the train formed in the station**

<table>
<thead>
<tr>
<th>The name of operation</th>
<th>Operation duration (min)</th>
<th>Performer/Company</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>After train arrive</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>1. Coupling wagons</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>2. Commercial inspection of train and composition</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>3. Arriving of maneuver locomotive</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>4. Technical inspection of train and brake probe</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>5. Separation and systematization of documents</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>6. Forming of travel list and their appendix</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>7. Handing over of documents to train staff</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>8. Removing and adoption of the final signal</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>9. Train dispatch</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td><strong>Total duration of the treatment train</strong></td>
<td><strong>55</strong></td>
<td></td>
</tr>
</tbody>
</table>

![Table Image](image-url)
On the basis of the chart of trains arrivals and departures in marshaling yard, plan of tracks occupancy is created. This plan includes 40 trains which can be transit trains or trains formed in Niš marshalling yard, and they are received and dispatched on tracks 1 to 9.

Graphic of occupancy of arrival-dispatch group of tracks 1-9 according to Time-table for 2016 is shown in Fig. 5.14.

Plan of trains reforming in Niš marshalling yard also is created according the time-table of freight train transport. Starting from the schedule of arrival trains which are planed for splitting up in the yard plan of shunting is formed. This plan includes 20 trains.

Graphic of occupancy of shunting-dispatch group of tracks 10-28 according to Time-table for 2016 is shown in Fig. 5.15.

The main tasks in the execution of shunting operations in the area of P-1, are disassembling and assembling trains and the possible exclusion of wagons from the transit trains, compression trains that are going to be dispatched over the LP -3.

The organization of work of locomotive in the field LP-3 is assembling of a collection train, weighing of wagons, setting up for the current repairs and pulling after the reparation, serving the same after the reparation, installation of wagons for eventual repairs of cargo and handling things, compaction trains on shunting-dispatch group of tracks that are going to be dispatch on area R-1 and disassemble trains.

The order of execution of certain tasks depending on the scope of work and it is prescribed by the Technological process of the station. Maneuver areas are not strictly divided, and in order to secure the
execution of tasks there should be close cooperation between the foreman shunter the field of R-1 and the area LP-3 and operators on signal box 1 and signal box LP-3.

In order to provide safe and efficient maneuver execution of tasks, it must be a mutual cooperation between all the movements’ inspectors at the station.

Priority execution of specific tasks in terms of disassembling trains; it is result of the plan of traffic trains.

Train dispatchers must agree with the operational assistant chief of station about the order of execution of shunting tasks.

5.4.2 Documents for regular operations management

5.4.2.1 Needed/available information for decisions

Before the train arrives at the marshalling yard, every previous station from which the train was sent must send the analysis of the train no later than 10 minutes after the train left their station. In this way, the marshalling yard during the day becomes information on the number of wagons that are coming into the station as well as their target.

When the train arrives at the marshalling yard Niš is performed commercial and technical inspection, on the basis of which is given the order to eject (shunting list) different wagon if there is a commercial or a technical irregularity. After an inspection of train is made shunting plan according to which, depending on the needs, allocated wagons on tracks where trains are grouped according to directions (Dimitrovgrad, Preševo, Prahovo Dock, Kursumljia or Belgrade).

The duty of the foreman shunter is, based on the list of trains in arrival, to compiles a shunting list that serves as the basis for the formation of shunting driving maneuver. Shunting list contains data on the number of trains, the start and end time of disassembling, as well as data on the pushing-off of the wagon, with labels of processed wagons. In addition, the foreman shunter, before the composition of the pick-up goods train, should review the gross accumulation on track and make a list of the same, and based on that, set up a shunting schedule.

When the train for dispatch is formed, guard should make a list of wagons and guard’s journal, perform calculation of the needed and real mass of the train, checks the necessary and effective braked weight, checks a commercial review of train travel list, compiled and submitted all necessary documents to the engine driver.

5.4.2.2 Types of decisions, decision making and implementation

Trains, which are coming to the treatment in the station, have commercial and technical inspection of the wagons, checking of the composition, preparation for disassembling and possibly removal of some minor technical and commercial faults. On the basis of the marshalling yard work plan the schedule of maneuvers is established - deployment plan for the accumulation of wagons on the marshaling tracks.

Technical inspection is performed by inspector immediately after the arrival of the train at the station with the aim of identifying and removing defects that endanger traffic safety. In the case of a minor defect reparation is performed without decoupling the wagon of the train. In case of malfunction due to ride is not technically functioning/able to run, the inspector prescribed labels affixed to the wagon and inform the movements inspector. Based on this information is done the change in the shunting list.

Commercial inspection carried out by goods porter foreman (checker) and guard with the aim of identifying and removing defects with the goods or cargo that endanger the safety of the goods or traffic. A review of the completed commercial notifies the movement’s inspector.
The main document on which is performed the implementation of decisions of sorting wagons is shunting schedule. It defines exactly what is needed to be done with a certain wagon. Shunting schedule makes operator of „Serbia Cargo“ and that goods porter foreman and operator assistants in marshaling yard.

Implementation of the decisions is based on the shunting schedule Executed „Infrastructure Railways of Serbia“ and movements inspector and foreman shunter are in charge. Job of movement inspector is to divide and distribute to the internal and outer movements inspector.

Internal movement’s inspector is responsible for the following:
- Forms running path of incoming, outgoing and transit trains and manages the interlocking equipment, according to a prior agreement with the outer movements inspector;
- plans train traffic in cooperation with operational service, announces changes in transport trains to station and railway staff and inform the signalman personal about the moved crosses;
- monitors the run of trains on the railway and publish delay with schedule section, to station and railway staff;

Outer movement’s inspector is responsible for the following:
- control over timely and proper composition and dispatch of trains in terms of traffic, technical and transport regulations (inclusion of wagons into train, weight and length of trains and axles, provided inclusion of the wagon to the marshalling yard regions), etc.
- Brake test of the train
- Provides a running path
- Welcoming and dispatch of trains based on the received reports of the internal movements inspector
- Review, classification and verificate the travel documents
- Supervision of maneuvering

The business maneuvering i.e. sorting wagons and mutual synchronization of activities are involved: supervisory signalman, signalman, telegraphist, foreman shunter, shunter, transport worker etc.

The part from the Traffic Regulations (procedure and criteria for the formation of the train): In the composition of the train, it is necessary that wagon should be: valid and capable for traffic (technically correct, properly loaded, capable for appropriate speed, type of braking, etc.). The vehicles must not exceed the permissible gross vehicle weight per axle, weight per meter and load profile of the respective tracks. Higher gross vehicle weight shall be placed, in principle, to the front of the train.

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

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

The composition of freight trains is prescribed with Traffic-transportation instruction to the timetable.

Inclusion of heavy breakdown cranes, vehicles for track maintenance and railway facilities shall be made to the terms of the instructions for use of such vehicles. Wagons loaded with hazardous substances are included in a train under special conditions in accordance with the Transport and Traffic Regulations.

**Length of train** expressed in meters and the number of axles and makes the actual length or number of axles of all vehicles on the train except for the length or number of axles running locomotive in service. The maximum length of the train depends on the type, composition and the maximum speed of the train, braking and usable length of the main track.

Exceeding the length of train considering usable length of main station tracks is allowed only if the train with longer length in such stations does not meet each other, i.e. train with exceeded length when meeting with other trains may enter or pass the station just as another train. About the exceeded the length of the drive crew is inform by the general order of stations that the train has exceeded the length. When seeking
D4.1 Identification of relevant information about train classification process and marshalling yard sorting methods

permission from such stations for trains with exceeded length, it must be indicates the length of the train in meters.

The planned **train mass** is the mass that is determined when timetable for each train is created, on the basis of which is selection of series and determines the number of tractive stock, running time is calculated and published in the booklet of the timetable. Actual tonnage of the train is the mass of wagons placed on the train, and shall be determined in the checking list. The total mass of the train is the gross weight of tonnage placed on the train and the mass of working locomotives in the train and the same is used for the calculation of train braking.

Regular tonnage of locomotives is that the maximum weight of a locomotive of specific series can be towed on a railway line by maintaining the regular timetable of the train.

Tonnage rating of locomotive is the largest load mass that locomotives can haul considering the permissible permanent strain of the pulled devices.

Actual train tonnage mass may be increased to the planned train mass when it do not prolong running time or to regular locomotive towed weight while it extend the running time.

Brake testing performs examiner and the driver who use brake or worker who use brakes.

During the assembling and dispatch of trains must be checked certain parameters with respect to the characteristics of the infrastructure along which trains should move.

With regard to usable length of the main running track and its neighboring track on certain sections, maximum length of the train can be:

- Marshaling yard Niš – Marshaling yard Niš Lapovo 585(m),
- Marshaling yard Niš - Mala Krsna- Marshaling yard Belgrade…. 585(m),
- Marshaling yard Niš –Mladenovac – Marshaling yard Belgrade 585(m),
- Marshaling yard Niš - Ristovac – Preševo......................... 439(m) ,
- Marshaling yard Niš – Crveni Krst - Dimitrovgrad ................. 524(m) ,
- Marshaling yard Niš – Kuršumlija – Kosovo Polje..................... 480(m) .

Maximum allowable vehicle axle load and the maximum load per meter on particular divisions are given in Table 5.2.

**Table 5.2 Allowable vehicle axle load and the maximum load**

<table>
<thead>
<tr>
<th>Relation</th>
<th>Maximum vehicle load</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>axle (t)</td>
</tr>
<tr>
<td>Marshaling yard Niš - Niš</td>
<td>22,5</td>
</tr>
<tr>
<td>Marshaling yard Niš -Cr. Krst</td>
<td>22,5</td>
</tr>
<tr>
<td>Marshaling yard Niš -Lapovo</td>
<td>22,5</td>
</tr>
<tr>
<td>Marshaling yard Niš -Preševo</td>
<td>22,5</td>
</tr>
<tr>
<td>Marshaling yard Niš -Dimitrovgrad</td>
<td>22,5</td>
</tr>
<tr>
<td>Marshaling yard Niš - Zaječar (Prahovo Pris.)</td>
<td>18</td>
</tr>
<tr>
<td>Marshaling yard Niš -Kuršumlija</td>
<td>16</td>
</tr>
</tbody>
</table>
5.4.2.3 Documentation in the normal operational management

Analysis of train is the report that the starting station of the train informs the end station, and if necessary intermediate station, on departure and on the composition of the train. Analysis of train compiled movement’s inspector on the basis of the guard’s journal.

Analysis of train contains:
- The type and number of train
- The departure time and name of the departure station
- Series and number of locomotives
- The mass and length of the train
- The composition of the train
- Vehicles that takes into intermediary stations and others.

Supporting documents of train are prescribed forms in which the information stated on the work of train locomotives and train staff, completed train journey etc. The basic form is a journey report; while additional are guard’s journal, reports on the composition of the train braking and the work plan of the train.

Journey report is written by guard or driver and movement’s inspector.

Guard’s journal is a form which shows the composition and weight of the train. Guard drawn up guard’s journal at the departure station.

Guard’s journal contains the following information:
- The number of train and travel route
- Date of train traffic
- Name of the departure station
- Numerous codes of wagons in the train
- Series and subseries og wagon
- Number of axles of wagon
- Length of wagon
- Weight of wagon
- Net weight of cargo in the wagon
- Braked weight of wagon
- Type of goods
- Name of the terminal stations

Shunting schedule (S-22) is a document based on which the operator on station form shunting running path.

The foreman shunter has the duty to examine the gross accumulation on track and make a list of the same before the composition of the pick-up goods train, and based on that, draw up a shunting list shunting schedule in two copies. One copy gives to operator on signal box 3 and the second keeps to himself for control.

Shunting schedule includes:
- Train number / mark and number of the wagon
- Number of tracks on which is the wagon
- Contents
- Track on which wagon are to be set up
- Time to what is necessary to set up
- Time when is was set up

According to the list of arrival trains, foreman shunter draw up a shunting list that serves to operator of signal box 1 as a first base for the establishment of the shunting running path.
Shunting list contains the following information:

- Number of train, the start time and end time of transformation, the ordinal number of pushing-offs,
- Number of wagons in a single pushing-off, marked "loaded" and "empty"
- Number of wagons in a single pushing-off, marked "loaded" or "low" number of tracks and
- Column "Note" in which is written the characteristic data (explosive, flammable, carefully maneuver)

### 5.4.3 Problems in the marshalling yard operations

The main task of optimization of the rail freight transport process is reflected in the transport plan i.e. time table which includes a plan of shunting/sorting work. Transport plan of freight trains should provide a fast delivery of goods to the recipient, more efficient use of the wagons, that is reduce their total transit time, optimal distribution of marshalling operation on transport line, as well as reducing the shunting operations on marshalling yards. Due to this, the tendency is to form direct trains, i.e. trains carrying the load without changing its composition from baseline to end station. The basic condition for the organization of direct trains is the existence of mass commodity flows.

The basic elements that define the quality of transport are transport time and transport costs. This means that the optimal transport of goods may be provided by minimizing the time and cost of transport. Transport time of freight depends on the wagon retention on commodity operations (loading and unloading), the speed of the trains on main lines and retention in technical yard. The organization of shunting operations directly causes wagons spent time at the technical yards and thus significantly affects to the overall transport time.

Traffic regulations and guidelines indicate that during shunting primary goal is safety. Shunting is done in such a way to achieve maximum efficiency in the work and most important factor is price. Practice on marshalling yards indicates that an important factor is the number of maneuvers and that the goal is with the least possible number of maneuvers to achieve greater impact.

### 5.4.4 Proposals for improving the decision making

The schedule is established for one year in the whole railway network of Serbia and harmonized with the international timetable. In the timetable of freight trains there can be regular and optional trains. Based on this timetable, shunting station sets the work plan, i.e. plan for trains to accept, disassemble, assemble and dispatches. Optional trains have determined route of movement reserved just for them. If it’s necessary, the introducing of new trains into traffic to be done in accordance with established routes of optional trains or on new route within the available capacity of railway lines. It is established from control of the infrastructure.

In carrying out the planned tasks, some unplanned situations can occur such as founded commercial or technical malfunction of individual wagons in train. The decision what actions to be taken on that occasion (extraction of wagon, etc.) are on the movement’s inspector in coordination with an currently present operator on marshaling yard.

In addition, interruption on sections of railway line can occur and train must stay at the marshaling yard. Existing problems in operational regime of the Marshaling yard Niš:

- Reduction of infrastructural capacity:
  - Hump is not used for more than 20 years;
  - Some tracks are not in use for several years due to malfunction;
  - Marshalling-dispatch tracks group (10-28) allows access to the main railway line only on one side (not both sides);
- A large number of garaged wagons mostly defective;
- Delay in dispatching trains to the south because of the frequent closing of the railway line Niš-Preševo;
- Synchronization of operations in the marshaling yard is difficult because, since 2016, liabilities are separated into two different companies "Infrastructure Railways of Serbia" and "Serbia Kargo".
6. ANALYSIS OF MARSHALLING YARD KARNOBAT, BULGARIA

6.1 Introduction - Short review of Bulgarian railways

The total length of railway lines in Bulgaria (according to the Report on the factual condition of the railway infrastructure, valid from 14.12.2014 to 12.12.2015) is 6,517 km as it is shown in Table 6.1.

Significant part of the railway lines were constructed more than 50 years ago, with geometric parameters, construction and facilities that are suitable for speed up to 100 km/hour and at some places it is with almost exhausted opportunities for keeping the speed and ensuring traffic safety and security. These sections are present along main directions such as Sofia – Plovdiv (section Sofia - Septemvri), Vidin - Sofia (section Vidin - Medkovets), Plovdiv - Burgas (section Plovdiv - Mihaylovo).

Table 6.1 Total unfolded length of the railway network

<table>
<thead>
<tr>
<th>Length of the railway network</th>
<th>Length (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single railway lines (track gauge 1 435 mm)</td>
<td>2,907</td>
</tr>
<tr>
<td>Double railway lines (track gauge 1 435 mm)</td>
<td>1,978</td>
</tr>
<tr>
<td>Station tracks</td>
<td>1,480</td>
</tr>
<tr>
<td>Narrow-gauge railway lines (track gauge 760 mm)</td>
<td>125</td>
</tr>
<tr>
<td>Narrow-gauge station tracks</td>
<td>13</td>
</tr>
<tr>
<td>Station tracks with wide track gauge (1 520 mm)</td>
<td>15</td>
</tr>
<tr>
<td><strong>Total length (1 435 mm)</strong></td>
<td><strong>6,517</strong></td>
</tr>
</tbody>
</table>

Some other relevant data are:

- Railway tunnels - 186 items with total length of 47,5 km.
- Railway bridges - 976 items with total length of 41,9 km.
- Crossings - 777 items.
- Curves with radius to 500 m with total length of 1 014 km.
- Railway switches - 7 300 items.

The facilities of the stations and division posts that are operational with security systems as following:

- Route-computer centralizations - 9 items.
- Relay centralizations with micro-computer visualization electric centralizations for small stations – MST - 4 items.
- Relay centralizations of the type RRC, EC - 175 items.
- Electric-mechanical centralizations - 35 items.
- Relay installations for key dependencies - 75 items.
- Without safety installation (temporary control panels) - 33 items.

In order to ensure traffic safety of trains in the sections in-between the stations the following systems are used:

- Relay semi-automatic blocking that is provided for around 2 031 km of the railroad network
- Blocking with passage signals - 335 km (unfolded length) of the railroad network
- Automatic blocking without passage signals, with axes’ counters - 1 119 km (length of the Railroad network).
- Direct binding - 29, 97 km.
Train traffic in the section Pirdop – Karlovo in the direction Sofia – Karlovo – Burgas and in the section Katunitsa – Yabalkovo in the direction Sofia – Plovdiv – Dimitrovgrad is ensured by centralized dispatcher systems.

Among all railroad crossings, 510 are equipped with elements and devices that ensure safe train passage through the crossing as follows:

- Automatic crossing devices with barriers, including in stations - 230 items
- Automatic crossing signalizations - 280 items.

Along the railroad line Sofia – Plovdiv and in the section from Skutare station to Stara Zagora station – on the side of Plovdiv system for automatic locomotive signalization was built - JZG 703 level 0, and in the railway junction Plovdiv, including the stations Plovdiv passenger (from the incoming signals – on the side of Sofia), post Crossroad, Trakiya, Filipovo and the section Stara Zagora – Burgas is equipped with ETCS level 1 - version 1.2.0/1999.

The section from station Katunitsa – Yabalkovo (five stations) is equipped with European system for train control Level 1, which is in conformity with the specifications for class 1 ERTMS/ETCS. The system software of the road and board equipment of the system is in conformity with version 2.3.0d.

After the liberalization of the railway services, the number of the licensed cargo carriers gradually increased. In addition to “Bulgarian State Railways – Cargo carriages” LTD, another 9 operators were licensed and they perform carriages throughout the Republic of Bulgaria, namely:

- “Bulgarian Railway Company” JSC (license issued in April 2005) – the company operations are about internal and international cargo carriages along the railway; the main commodities transported by this company are ores and metal concentrates, chemicals, fuels and non-metal minerals;
- “Bulmarket - DM” LTD (license issued in October 2005) – the main operations are related to the distribution of the propane-butane gas, diesel, gasoline and other fuels;
- “DB Schenker Rail Bulgaria” LTD (license issued in May 2010) – the main cargos being transported by the company are metal concentrates, metal items, quarry materials, construction materials and recently they have been performing transit transport of trailers;
- “Express service” LTD (license issued in June 2010) – the company performs locomotives’ manufacturing and repairs;
- State enterprise “Transport construction and refurbishment” (license issued in April 2011) – the company is one of the largest construction companies in the country;
- “Cargo Trans Vagon Bulgaria” JSC (license issued in May 2011);
- “Port Rail” LTD (license issued in April 2012);
- “Gastrade” JSC (license issued in December 2013) – the main operations of the company are in the area of internal and international trade with liquefied petroleum gas (LPG) and liquid fuels;

In 2007 after transformation and separation from “Bulgarian State Railways” JSC three companies were incorporated: “Bulgarian State Railways – Passenger carriages” LTD; “Bulgarian State Railways – Freight services” LTD; “Bulgarian State Railways – Traction rolling stock (Locomotives)” LTD.

In order to perform its main operations – carriage of passengers, “Bulgarian State Railway – Passenger carriages” LTD rents railway rolling stock (wagons from “Bulgarian State Railways” JSC and locomotives from “Bulgarian State Railway – Traction rolling stock (Locomotives)” LTD. The revenues from the operations are distributed according to the administrative principle. The per cent of the revenues received by “Bulgarian State Railways – Freight Services” LTD receives annually for its business varies from 52.5% in 2007, 83.6% in 2008 and 80.6% in 2009. The costs are formed in “Holding Bulgarian State Railway” JSC and in “Bulgarian State Railway – Traction rolling stock (Locomotives)” LTD and are transferred to “Bulgarian State Railways – Freight services” LTD, via contracts for mutually rendering services. As a result in 2009 with revenues of 137 million BGN, “Bulgarian State Railways – Freight services” LTD generates operational loss at the amount of 25 million BGN. (indicator profit/loss before interest, taxes and amortizations - EBITDA).

From 2010 to 2013 period of reforms followed during which new business model was set whereas the costs were controlled in comparison to revenues. In 2011 the company managed to turn the trend around of annual shrinkage of the work volume, and increased the transported tonne-kilometres. As a result, in 2013 the company gradually managed to achieve operational profit (EBITDA).
In 2014 with continuously decreasing operational volumes, the revenues decreased but the costs increased once again and the company got back to operational loss and its fixed capital shrank with almost one-third reaching 54 million BGN.

![Figure 6.1 Financial indicators of Bulgarian Railway State Company](image)

The total volume of the road transport increased during last decade, while the railway freight transport decreased in absolute and in relative values, as it is shown in Fig. 6.2.

![Figure 6.2 Basic market trends of the cargo transport](image)

As a result of the high cost base, functionally and physically obsolete operational assets due to the insufficient investments, low engagement of employees, outdated management mechanisms and political intervention in its business, the company does not have sufficient flexibility in order to cope with the market dynamics.
6.2 General information and importance

Karnobat railway station (KARNOBAT) with the initials (Kn) is located at kilometre 233+333 along the railway line № 8 Po-Sz-Kn-Sd-Va and it is the main manufacturing unit where the manufacturing process starts and ends, and the performance of the orders for carriage of cargos and passengers by the railway transport greatly depends on it.

Karnobat station is located on the 8th railway line. (Figure 6.3) The construction of the railway line Karnobat-Komunari-Sindel started from Karnobat station in 1916 and continued until 1918. On 20.08.1971 sub-region Karnobat was outlined as individual unit. In 1975 the railway line Karnobat-Varna was electrified. In 1974 wagon-repair workshop was built and in the very beginning it was wagon-repair track, and later on, in 1978 the building was constructed. The locomotive depot was built in 1943-1945. The new acceptance building of the Karnobat station was built back in 1988. The route relay centralization in Karnobat station was commissioned in July 1990. Station Karnobat has distributive hump that was built in 1981-1982.

Station’s essence role in the railway transport necessitates organizing its work in the strictly established manner. It is a station from which railway lines № 8 and № 3- deviate – Sf-Kv-Kn-Va in view of its important and strategic location.

The sections in-between the stations adjacent to this one are:
a) in even direction:
- to Tserkovski station road №1 and road №2
b) in odd direction:
- to Chernograd station road №1 and road №2
- to Lozarevo station road №1 and road №2

Figure 6.3 Location of Karnobat station
6.2.1 Volume of work and the importance of Marshalling yard Karnobat in railway freight transport

The seat wagons and the ones received in Karnobat station undergo comprehensive and continuous processing. If the seat wagons arrive and set off from the stations in composed trains, the processing operations include delivery to the industrial branch or to the tracks in the TS, and taking away, welding the wagons, measuring at wagon scale (with or without levelling – in the case of bulky cargos) and cargo marking, preparing travel and customs documents etc.

In order to be able to ensure the minimal wagons’ stay in the station, the technology of operating them should foresee mutual coordination in the performance of the technical, manoeuvring, commercial and loading operations.

In Karnobat station we performed research of servicing the seat wagons depending on the cargo types. The only wagons being unloaded are the wagons loaded with fertilizer being processed at 16D track in the Freight station. The transportation is performed by G wagons and the stay at the track for unloading usually is 24 hours. In the last six months the number of served wagons is presented in Fig. 6.4.

![Figure 6.4 Unloaded wagons with fertilizer monthly on Karnobat station](chart)

The average number of processed wagons is 14.83 i.e. 15 wagons average monthly.

The operation of loading wagons with straw for Svilengrad is performed in the station. Wagons being utilized for straw loading are G wagons. In the cases of single wagons for straw loading wagons’ stay is 24 hours per 1 wagon, and in the cases of block train of 10 wagons (or more up to 700t.) it is being loaded for 72 hours and is being driven out by train 80612 departing at 02:07 a.m. The number of loaded wagons in last 6 months is shown in Fig. 6.5.

![Figure 6.5 Loaded wagons with straw monthly on Karnobat station](chart)
The average number of processed wagons amounts to 49.67, i.e. 50 wagons average monthly.

### 6.2.2 Ownership and organizational structure

National Company “Railway Infrastructure” (NCRI) is operational since the 1st of January 2002 and in conformity with the Railway Transport Act National Company “Bulgarian State Railways” was divided into two companies – Bulgarian State Railways JSC and National Company Railway Infrastructure. It is the successor of the National Company “Bulgarian State Railways” (NC BSR) and succeeded the corresponding part of its assets and liabilities according to the balance sheet as of 01.01.2002 which refers to the railway infrastructure.

Additionally, in the station region the following railway operators do business and perform carriage of people and cargos while taking into account its features, location within the structure of the railway administration, as well as the technical and technological parameters if the station tracks, security and manoeuvring systems such as TMS – train movement schedule as follows: Bulgarian Railway Company JSC, Bulmarket – DM LTD, “Bulgarian State Railway – Freight Services” LTD, “Bulgarian State Railway – Passenger Services”, LTD, Gastrade JSC, Unitranscom JSC, “DB Schenker Rail Bulgaria” LTD, “Express Service” LTD, State Enterprise “Transport construction and refurbishment”, “CARGO TRANS WAGON BULGARIA” JSC, “Port Rail” LTD.

### 6.3 Marshalling yard infrastructure

#### 6.3.1 Infrastructure and equipment

Karnobat station is junction station that serves the passenger and cargo movement and performs decomposition and composition of the freight trains and it is the final one for the ordinary passenger trains. Hence it underwent significant track development and track groups’ outlining that are specialized for serving particular operations. Tracks’ specialization means outlining each and every track in view of the individual designation of trains or points for local operation. This specialization reflects the mutual connection of the plan for train composition to the technology of processing the wagons in the stations and the station regions.

The station has the following regions: two individual regions – Eastern and Western (Table 6.2 and 6.3):

<table>
<thead>
<tr>
<th>Appellation of the park or the group of tracks</th>
<th>Track №</th>
<th>Track specialization</th>
<th>Type</th>
<th>It is limited by switches №№.</th>
<th>Useful length in meters</th>
<th>Wagon capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Eastern region</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADP 1</td>
<td>Acceptance-directing</td>
<td>Connected</td>
<td>24-95</td>
<td>459</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>ADP 2</td>
<td>Main acceptance-directing track</td>
<td>Connected</td>
<td>16-95</td>
<td>342</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>ADP 3</td>
<td>Main acceptance-directing track</td>
<td>Connected</td>
<td>18-45</td>
<td>616</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>ADP 3-deaf</td>
<td>Acceptance-directing</td>
<td>Connected</td>
<td>41</td>
<td>363</td>
<td>16</td>
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</tr>
<tr>
<td>ADP 4</td>
<td>Main acceptance-directing track</td>
<td>Connected</td>
<td>20-39</td>
<td>645</td>
<td>29</td>
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<tr>
<td>ADP 5</td>
<td>Acceptance-directing</td>
<td>Connected</td>
<td>22-39</td>
<td>693</td>
<td>31</td>
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</tr>
<tr>
<td>ADP 1-A</td>
<td>Main (interim)</td>
<td>Connected</td>
<td>102-6</td>
<td>1136</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>ADP 2-A</td>
<td>Main (interim)</td>
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<td>106-4</td>
<td>1136</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>ADP 1-B</td>
<td>Main (interim)</td>
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<td>51-263</td>
<td>1200</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>ADP 2-B</td>
<td>Main (interim)</td>
<td>Connected</td>
<td>55-255</td>
<td>1200</td>
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<td></td>
</tr>
<tr>
<td>ADP 1-B</td>
<td>Main (interim)</td>
<td>Connected</td>
<td>35-281</td>
<td>651</td>
<td>-</td>
<td></td>
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D4.1 Identification of relevant information about train classification process and marshalling yard sorting methods

<table>
<thead>
<tr>
<th>ADP</th>
<th>Track</th>
<th>Main (interim)</th>
<th>Connected</th>
<th>Useful length in meters</th>
<th>Wagon capacity</th>
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<tbody>
<tr>
<td></td>
<td>2-B</td>
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<td>33-285</td>
<td>651</td>
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<tr>
<td>RDP</td>
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<td>RDP</td>
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<td>23</td>
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<tr>
<td>RDP</td>
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<td>Directing</td>
<td>88-93</td>
<td>272</td>
<td>12</td>
</tr>
<tr>
<td>RDP</td>
<td>17</td>
<td>Directing</td>
<td>88-93</td>
<td>271</td>
<td>12</td>
</tr>
<tr>
<td>RDP</td>
<td>18</td>
<td>Carriage</td>
<td>54-local depot</td>
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<table>
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<tr>
<th>Drawing tracks</th>
<th>Track</th>
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<th>Type</th>
<th>It is limited by switches №№.</th>
<th>Useful length in meters</th>
<th>Wagon capacity</th>
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<tr>
<td>1d</td>
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<td>19</td>
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<tr>
<td>5d</td>
<td>Manoeuvring</td>
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<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>ADP 6d</td>
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<tr>
<td>RDP 13d</td>
<td>Garage-DM</td>
<td>Deaf</td>
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<td></td>
<td></td>
<td>75</td>
</tr>
<tr>
<td>RDP 15d</td>
<td>Garage-DM</td>
<td>Deaf</td>
<td></td>
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<table>
<thead>
<tr>
<th>Appellation of the park or the group of tracks</th>
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<th>Track specialization</th>
<th>Type</th>
<th>It is limited by switches №№.</th>
<th>Useful length in meters</th>
<th>Wagon capacity</th>
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<tbody>
<tr>
<td>II-Western region</td>
<td>RDP 21</td>
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<td>Connected</td>
<td>126-113</td>
<td>778</td>
<td>35</td>
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<tr>
<td></td>
<td>RDP 22</td>
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<td>126-115</td>
<td>731</td>
<td>33</td>
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<tr>
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<td>RDP 23</td>
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<td>128-115</td>
<td>711</td>
<td>32</td>
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<td></td>
<td>RDP 24</td>
<td>Acceptance-directing</td>
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<td>128-109</td>
<td>804</td>
<td>36</td>
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<tr>
<td></td>
<td>RDP 25</td>
<td>Acceptance-directing</td>
<td>Connected</td>
<td>132-121</td>
<td>803</td>
<td>36</td>
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<tr>
<td></td>
<td>RDP 26</td>
<td>Acceptance-directing</td>
<td>Connected</td>
<td>134-121</td>
<td>799</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>RDP 27</td>
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<td>Connected</td>
<td>136-123</td>
<td>729</td>
<td>33</td>
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<td></td>
<td>RDP 28</td>
<td>Carriage</td>
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<td>847</td>
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<td></td>
<td>RDP 30</td>
<td>Directing</td>
<td>Connected</td>
<td>150-131</td>
<td>855</td>
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<td></td>
<td>RDP 31</td>
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<td>154-137</td>
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<td>778</td>
<td>35</td>
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<tr>
<td></td>
<td>RDP 33</td>
<td>Directing</td>
<td>Connected</td>
<td>152-141</td>
<td>740</td>
<td>33</td>
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<td></td>
<td>RDP 34</td>
<td>Directing</td>
<td>Connected</td>
<td>156-143</td>
<td>603</td>
<td>27</td>
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<td></td>
<td>RDP 35</td>
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<td>Connected</td>
<td>156-143</td>
<td>537</td>
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<table>
<thead>
<tr>
<th>Drawing track</th>
<th>Track</th>
<th>Manoeuvring</th>
<th>Type</th>
<th>It is limited by switches №№.</th>
<th>Useful length in meters</th>
<th>Wagon capacity</th>
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<td>RDP 4D</td>
<td>Semi-hump</td>
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<td>Hump</td>
<td>Manoeuvring</td>
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<td>52-60</td>
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<tr>
<td>Connecting</td>
<td>Passage for Eastern and Western regions</td>
<td>Connected</td>
<td>2-101</td>
<td>150</td>
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</tr>
<tr>
<td>Manoeuvring</td>
<td>Manoeuvring</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>64-101</td>
</tr>
</tbody>
</table>

Table 6.3 Western – from 19 to 35 tracks
Special tracks are provided in Table 6.4 and are designated for loading-unloading operations.

Table 6.4 Special tracks

<table>
<thead>
<tr>
<th>Track №</th>
<th>Specialization of tracks</th>
<th>Type</th>
<th>These are separated from Track №</th>
<th>Switch №</th>
<th>Useful length in m</th>
</tr>
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<tbody>
<tr>
<td>Scales</td>
<td>Scale track</td>
<td>Deaf</td>
<td>16D</td>
<td>151</td>
<td>30</td>
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<tr>
<td>16D</td>
<td>Loading-unloading activity</td>
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<td>2B</td>
<td>3/1</td>
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<tr>
<td>17D</td>
<td>Loading-unloading activity</td>
<td>Deaf</td>
<td>Scale track</td>
<td>157</td>
<td>83</td>
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<tr>
<td>18D</td>
<td>Loading-unloading activity</td>
<td>Deaf</td>
<td>17D</td>
<td>165</td>
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<td>19D</td>
<td>Loading-unloading activity</td>
<td>Deaf</td>
<td>17D</td>
<td>163</td>
<td>329</td>
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<tr>
<td>20D</td>
<td>Loading-unloading activity</td>
<td>Deaf</td>
<td>19D</td>
<td>167</td>
<td>329</td>
</tr>
<tr>
<td>21D</td>
<td>Loading-unloading activity</td>
<td>Deaf</td>
<td>5D</td>
<td>49</td>
<td>150</td>
</tr>
</tbody>
</table>

The tracks where the wagons are left loaded with dangerous cargos are: special platform in the bottom of 50 meters, separately from the other wagons for the Eastern region.

The damaged wagons should be left at the 17th track of the Eastern region. After their recruitment they should be delivered in the WRD. The damaged wagons from the Western region should be recruited at the 26th track and then delivered to the 17th track in the Eastern region.

Tracks along which non-gauge wagons cannot pass /with cargos out of gauge/ and wagons for 1520 mm are: first acceptance-directing track, special platform, omnibus platform and scale track.

Heavy locomotives and heavily loaded wagons cannot pass or along which the latter should move with lowered speed at the scale platforms in the loading station. Tracks with slope of over 2.5% are 1D; 4D; 5D; 19; 20; HUMP.

The station is equipped with Route-relay centralization of the type “Russian block with routed manoeuvres”. The station centralization performs centralized remote control and management of switches, traffic lights and isolated sections within the station and creates the necessary dependencies that ensure traffic safety of trains and manoeuvring operations in the station region.

To Lozarevo station the section in-between the stations along road №1 and road №2 is equipped with semi-automatic blocking type “Stepanov”, with specialized movement (without de-personification). The section in-between the stations Karnobat-Lozarevo along road №1 are equipped with key-spectre for operational train. To the stations Chernograd and Tserkovski the sections in-between the stations along road № 1 and road № 2 are equipped with automatic blocking with axles counters without passage traffic-lights with specialized movement (without de-personification).

The section Tserkovski, Karnobat, Chernograd is equipped with the system for automatic locomotive signalization (ALS) ALTRACS BDZ (point type) which is microprocessor system performing continuous control of the train movement based on information transfer by the road signals inside the locomotive cabin.
D4.1 Identification of relevant information about train classification process and marshalling yard sorting methods

Remote information boards (RIB) are located at km 3+303 side LZ, and at km 230+320 side TS are in-built in the light-scheme board are bound with Route relay centralization. The board for controlling the section switchers are located in EDE Karnobat. Switching the switchers is performed by the employees on duty of EDE Karnobat, after an order issued by the power dispatcher recorded in log XXI-01. In the case of emergency situations, in order to avoid failures, wrecks and catastrophes, voltage switch off in the contact network could be performed without order issued by the power dispatcher, and the manager “movement” on duty first person gets in touch with the employee on duty in Sub-station Karnobat via telephone 318, and explains him/her the situation and asks for switching the voltage off in CN – station outlet (Karnobat Eastern region) or outlet “Iskra” (Karnobat – Western region), then immediately notifies the power dispatcher.

The broadcasting devices are provided in Table 6.5:

Table 6.5 The broadcasting devices on Karnobat

<table>
<thead>
<tr>
<th>Type /appellation/ of the connection</th>
<th>It connects</th>
<th>Where it is located</th>
</tr>
</thead>
<tbody>
<tr>
<td>Telex</td>
<td>Broadcasting machines</td>
<td>Room teletracks</td>
</tr>
<tr>
<td>Conference</td>
<td>State Enterprise “NC RI” and directorates</td>
<td>Deputy-station chief</td>
</tr>
<tr>
<td>Dispatcher</td>
<td>Manager II – train dispatcher</td>
<td>Movement manager</td>
</tr>
<tr>
<td>Energy-dispatcher</td>
<td>Energy - dispatcher</td>
<td>Movement manager</td>
</tr>
<tr>
<td>Inter-station</td>
<td>Manager II – neighbouring stations</td>
<td>Movement manager</td>
</tr>
<tr>
<td>Loudspeaker</td>
<td>Region Sounding</td>
<td>Movement manager; information</td>
</tr>
<tr>
<td>Post</td>
<td>Manager II – with the posts</td>
<td>Movement manager - posts</td>
</tr>
<tr>
<td>GSM</td>
<td>It connects the subscribers of Mtel in group State Enterprise “NC RI”</td>
<td>Movement manager</td>
</tr>
</tbody>
</table>

6.4 Main processes in the marshalling yard

Marshalling yard is usually found in the context of large railway nodes, which are close to industrial or commercial transport centers, mining and metallurgical companies, distribution centers or major sea or river ports.

From that point of view, Karnobat is not a typical marshalling yard due the fact that large part of operations are going to passenger trains. Typical marshalling yards usually consider just freight transport and services and freight transport is also the main topic of SMART project. That’s why the focus in this analysis is on freight transport data and services.

On the other hand, mixed station as Karnobat is good for analysis because it can encircle some scenarios and procedures which don’t exist on typical marshalling yard.

The main task of marshalling yard consists of arriving and checking incoming trains, disaggregating and aggregating trains, wagon shunting within the yard, throwing wagon using the hump and/or the locomotive and checking and departure outgoing trains.

Regarding that, the main technological operations and main processes in the each marshalling yard in Bulgaria has to be in line with requirements of the National Company Railway Infrastructure and on the other hand, in line with technical and technological level of station equipment.

Manoeuvre is every organized movement of railway rolling stock performed along the railroad according to manoeuvring signals. Manoeuvre along the acceptance-directing tracks is performed according to request submitted in writing and approved by the carrier only with permission of the chief “movement” on duty and the train dispatcher for stations of the central dispatcher control.
The manoeuvre is being managed by one person with the necessary capacity. The manoeuvring operations in the operational points are performed in the order and manner defined by the railway infrastructure manager. The compounds of the manoeuvring brigade are defined by the carrier. The obligations of the locomotive and manoeuvring brigade are defined by the carriers and coordinated with the railway infrastructure manager. The train movement and manoeuvring operations’ rules are:

- Manoeuvre zoning;
- Planning and management of the manoeuvring work;
- Order for allowing the manoeuvring work;
- Order and manner of operating the switches when manoeuvring;
- Speeds when performing the manoeuvre;
- Order and manner of terminating the manoeuvre;
- Performance of manoeuvre in stations equipped with centralizations of routed manoeuvres;
- Performance of manoeuvre in stations of section with DC;
- Manoeuvre along the acceptance-directing tracks and getting out of the entrance traffic-light;
- The order of performing manoeuvre in regions not being served by the railway infrastructure;
- Manoeuvre at stops and deviations of the inter-station sections;
- Movement of isolated locomotive in the station region;
- Performance of manoeuvre along the drawing tracks;
- Performance of manual manoeuvre;
- Performance of manoeuvre with dangerous cargos and other special cases;
- Delivering wagons to the railway line and tracks being constructed;
- The tracks where no wagons are being pushed away;
- Operation of skids;
- Order for procuring the wagons against self-movement;

The order and duration for the performance of the individual manoeuvring operations in the 24-hour period are defined by the operational schedule of each and every manoeuvring locomotive. Annually, before the new train movement schedule becomes effective, the chief “carriages” service in the station prepares schedule for the operations of every manoeuvring locomotive and manoeuvring brigade.

The schedule should be coordinated with the station chief and should be presented for approval to the chief who approved of the technology of the operational point. The schedules should be prepared in the case of modifications performed in the operational organization and in the track development of the station. The operational schedule of each and every manoeuvring locomotive and manoeuvring brigade should be attached to the technology of the operational point, and each excerpt should be submitted to every manoeuvring chief. In operational manner the operational schedule of each manoeuvring locomotive and manoeuvring brigade, just like the operational region could be modified by the person ordering the manoeuvre in coordination with the chief “movement” on duty.

In order to perform the manoeuvre, it should be planned in advance. In the stations where there is no manoeuvring personnel, if damaged wagons should be taken out of the train composition, the manoeuvre is performed by a train locomotive and by station personnel with the necessary capacity under the guidance of the chief “movement” on duty or by the station chief reflected in the work technology concerning the operational point. In the stations where there is no individual manoeuvring locomotive and manoeuvring brigade, the manoeuvring work should be performed with train locomotives operated by the carriage brigades of certain trains under the guidance of the train chiefs (manoeuvring experts).

In the start and final stations where there are no manoeuvring locomotives and manoeuvring brigades, composing and de-composing trains and processing the local wagons is performed by the train brigades in question. In the stations with individual manoeuvring locomotive and manoeuvring brigade if these are busy with the manoeuvring operations in the station or in the industrial railway branches, leaving wagons from the trains and taking a wagon group prepared in advance by the station manoeuvre are performed by the train locomotive and the carriage brigade for the particular train. In order to perform manoeuvre plan should be drawn for the manoeuvring work.

In Karnobat station the following manoeuvring facilities and devices presented in Table 6.6 are operated.
D4.1 Identification of relevant information about train classification process and marshalling yard sorting methods

Table 6.6 Manoeuvring facilities and devices on Karnobat

<table>
<thead>
<tr>
<th>Mechanized or non-mechanized hump, semi-hump or profiled drawing track</th>
<th>Works are performed in the direction</th>
<th>Slope</th>
<th>t meter</th>
<th>Brake per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-mechanized hump</td>
<td>Burgas and Varna</td>
<td>25,75‰</td>
<td>4</td>
<td>35%</td>
</tr>
<tr>
<td>Drawing track 5D side CH</td>
<td>Chernograd station</td>
<td>4,46‰</td>
<td>9</td>
<td>6%</td>
</tr>
<tr>
<td>Drawing track 1D side LZ</td>
<td>Lozarevo station</td>
<td>3,63‰</td>
<td>3</td>
<td>6%</td>
</tr>
<tr>
<td>Non-mechanized semi-hump in drawing track 4D</td>
<td>Stara Zagora, Tulovo</td>
<td>26,58‰</td>
<td>5</td>
<td>14%</td>
</tr>
</tbody>
</table>

The chief “movement” on duty – first person maintains connection with:
- train dispatchers
- all post switchers;
- the neighbouring stations;
- the power dispatcher;
- locomotives that approach the station;
- chiefs on duty second persons;
- revise-wagons;
- manoeuvring locomotives;
- manoeuvring experts;
- And all services in the station via telephone, radio station and loudspeaker.

The manoeuvring experts maintain connection with the:
- locomotive drivers of the manoeuvring locomotives;
- the chief “movement” on duty – first person via radio stations;
- post and manoeuvring switchers via the loud speaking installation;
- and with all other services in the station via telephone.

Ordering person for performing the manoeuvre in Karnobat station is the chief “carriages” on duty of the carrier.

The elaboration of the shift plan in view of acceptance, de-composition, composition and dispatch of the trains, as well as tasks related to the local works is performed by the Chief SFT or by his/her deputy. The shift plan is elaborated and submitted for coordination to the Station chief or his/her deputy not later than 2 hours before the start time of the shift in the station. The operational planning of the manoeuvring operations is performed by the chief “carriages” on duty.

Annually, before the new Train movement schedule becomes effective, the chief of the SFT in the station draws schedule on the operations of each manoeuvring locomotive and manoeuvring brigade. The schedule should be coordinated with the Station chief and it should be approved by the Chief who approved of the Station technology and is applicable towards it. The modifications in schedule’s operational order should be performed by the chief “carriages” on duty according to the chief “movement” on duty first person.

The manoeuvre in the station is performed as two manoeuvres of the carrier Bulgarian State Railways. The person directly in charge is the manoeuvring expert of the manoeuvre in particular. The manoeuvring work is being performed by locomotive brigade consisting of locomotive driver and manoeuvring brigade of not less than three people, including the manoeuvring chief. The composition of the manoeuvring brigades is defined by the carrier. Manoeuvre with a single switcher could be performed when pushing the manoeuvring composition to the hump top.

The two manoeuvres serve the region of Karnobat station, Lozarevo station and Tserkovski station under the orders issued by the chief on duty.
D4.1 Identification of relevant information about train classification process and marshalling yard sorting methods

- I manoeuvre – works on the hump such as de-composing trains from 21 to 27 tracks through the hump to the Eastern region from 6 to 17 tracks of the park beneath the hump.
- II manoeuvre – works along the drawing track 4D in the Western region such as de-composing and composing the trains from 29 to 35 tracks.

You are not allowed to release, push away and push in along free tracks against the neck of the incoming train. Taking up the acceptance-directing tracks could be performed only with the permission of the chief “movement” on duty first person. The movement of manoeuvring composition from one part to another is performed after providing the composition with brake mass. Every manoeuvring brigade performs work only within its manoeuvring region. The works of more than one manoeuvring locomotive and manoeuvring brigade in a single manoeuvring region are allowed only after coordinating the matter with the manoeuvre chief in advance in whose region the operations are to be performed under the guidance and control of carrier’s chief on duty.

While manoeuvring, switches’ operations are performed by:
- Chief “movement” on duty first person of TSP of the route-relay centralization – in the case of routed movements.
- The post switcher – when delivering the switches to the local management. In this case after preparing the switches and opening the manoeuvring signal the manoeuvre could be moved after the signal emitted by the post switcher.
- Manoeuvring switcher – in the regions with manual switches upon the orders issued by the manoeuvring expert or personally by him/her.

Manoeuvre in a locomotive depot for directing and taking out wagons is performed after coordinating the matter with the depot master on duty. The manner of performing the manoeuvre inside the locomotive depot and in WRD Karnobat is defined in individual guidelines attached to this Station technology.

If the locomotive should be moved inside the station along the acceptance-directing tracks, this should be performed only with the oral permission and upon the order of the chief “movement” on duty first person, but always with allowing indication of the manoeuvring traffic lights.

If the locomotive is moving from one post to another, its movement is allowed orally by the chief “movement” on duty first person and is ensured between the post switchers with telephonogram. In this case the locomotive driver should stop at a distance and could advance only after receiving signal from the post switcher.

Locomotives hung off a train are being moved not farther than the remote indicator only upon the oral order issued by the chief “movement” on duty in person or via the post switcher and after a signal provided by the worker who hooked them off, to the remote indicator. Moving the locomotive from the switch post for hooking it onto the train composition is performed after notification and signal issued by the post switcher.

Moving locomotives from and for locomotive depot Karnobat is regulated in individual Instruction attached to Station’s technology.

The technological operations to which the freight trains arriving in Karnobat station are subjected for decomposing are presented in Fig. 6.6.
### D4.1 Identification of relevant information about train classification process and marshalling yard sorting methods

#### Servicing the arriving freight trains

<table>
<thead>
<tr>
<th>№</th>
<th>Operations</th>
<th>Time norm</th>
<th>Duration in minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Submission of the documents and ticking them according to the delivery payroll</td>
<td>3'</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Hooking off and releasing the locomotive</td>
<td>3'</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Commercial inspection and description of wagons</td>
<td>10'</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Technical inspection of the wagons by wagon reviser</td>
<td>10'</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>De-composition preparation</td>
<td>10'</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>De-composing the arrived train including:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Manoeuvring locomotive passing behind the train composition</td>
<td>5'</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pushing in the composition from the track to the top of the hump</td>
<td>2'</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Release through the hump and wagons’ arrangement in view of directions</td>
<td>10'</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pushing in and hooking the released wagons along the tracks</td>
<td>2'</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Total duration</td>
<td>30'</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 6.6 Servicing the arriving freight trains**

Servicing the departing composed freight trains in Karnobat station is presented in Fig. 6.7.

The operations being performed that are coloured in the scheme are limiting and the total duration of the whole cycle depends on them, and the non-coloured operations are performed in parallel with the limiting ones (in parallel to the operations).
## Servicing the departing freight trains

<table>
<thead>
<tr>
<th>№</th>
<th>Activity Description</th>
<th>Duration</th>
<th>Time norm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Composition of the dispatch train compounds</td>
<td></td>
<td>30'</td>
</tr>
<tr>
<td>2</td>
<td>Commercial inspection and description of wagons</td>
<td></td>
<td>10'</td>
</tr>
<tr>
<td>3</td>
<td>Preparation of documents: acceptance-delivery, train etc.</td>
<td></td>
<td>10'</td>
</tr>
<tr>
<td>4</td>
<td>Hooking the train locomotive</td>
<td></td>
<td>5'</td>
</tr>
<tr>
<td>5</td>
<td>Technical inspection and complete trial, elaboration of the VP-11 by the wagon revisor</td>
<td></td>
<td>25'</td>
</tr>
<tr>
<td>6</td>
<td>Sending operations: Route preparation, procurement of train movement, clocks’ check</td>
<td></td>
<td>5'</td>
</tr>
<tr>
<td>7</td>
<td>Total duration</td>
<td></td>
<td>65'</td>
</tr>
</tbody>
</table>

**Figure 6.7 Servicing the departing freight trains**
6.4.1 Planning and organization of shunting operations

The main tasks in the execution of shunting operations in the area of receiving group of tracks are the disassembling and assembling trains and eventually exclusion of wagon from the transit trains.

Time-table of traffic in marshaling yard Karnobat is determined according the annual freight transport time-table in Bulgarian railway. The chart of arrivals and departures of trains in Marshaling yard Karnobat in ongoing year presents the basis for organization of shunting operations and plan of engagement of human and equipment resources.

The main manoeuvring operations in the station are performed by “Bulgarian State Railways Freight Services”. 24-hours plan-schedule of manoeuvring operations in Karnobat station for two shifts provided in Fig. 6.8 and 6.9 for the shifts from 7-19 and from 19-7, respectively.

**Figure 6.8 24 – hours plan schedule of manoeuvring operations in Karnobat station 1**\(^{st}\) **shift**

**Figure 6.9 24 – hours plan schedule of manoeuvring operations in Karnobat station 2**\(^{nd}\) **shift**

In order to provide safe and efficient maneuver execution of tasks, it must be a mutual cooperation between all the movements’ inspectors at the station. Priority execution of specific tasks in terms of disassembling trains; it is result of the plan of traffic trains. Train dispatchers must agree with the operational assistant chief of station about the order of execution of shunting tasks.
7. MARSHALLING YARD MANAGEMENT

7.1 Train classification

Freight trains are classified due to forming conditions, travel distance, type of transported goods, transportation speed, etc.

If train carrying the load without changing its composition from starting station to the end station it is direct (block).

According the type of transported goods and transportation speed, freight trains are divided into express freight train, direct freight trains, pick-up trains, military freight trains, breakdown freight trains, service freight trains etc.

According the incorporated wagons in the train composition, freight trains are divided into trains compound from loaded wagons, empty stock, mixed (loaded and empty) wagons, and special wagons (tank wagons, refrigerator wagons etc).

According the number of wagon groups incorporated in train, freight trains are divided into single-consignment and multiple consignment trains. Single-consignment trains do not change their composition to the destination. Multiple consignment trains are prepared of two or more groups of wagons which are transported to the different receiving stations; respectively they change their composition along the transport road.

Numbering of freight trains is performed due the UIC Lefalet 419-2. According to the provisions of Leaflet 419-2 the series 4xxxx is used for numbering international freight trains.

The type of service:

- 40xxx and 46xxx - multilateral (four networks or more)
- 41xxx to 45xxx - bilateral and trilateral
- 47xxx to 49xxx - bilateral and trilateral

The type of traffic:

- 40xxx to 43xxx - combined traffic trains
- 44xxx to 45xxx - group traffic trains
- 46xxx - group traffic trains and special purpose trains
- 47xxx to 49xxx - special purpose trains.

Thousands digit determines the type of train:

- 0 transeuropean express trains
- 1 express freight trains
- 2 express freight combined transport trains
- 3 express freight (TEF) trains
- 4÷6 block freight trains
- 7÷8 block freight trains with one type of good
- 9 freight trains with empty wagons.

Freight trains in domestic service in Serbia are numbered with numbers 50000 – 59999, and thousands digit determines the type of train:

- 0 express freight trains
- 1 speed freight trains
- 2 direct freight trains
- 3 wagonload freight trains
- 4 speed unit freight trains
- 5-6 pick-up freight trains
- 7÷8 touring and industry trains
Service freight trains are numbered with numbers 70000 – 79999 and thousands digit determines their use:
- 0, 1 and 2 - locomotive trains, and
- 3, 4 and 5 - work trains.

### 7.2 Types of decisions and decision maker

The schedule is established for one year in the whole railway network of Serbia and harmonized with the international timetable. In the timetable of freight trains can be regular and optional trains. Based on this timetable, shunting station sets the work plan, i.e. plan trains to accommodate disassemble, assemble and dispatches. Optional trains have determined the route of movement that are reserved for them. If necessary, the introduction of new trains into traffic is done in accordance with established routes of optional trains that do not run or on new route within the available capacity of railway lines. It establishes control of the infrastructure.

The composition of freight trains is prescribed by timetable i.e. annual traffic plan of trains. However, the real composition of the train may deviate from the plan. Each station from which the train is arriving have to send the analysis of the train to the next station after the train left the station. In this way, the marshalling yard during the day collect information about trains and wagons that come to the station as well as their final destination. Marshaling yard, on this way, has data on the composition of the train before the train arrives at the station.

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

In addition, can occur interruption on sections of rail line and train must stay at the marshaling yard.

The main document on which is performed the implementation of decisions of sorting wagons is shunting list. It defines exactly what needs to be done with a certain wagon. Shunting list is made from the representative of the operator. Implementation of the decisions i.e. sorting of wagons, based on the shunting list is performed from the infrastructure representative. The sorting wagons and mutual synchronization of activities are involved from infrastructure representatives: supervisory signalman, signalman, telegraphist, foreman shunter, shunter, transport workers and others.

### 7.3 Parameters for Marshalling Yard Management

In the composition of the train, it is necessary that wagon should be: valid and capable for traffic (technically correct, properly loaded, capable for appropriate speed, type of braking, etc.). The vehicles must not exceed the permissible gross vehicle weight per axle, load per unit of length and load profile of the respective tracks. Higher gross vehicle weight shall be placed, in principle, to the front of the train.

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

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

In order to perform optimal marshalling yard management data that should be available are next:

- Timetable of incoming and outgoing trains
- Trip planes of wagons
- Roster of the required staff categories at marshalling yards
- Regular schedule of marshalling, shunting and check activities at marshalling yards
- Lack of assets against the regular schedules
- Any significant actual and/or proposed deviations of the scheduled operations
D4.1 Identification of relevant information about train classification process and marshalling yard sorting methods

- Layout (infrastructure) of the marshalling yard
- Relevant characteristics of technical assets and qualifications of the staff
- Relevant load characteristics (weight, dangerous goods)
- Rules and restrictions for the operation’s performance.

The parameters that affect on the management processes in marshalling yards are:
  - Train type;
  - Train number;
  - Dispatch time of starting station
  - Name of starting station
  - Train mass in tones
  - Train weight per axle;
  - Train length in meter;
  - Train composition;
  - Wagon series and subseries
  - Number of wagon axles
  - Wagon length
  - Wagon mass
  - Net mass of cargo in wagon
  - Braked weight
  - Type of cargo
  - Type of train escort and domicile of train crew;

**Shunting schedule contains following data:**
  - Train number/label and train number
  - Track number at which the wagon is
  - Wagon content
  - Track number at which the wagon have to be placed
  - Time to what is necessary to place the wagon
  - Time when wagon was placed

**Shunting list contains following data:**
  - Train number, starting and end time of transformation, serial number of wagon pushing-off
  - Number of wagons in a single pushing-off, marked "loaded" and "empty"
  - Number of wagons in a single pushing-off, marked "loaded" or "low" number of tracks and
  - Characteristic data (explosive, flammable, carefully maneuver).
8. MARSHALING YARD SORTING METHODS

8.1 Introduction

Professional organizations of railway transport lies on experience and mathematics, optimization techniques and modeling implementation of the technological process. The organization of the work process is based on predicting the future volume of work (transport). For this reason, it is somewhat uncertain effectiveness of transport implementation except in the case of stationary conditions. Therefore, the technology of the railway transport is based on a prediction of future traffic demands. The hallmark of rail transport is the complexity of the system, which in functional terms is characterized by mass and time-based variations process, which is why the basis for setting up a system of analysis and prediction based on stochastic. The substrate for this application is the theory of mass servicing or closer - Queuing theory. This category of engineering tasks using probabilistic methods for the prediction process, their scale, mathematical expected time, standard deviations from the mean random variables, is known as simulation. Tasks which are solved in traffic can use approximations of random sizes that can be linear or quadratic and others. For solving these tasks can use the methods of linear or approximate programming. One particular group of tasks in rail transport have varying character of traffic flows, however, in predicting these processes use mathematical methods of dynamic programming.

Given that the infrastructure and technology of rail transport is very expensive category of every developed society that are the goals which is set are various. We suppose the minimum transport costs, minimum maintenance, maximum reliability functions, the maximum safety of people and goods in the process. So these are multicriteria objectives of setting up transport system. According on that on transport system affects the atmosphere (Information, Economic, logistics, qualification), which changes his behavior. Considering that the transport system has tasks and changing environmental influences, by technology of work the transport rail system adjusts the assigned tasks - a dynamic model of functioning. The main aim of unscrewing transport technology besides social and economic realization function and profit is also set the system by which managed (manageability). The management is affecting of the functions system with pre-set goals. In the railway traffic are managed with resources - infrastructure, people, materials, energy and information. Such a complex system control is defined as cybernetic control. Platon defined cybernetics as "management skills". The management system is achieved by the existence of a model system, the existence of objective and operation of the allowable set of activities prescribed for the technology work. Management activities are not only a technical nature already are based on the experience of operation, routine repetition of the operational rules of work, intuition and knowledge of the situation - informing.

Managing with large transportation system has its current policy (priorities, trends, developments), strategy (general rules aspirations order), restrictions (allowed to use the resources, rights of access to resources, constraints function), goals (economic, technical) decision on the implementation alternatives.

What are modeled in railway traffic: forecasts optimize are technology to improve the capacity, automating are processes. By forecasts are made predictions of technological and economic parameters for short-term or long-term periods of work.

Optimization tasks are as follows: Optimal allocation of empty freight cars, Planning volume of transport of goods and passengers for the existing transport system, Planning the use of special wagons, Transport planning quantities on lines with limited flow, The rational organization of the flows of railway wagons for the formation of trains and shunting, Training current operational in railway nodes, Making timetable for lines and networks. Further: The selection the route of movement of goods, choice of optimal capacity of railway lines in the design, technical norming of transport impact, rational organization of suburban passenger traffic, rational organization of remote traffic. Also: Optimization of reserves and staff, The deployment locomotive depots and workshops for maintenance of wagons, Optimal equipment with machinery for transshipment of goods at the stations, Optimization of various modes of transport.

The system of queuing is the theoretical basis for modeling technology - a process of receiving and processing of trains on marshalling stations. The processes of arrivals and servicing are so different in requirements and trains that take place only by random laws. Parameters variable accidentally characterize the duration and scope of activities in business dissolution and assembly of trains. Volume of work is massive and therefore applies stochastic approach queues and channels serving.
For example, when it comes to Poisson flow, then the system has n channels serviceability and m places in the queue. The inflow unit for servicing has Poisson intensity λ, and service time has an exponential distribution with intensity μ. With these sizes has multiple possible states and for process of marshalling and disassembling composition can be observed typical models that then apply for the prediction process. For processes of queuing theory mathematical relations determining probability are derived, the number of clients, waiting time and dwell time in the system. These relations lead to the determination of exploitation reliability marshalling yards and it is determined based on the capacity of the station to receive with high probability all the requirements for shunting. This ability depends on the equipment of the station, number and arrangement of tracks, staff and their organization.

Complex technical and technological systems are shunting, department, major travel and technical passenger station. These technical systems are interconnected by functions and operations. The work of one technical system affects the work of other inter-related lines. In marshalling stations are perform the processes of forming the composition order of arrivals and with an interval arrivals of trains in the receiving part of the station. The process is characterized by the duration of the operations that are carried out capacity of hump i.e. for each station interval of hump.

If all trains evenly come on shunting in regular intervals and if the time of train processing less than arrival train time than the time won’t appear between operation retention. There would be no queues! But these conditions are often disrupted and trains waiting for between operation retention (for subsequent shunting operations). Organizing uniform train movement by sections of the railway network and bringing them to commodity, shunting and other station is not possible at regular intervals. Reasons: the seasonal nature of traffic, non-working days, working in one or two shifts, that the capacity of different modes of transport.

The scope of work in the shunting station to the formation of a composition depends on the length composition (number of wagons) and it is a known technology category for normal (average) length of the composition. Significantly greater waiting time occurs as a result of the uneven arrival of composition in marshalling park or shorter intermediate arrivals of trains. Also appear internal weaknesses resulting inefficiency teams for shunting trains (fatigue, the impact of bad weather, holidays).

In the framework of the International Initiative for the reform of the railway system, railway administrations suggested that the focus on liberalization and market integration, optimization of wagon flows and greater participation multigroup trains in remote traffic. In the former organization of wagon flows, remote traffic is implemented one group trains, while multigroup trains primarily been represented in local traffic within the collection and delivery wagons between technical freight stations and end stations. With greater involvement of multigroup trains in remote traffic can be greatly affected by on shortening of the time that wagons spend in the technical freight stations.

8.2 Methods for formation of multigroup trains

In order to take full advantage of technical stations and marshalling capacities multigroup train formation should be performed only partially in the process of dissolution, or totally by subsequent shunting and applying of specific methods.

Multigroup trains also play a significant role in the industrial railway transport, which is a significant link in the transport chain between the industry and public transport.

The formation of multigroup trains is considered a highly complex problem of railway. Multigroup trains are composed of a number of railway wagon groups that have to be classified according to the order of intermediate stations.

Formation of multigroup trains shortens the time needed for collection, and enables concentration of maneuvering operations to a smaller number of marshalling yards. This concentration of maneuvering operations leads to greater use of track capacities, maneuvering facilities and personnel, while also enabling rationalization of capacities and operating technology at intermediate and final stations where maneuvering is reduced to separation of vehicle groups that have already been formed.
Methods for simultaneous formation of multigroup trains are generally divided into methods for consecutive formation of trains, and methods for simultaneous formation of trains. According to consecutive formation methods, which are more frequently used in railways, the next train cannot be formed before formation of the previous train is completed. The distinguishing feature of simultaneous methods primarily lies in the fact that wagons are collected according to the order of appropriate intermediate stations i.e. according to vehicle groups belonging to intermediate stations of the same number for different trains, rather than according to trains.

This brings about the difference in the use of track capacities, and hence in the realization of the overall forming process. Simultaneous methods can greatly improve station operating parameters, as they enable simultaneous formation of several trains, which in turn enables their timely dispatch from marshalling yards and delivery of vehicles to their destinations. Application of simultaneous methods, in practice and everyday tasks requires appropriate adaptation of the timetable and professionally trained maneuver staff. Sensitivity to possible disturbances can be indicated as the major shortcoming and faults as well as their direct negative impact on the dispatch of trains.

### 8.2.1 Methods for consecutive forming of multigroup trains

In forming of multigroup trains (pick-up trains) may apply different methods, which differ according to the required number of shunting tracks and shunting mode. Which will be applied depends on the technical characteristics of marshalling stations and the number of intermediate stations. Thus, if the number of intermediate stations 4 or less than applied conventional shunting method which means that at every track, wagon allocate to each individual intermediate stations.

However, in the case, which is more common, applies some of methods for succession forming a multigroup trains. These methods are considered the train marshalling problem, which consists of disassembling the incoming accumulated composition wagons on a separate marshalling track (track for sorting) and reassembly (merging) group of wagons (cars) according to the plan for formatting multigroup train. Shunting is conducted in such a way that the cars with the same destinations (intermediate stations) occurring in succession, forming individual groups of cars, in the final formed multigroup train.

#### 8.2.1.1 Single-stage sorting method

Single stage sorting method, in addition to the initial disassembling operation (roll-in operation), allows only one more operation - the car accumulation according to the plan of formation the group of trains. Both processes are performed maneuver locomotive.

In a single stage sorting, required number of tracks for one train sorting is equal to the number of groups of cars i.e. the number of intermediate stations [15].

However, analyzes of the [16] have shown that the number of tracks for sorting does not depend on the number of intermediate stations, so that there are two important parameters:
- Number of accumulated composition cars of the train and
- The minimum number of cars from one of intermediate stations.

Let $S = \{S_1, ..., S_t\}$ be a partition of the set $I_n = \{1, 2, ..., n\}$. The numbers from $I_n$ correspond to cars of a train, while elements of $S$ correspond to intermediate stations. Thus, cars $a_i$, $a_j$ have the same destination if and only if the numbers $i$, $j$ belong to the same part of $S$. Now, the train marshalling problem (TMP) reads as follows: Find the smallest number $k = K(S)$ so that there is a permutation $\pi(1), ..., \pi(t)$ of $1, ..., t$ so that the sequence of numbers $1, 2, ..., n, 1, 2, ..., n, 1, 2, ..., n, 2, ..., n$, where the interval $1, 2, ..., n$ is repeated $k$ times, contains all the elements from $S\pi(1)$, followed by all the elements of $S\pi(2)$, ..., and finally all the elements of $S\pi(t)$. In this formulation the trivial bound becomes $K(S) \leq t$ [16].

This example is shown schematically as a rearrangement of railway cars in Fig 1.
D4.1 Identification of relevant information about train classification process and marshalling yard sorting methods

Thus, according to the authors, the best possible ways to determine the number of shunting track, in the event that the dispatcher has only information on the total number of cars, represents dependency:

\[
K(S) = \frac{n - 6}{4} + 2
\]

(8.1)

where is: \( n \) - the total number of incoming accumulated composition cars of the train

In the case of \( d(\sqrt{n} \text{ then } m)\sqrt{n} \) cannot get anything better than do \( K(S)=d \)

![Diagram](image.png)

Figure 8.1 The forming of single stage multigroup train [15]

8.2.1.2 Futhner’s method

Futhner’s method is based on marshalling system where on one track (marshalling track) performs classification of the cars - wagon for several different intermediate stations. The root of the number intermediate stations determines the required number of shunting track for two-step sorting procedure [17]:

\[
n_i = \sqrt{n_{is}}
\]

(8.2)

where is: \( n_i \) - the required number of shunting track, rounded to a whole number, \( n_{is} \) - number of intermediate stations. After determining the required number of shunting track, the procedure disassembling of accumulated cars is done in relation to the number of intermediate stations as follows:

- **In the first sorting phase**
  on the first track segregate cars for intermediate stations: \( 1, \sqrt{n_{is}} + 1, 2\sqrt{n_{is}} + 1, n_{is} - \sqrt{n_{is}} + 1 \)
  on the second track segregate cars for intermediate stations: \( 2, \sqrt{n_{is}} + 2, 2\sqrt{n_{is}} + 2, ... \)

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on $n_t$-th track segregate cars for intermediate stations: $\sqrt{n_{is}}, 2\sqrt{n_{is}}, ..., n_{is}$

Now the first phase of sorting is completed in which, on each track, segregate the group of cars for the same intermediate stations but not yet in a order that would correspond intermediate stations. With that, go to the second sorting phase.

- **In the second sorting phase**, after the unification of multigroup train (in order of increasing tracks number) sorting performs on the marshalling tracks in the order of intermediate stations [17].

  On the first track segregate cars for intermediate stations: $1, 2, 3, ..., \sqrt{n_{is}}$.
  On the second track segregate cars for intermediate stations: $\sqrt{n_{is}} + 1, \sqrt{n_{is}} + 2, \sqrt{n_{is}} + 3, ..., 2\sqrt{n_{is}}$.

  On the third track segregate cars for intermediate stations: $2\sqrt{n_{is}}, 2\sqrt{n_{is}} + 1, 2\sqrt{n_{is}} + 2, 2\sqrt{n_{is}} + 3, ..., 3\sqrt{n_{is}}$.

  On $n_t$-th track segregate cars for intermediate stations: $(\sqrt{n_{is}} - 1)\sqrt{n_{is}} - 1, ..., n_{is}$.

So, two important parameters for application Futhner’s method are:
- The number of intermediate stations on the basis of which is determined
- The number of shunting tracks

An example of the real system. - Let accumulated composition of 19 cars for 9 intermediate stations in order 5-3-3-4-8-7-2-1-1-9-6-9-2-2-4-7 (Figure 8.2) [18].

![Figure 8.2 Futhner’s method](image)

The first determines the required number of shunting track according to equation 1:

$$n_t = \sqrt{n_{is}} = \sqrt{9} = 3$$  \hspace{1cm} (8.3)

When the number of necessary tracks is determined $n_t = 3$ shunting is performed as follows:

I track: 1, 4, 7
II track: 2, 5, 8
III track: 3, 6, 9

After the first sorting, follow the second phase of sorting, according to accumulated composition from the first stage (first pulling groups from the first track, then the second and the third at the end of the track). Next, composition of the train is formed in order of intermediate stations.
8.2.1.3 General method

In contrast to the Futhner’s method which, at \( n_t \) tracks, can form a train which consists of \( n_t^x \) group of cars, the general method can form the train whose number of intermediate stations is the highest:

\[
n_{is} = \frac{n_t (n_t + 1)}{2}
\]

After determining the required number of shunting tracks, the procedure disassembling accumulated composition of cars is done on the basis of equality between the ordinal number of tracks in the group for forming and the number of groups that are segregated on track at the moment to begin the process of sorting cars [16].

Thus, in the first phase of the sorting

On the first track segregate cars for intermediate stations: \( 1, - \)

On the second track segregate cars for intermediate stations: \( 2, n_t + 1, - \)

On the third track segregate cars for intermediate stations: \( 3, n_t + 2, (2n_t - 1) + 1, - \)

... On \( n_t-\text{th} \) track segregate cars for intermediate stations: \( n_t, 2n_t - 1, 3n_t -(1+2), 4n_t -(1+2+3), ... \)

Next steps sorting do not have to implement by unified pulling and sorting of all cars from all tracks, but can be achieved with a series of extraction and sorting cars from individual tracks.

This characteristic can come to the fore with limited resources (insufficient length of pull out or insufficient power of maneuvering locomotives) [16].

Thus, in the second phase of the sorting

On the first track segregate cars for intermediate stations: \( 1, 2, 3, ..., n_t \)

On the second track segregate cars for intermediate stations: \( n_t + 1, ..., 2n_t - 1 \)

On the third track segregate cars for intermediate stations: \( (2n_t - 1) + 1, ..., 4n_t -(1+2+3) \)

... On \( n_t-\text{th} \) track segregate cars for intermediate stations: \( \frac{n_t (n_t + 1)}{2} \)

However, the negative characteristic of the general method is that at certain the number of tracks can sort a smaller number of groups in accordance with the Futhner’s method.

To make it easier to detect characteristics of these methods shows an example of forming multigroup trains that consists of 10 cars for intermediate stations (Figure 8.3). In the first step of sorting at the first track, segregate the car for intermediate stations 1, at the second track, cars for stations 2 and 5, at the third track, cars for stations 3, 6 and 8, at the fourth, cars for stations 4, 7, 9 and 10.

The second step of sorting can be realized pulling of unified cars or individual cars pulling from each tracks separately. At the end of the second step of sorting are obtained sorted cars, according to intermediate station, and that, at the first track cars for intermediate stations 1, 2, 3 and 4, at the second 5, 6 and 7, at the third 8 and 9, and at the fourth 10.

The process of forming multigroup trains train ends up assembling a car for tracks and their by dragging at track with which it is carried relegate [16].
D4.1 Identification of relevant information about train classification process and marshalling yard sorting methods

8.2.1.4 The special method

Special method is based on an arbitrary number of tracks, i.e. the number of tracks that is available for shunting. In contrast to the previous methods in the special methods, therefore, there is no correlation between number of intermediate stations and the number of shunting tracks. [19]

Forming of multigroup train after classification according the intermediate stations is carried out to the following procedure:

In the first stage of sorting, cars for intermediate stations $n_i$ to $n_i+n_t+2$ leave on separate tracks, and all the other cars together at first track. Then, the first assembly of cars on the tracks should be followed and unification from the first to the $n_t$-1 track, in order to prepare for the second stage of sorting.

At this stage all cars for intermediate stations from $n_i-1$ to $n_i+n_t+2$ are grouped according to the order of intermediate stations and are left on track $n_i$ where there are already cars for intermediate station $n_i$.

Groups of cars on track $n_i$ added cars for intermediate station $n_{i-1}+n_t+1$, and on the other tracks is carried out sorting in the following order: on track $n_t-1$ cars for intermediate station $n_{i-1}+n_t$, on track $n_t-2$ cars for intermediate station $n_{i-2}+n_t-1$ and so on, until the second track where coming cars for intermediate station $n_{i-2}+2n_t+3$.

Any remaining cars, for intermediate station $l$ to $n_i-2n_t+2$, leave to the first track. After this disassembling is carried out unification of cars per tracks from the first to the $n_t-1$ tracks and pull them in order to prepare for the third stage sorting which procedure is similar to the previously described procedures.

This process continues until are not sorted cars the first intermediate station [16] [20]. So, as an important parameter for the use of special methods, stand out the number intermediate station, which does not condition the required number of shunting track.
An example of the application of special methods is shown in Fig. 8.4 for the case of multigroup trains for 9 intermediate stations and 3 tracks for shunting.

Figure 8.4 Example of special methods [16]

Modification of special methods is achieved by eliminating the need for merging and uniting segregate group of cola, after the completion of each step of sorting. This switching operation of each next step further facilitates because of the smaller number of cars that need to move. Unifying composition cars segregate per tracks is done only after the last step of sorting thereby forming a composition for multigroup train, in the order of intermediate station. In the case of applying the modified special methods, in the same case, sorting 9 groups on 3 tracks is done in the following way. In the first step of sorting at the second and third track stand out cars for intermediate station 5 and 9, and all remaining cars accumulate on the first track. In the coming steps move is done only with unsorted cars accumulated on the first track. In these steps on the second and third track leave the cars whose serial number of intermediate station one less compared to those that have been separated in the previous steps on the tracks. The process of forming multigroup train by using special methods of modification is shown in Fig. 8.5 [16].
8.2.1.5 Method unified group

The parameter that characterizes the method of unified groups is a large number of groups to sort and insufficient number of tracks. This method is based on the implementation process of sorting a group of some of the previous method which is suitable for forming the train which has a half less intermediate station \(n_{i}/2\). Unifying the group is carried out by pairing the cars for: intermediate stations: \(1 \times n_{i}/2+1\), \(2 \times n_{i}/2+2\), \(3 \times n_{i}/2+3\) etc.

An example of application method of unified group is shown in Fig. 8.6 for the case of multigroup train for 18 intermediate stations and 3 tracks for shunting. In the first step the cars for intermediate stations 1, 4, 7, 10, 13 and 16 are left on the first track, the cars for intermediate stations 2, 5, 8, 11, 14 and 17, on the second, and cars for intermediate stations 3, 6, 9, 12, 15 and 18 on the third track.

The process of sorting cars continued by pulling all cars and forming a unified group for intermediate stations: on the first track is pairing the group 1 and 10, 2 and 11, 3 and 12, on the second track 4 and 13, 5 and 14, 6 and 15, and on the third track 7 and 16, 8 and 17, 9 and 18. In a further sorting procedure is necessary to once again pull out all cars and disassemble unified groups.

At the end of this step, the two sorted compositions are obtained, on the first track for the first nine and on the second, for the remaining nine intermediate stations. The process of forming multigroup train ends up by uniting these two compositions and pulling on a track which performs carried relegate [16].
8.2.1.6 The Japanese method

Technology deployment of the final assembly of trains using the Japanese method does not depend on the number of track structures which are composed of these stations but from track technical solutions, respectively, applied of track links, single successive track links (Figure 7a) or double successive track links (Figure 7b) [20].

These systems consist of three shunting tracks connected by a larger number of track links, usually simple or double track links. Furthermore, all these tracks must have a downward grade of 2.5‰ and must be equipped with track brakes, radars, and axle counters. The central delivery track is usually by 50 to 80 mm higher then the end tracks, so that wagons can easier move to end tracks, depending on their use. In marshalling or classification yards, such track solutions can be:

- With only one track structure on which the final sorting is operated for all trains,
- With several track structures, where the number of such structures corresponds to the number of feeder trains to be formed at a particular yard,
- With several track structures that is defined depending on the needs and expected effects [Ivic Track properties]. Here it is important that in each track group the central track assumes the role of delivery track, while two end tracks are used for wagon collection by intermediate stations. This is why both end tracks must have the number of parts that corresponds to the maximum number of intermediate stations at a distribution section for which feeder trains are formed (e.g. in Fig. 7, there are 10 parts at end tracks (5 on each track) on which feeder train forming is possible for ten intermediate stations). The method of wagon forming or wagon collection at sections, and by intermediate stations, depends on crossovers used:

  -- If simple crossovers are used, then the use of parts at end tracks must correspond to the order of intermediate stations (on one side 1, 2, ..., 5, and on the other 6, 7, ..., 10, or on the one side 1, 3, ..., 9, and on the other 2, 4, ..., 10);
  -- If double crossovers are used, then the use of parts at end tracks can be arbitrary.
This solution enables wagon sorting and grouping according to appropriate intermediate stations in a single classification effort, so that this phase is followed solely by grouping according to the order of intermediate stations. In the end, we could state that this solution is generally characterized by an increase in investment due to use of additional crossovers and track brakes, while on the other hand significant savings are made by shorter downtime of wagons.

Attached is given in Table 1. the name of methods, their parameters, the basic characteristics and advantages and disadvantages. Number of group cars on the formation and size of the wagons flow affects the process of sorting the car, which is particularly evident in terms of the large number of cars on the formation.

Figure 8.7 Track use during feeder train forming by Japanese method) for solution with simple crossovers; b) for solution with double crossovers [20]
### Comparative analysis consecutive methods for formation of multigroup trains

<table>
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<tr>
<th>Method name</th>
<th>Parameters for application</th>
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<td>With the increase the number of cars or a number of groups within the cars, increasing complexity of the problem, and the possibility of reducing the number of required tracks is reduced</td>
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<td>Special method</td>
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<td>the number of intermediate stations, the available number of shunting tracks</td>
<td>Shunting according to the available number of shunting tracks</td>
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</table>
8.2.2 Methods for simultaneous formation of multigroup trains

As opposed to the previous group method, simultaneous formation more of multigroup trains is enabled the simultaneous methods. Simultaneous formation of multigroup train starts in the process of disassembling. Wagons of multigroup trains accumulate on the tracks by a particular rule that is a function of the number of groups in trains. This is an important difference compared to conventional methods where is the number of tracks for the accumulation in function of the number of trains.

8.2.2.1 Elementary method

The elementary simultaneous method consists of two phases. In the first phase, wagons are collected according to intermediate stations. Wagons collection is performed in such a way that wagons for all first, subsequent and all other intermediate stations are brought to tracks previously determined for each intermediate station, despite the fact that wagons belong to different trains. The theoretical minimum number of tracks for collection \( n_k \) is equal to the maximum number of intermediate stations \( g_{\text{max}} \) in some of train for forming \( (1) \). The rule for collection of groups of wagons \( g_j \) \((j=1,\ldots, g_{\text{max}})\) by track is given in the expression \( (2) \), according \([21]\), where \( g_k \) is the number of intermediate stations for trains from which wagons are gathered at the track \( k \):

\[
\begin{align*}
  n_k &= g_{\text{max}} \\
  g_k &= g_j, \quad k=1,\ldots,g_{\text{max}}
\end{align*}
\]

(8.5)

(8.6)

After completion of collection phase, start the second phase (formation phase) in which wagons are moved from collection tracks, and are grouped according to the corresponding trains (Figure 8.8).

This method enables formation of a great number of multigroup trains with a minimum scope of maneuvering work (number of moves is equal for all groups and amounts to precisely one move per vehicle \( h=1 \)) and the number of wagons moved, i.e. of wagons which were used in the multigroup train forming process, corresponds to the total number of wagons in all trains.
8.2.2.2 Triangular method

This method also consists of two phases. Wagons are gathered together in the first phase, and are sorted in the second phase, first partly sorted (at wagon collection tracks) according to intermediate stations, and second partly (at train forming tracks) according to trains they belong to, and according to the order of intermediate stations (Figure 8.9).
D4.1 Identification of relevant information about train classification process and marshalling yard sorting methods

Figure 8.9 Triangular method for simultaneous formation of multigroup trains [22]

The connection between the maximum number of intermediate stations in a train ($g_{\text{max}}$) and the required number of wagon collection tracks ($n_k$) is shown in the expression (3) [23]:

$$n_k = \begin{cases} \sqrt{2g_{\text{max}}} - \frac{1}{2}, & \sqrt{2g_{\text{max}}} - \frac{1}{2} \in N \\ \sqrt{2g_{\text{max}}} - \frac{1}{2}, & \sqrt{2g_{\text{max}}} - \frac{1}{2} \notin N \end{cases}$$  \hspace{1cm} (8.7)

The rule for collecting wagon groups $g_j$ ($j = 1, ..., g_{\text{max}}$) at intermediate stations and tracks $k$ is given in the expression (4), where wagons for intermediate stations are collected at track $k$ at point $i$ [24]:

$$g_{k,j} = \frac{k(k-1)}{2} + ik + 1 + \frac{(i-1)(i-2)}{2}, \quad k = 1, ..., n_k, \quad i = 1, 2, 3, 4, ...$$  \hspace{1cm} (8.8)

Unlike the elementary method, in case of triangular forming, wagons for more than one intermediate station are collected at a single track. This calls for a more complex classification plan, and hence a greater scope of maneuvering operations, such as the number of pullout operations per wagon or the number of wagons moved. The number of pullout operations is two for all wagons belonging to the same intermediate
station, except for wagons (4a) which represent the so-called "frontal groups" at tracks \( k \) and are pulled out once (\( h=1 \)) [23]. In practice, this means that these wagons pass through the forming process in the same way as in the elementary simultaneous method. As to the number of wagons moved, with which the multigroup train forming process was accomplished, it is greater than the total number of wagons in all trains, as up to two pullout operations are made with some trains [22].

\[
g_{k,1} = \frac{k(k-1)}{2} + 1
\]  

(8.9)

8.2.2.3 Geometrical method

The geometrical classification constitutes a further advance in the development of simultaneous methods. In fact, an additional reduction in the number of tracks needed for train forming operations has been achieved by using this method (Figure 8.10).

The connection between the maximum number of intermediate stations in a train (\( g_{\text{max}} \)) and the required number of shunting tracks (\( n_k \)) where wagons are collected and sorted according to groups belonging to the same intermediate station, is given in the relation (8.10), while the general principle for collecting wagons at tracks is given in the relation (8.11) [24].

\[
n_k = \begin{cases} 
\log_2(g_{\text{max}} + 1), & \log_2(g_{\text{max}} + 1) \in \mathbb{N} \\
\frac{\log_2(g_{\text{max}} + 1)}{2}, & \log_2(g_{\text{max}} + 1) \notin \mathbb{N}
\end{cases}
\]

(8.10)

\[
g_{k,j} = 2^{k-1} + 2^k (i-1), \; k = 1, \ldots, n_k, \; i = 1, 2, 3, 4, \ldots
\]

(8.11)

The reduction in the number of tracks according to this method leads however to an increase in the scope of maneuvering operations, with respect to both the pullout operations and the number of wagons moved. The number of wagon pullout operations is dependent on the number assigned to the intermediate station the wagons belong to, and may amount to no more than \( h = \lceil \log_2 g \rceil \). Just like in triangular method, the "frontal groups" have the lowest number of pullout operations, as wagons are pulled out only once (\( h=1 \)). Unlike the triangular method, the number of pullout operations for other groups is not limited to a particular value, but rather varies with the change of intermediate stations for a train. In case of geometrical classification, the frontal track group \( k \) is the group \( g_{k,1} = 2^{k-1} \).
Figure 8.10 Geometrical method for simultaneous formation of multigroup trains [22]
8.3 The analysis of methods and parameters for simultaneous formation of multigroup train

The characteristic of these methods is the simultaneous formation of more trains, which began in the dissolution process. The first phase of wagon collection according to intermediate stations, and the first part of the second phase of wagon classification according to intermediate stations, take place at tracks of the marshalling or marshalling departure park, while the second part of the second phase ie wagon sorting phase according to trains and intermediate stations can be operated for all methods on tracks of the marshalling or marshalling-departure park, and for elementary method even on tracks of the departure park.

During the common collection of multigroup trains number of tracks depends on the maximum number of intermediate stations of one train and made a superb sorting plan of wagons. There are two options, ie. the formation of multigroup trains with a simple sorting plan that requires the engagement of a large number of tracks or complex sorting plan by engaging a smaller number of tracks. The possibility of application simultaneous method should be assessed according to their basic characteristics ie each method has its own characteristics in terms of the necessary number of tracks and the quality of the work station. Elementary method allows the formation of trains separating wagons for intermediate stations on separate tracks, after which it is enough to sort wagons belonging to the trains. Geometric methods engaging the smallest number of tracks by applying the most complex sorting plan. Unlike the previous two methods, triangular method applies a different sort plan complexity and limits the maneuver work on two movement per wagon during sorting.

In order to implement the method for the formation of multigroup train in practice it is necessary to analyze the technical and technological conditions maneuver work in the station. The very process of forming trains requires engagement of appropriate station facility and maneuvering capacity, in conjunction with the appropriate organization and technology of work. Practical application of methods for multigroup train formation depends on the choice of station facility, maneuvering capacity and technology work. For the realization of the above methods is necessary to define the technical conditions i.e. necessary tracks group for and type of the processing facilities, the required number and length of tracks, applied connection within the group of track, links between the tracks groups and of the processing facility and the required technical and operational characteristics of shunting locomotives to operate on processing. Besides the technical equipment it is necessary to analyze and technological conditions relating to the interdependence of the activities and operations during the accumulation wagons and the formation of trains, order of execution and norming the time of their realization.

The shape and capacity of track facilities for the accumulation and sorting wagons is differs depending on the applied method. While the accumulation of wagons for the multigroup trains can be done on tracks of the marshalling or marshalling departure park for dismantling incoming trains in order to accumulate wagons are used hump, very rare pullout track, while for sorting wagons during the formation can be used hump, or pullout track or modified hump.

Simultaneous methods require two groups of shunting tracks:

- group for collecting and sorting vehicles according to intermediate stations and
- group for sorting vehicles according to trains and intermediate stations.

Technical and operational characteristics of shunting locomotives affect on possibility and effects of the application a particular method for the formation of multigroup train. When using the method for simultaneous formation of multigroup trains, shunting locomotive must allow extraction maneuvering composition from track with the accumulated wagons and pushing them on the hump. The total mass of accumulated wagons on one track must not exceed the maximum permitted mass of the composition according to the criteria of movement also and to the criteria by starting from the beginning of maneuvering composition.

In applying the methods for succession formation of multigroup trains primarily used pullout track. Technology work on pullout track in the formation of multigroup train depends on the applied method for forming of multigroup trains, the number of intermediate stations, the size of composition and technical requirements for successive formation of multigroup trains.
It can be concluded, by comparing methods for simultaneously forming, that sorting time of wagons using the geometric and the triangular method lower in terms of small scale work and a large number of intermediate stations. The elementary method features a smaller train forming time under conditions characterized by a greater number of wagons. If we compare triangular method with geometrical method, we can see that the triangular method is more advantageous in that it is less dependent on the number of intermediate stations.

According to elementary method, trains are formed in such a way that all wagons are moved only once in the course of the sorting process. In geometrical method, the number of movements per vehicle generally increases with an increase in the number of intermediate stations which exceed two movements (applicable to more than 15 groups) [22]. Something more moderate increase which does not exceed two movements per wagon in the sorting process has triangular method.

The elementary simultaneous method features the best total effects with regard to formation of trains composed of smaller number of groups with a great quantity of wagons. Triangular and geometrical forming requires a similar number of tracks, but the total track lengths are greater when geometrical method is applied. These methods have differed considerably with regard to quality of service rendered, especially under conditions characterized by a great number of wagons at the forming stage. At the end of this section are given comparative analysis methods for simultaneous formation of multigroup train.
### Table 8.2 Comparative analysis methods for simultaneous formation of multigroup train

<table>
<thead>
<tr>
<th>Method name</th>
<th>Parameters for application</th>
<th>Basic characteristics</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Elementary</strong></td>
<td>The number of tracks for collecting</td>
<td>Wagons accumulation to the intermediate stations and the dismantling of incoming trains. Pull wagons with tracks for the accumulation and sorting according to the corresponding trains</td>
<td>The formation of a large number of multigroup trains with the minimum amount of maneuvering work. The simplest plan sorting wagon.</td>
<td>Engagement a large number of tracks.</td>
</tr>
<tr>
<td></td>
<td>The number of intermediate stations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Triangular</strong></td>
<td>The number of tracks for collecting</td>
<td>On the one track are accumulated wagons for a few intermediate stations.</td>
<td>Engagement a smallest number of tracks.</td>
<td>The more complex sorting plan (increase in the volume of maneuvering work).</td>
</tr>
<tr>
<td></td>
<td>The number of intermediate stations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Geometrical</strong></td>
<td>The number of tracks for collecting</td>
<td>Number of pull out the other wagons groups is not limited to a single value, and he is changes with the number of stations in the train.</td>
<td>Reducing the required number of tracks for the process of formation trains. Increasing the volume of maneuvering work.</td>
<td>The mathematical complexity of the method.</td>
</tr>
<tr>
<td></td>
<td>The number of intermediate stations</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
8.4 Using heuristic approach for simultaneous formation of multigroup train

Combinatorial optimization problems are generally NP-hard problems, and therefore the execution times of algorithms, which find the optimal solution, unacceptably long [26]. Therefore, to solve these problems are used heuristics. Under heuristics means techniques for solving problems by which are required a good solution for a relatively short time. Heuristics does not give any information about how is obtained solution close to the optimal solution of problem. The aim of user is that with heuristics quickly come up to the solution which is good "enough" for the problem which is being solved. Heuristics are widely used for solving optimization problems, especially for large instances. Heuristics applied to the problems of large size in a short time give good solutions, which are often optimal although optimality can not be proven.

Heuristics can be classified in several ways. They are mainly divided into: heuristics based on improving one solution and heuristics based on improving the population solutions. User of heuristics based on improving one solution works exclusively with one permissible solution, while user of heuristics based on improving the population solutions works with a set of permissible solution that seeks to improve.

Example of heuristics based on improving one solution is local search (Figure 8.11).

Methods of local search troubleshooting start with positioning in an initial permissible solution $x_0$, which by iterative steps seeks to improve the limited search into smaller parts area $K$. In each step, is carried out search for a specific environment of permissible solutions $N(x)$, for which applies $N(x) \subseteq X$ and in which $x$ is called the initial solution. Iterative search environment is carried out according to predefined rules of selection the starting solution, forming adjacent solutions and stopping local search.

![Local search LS ($x_0$)]

1. Initialization: Generate initial solution $x_0$ and identify $f(x_0)$;
   Define the condition of stopping
2. $x^* \leftarrow x_0$ and $f^* \leftarrow f(x_0)$
3. Repeat the cycle of local search:
   a. $x \leftarrow x^*$
      $n \leftarrow 0$
4. Repeat the cycle for search environments:
   $n \leftarrow n + 1$
5. 1) Selection neighbors:
    In environment $N(x)$ find a adjacent solution $x'$
6. 2) Check solution:
    If $f(x') < f^*$ then $x^* \leftarrow x'$ and $f^* \leftarrow f(x')$
7. 3) The selection of the starting solution for the next iteration:
    Determine whether the $x \leftarrow x'$
8. Until fulfilling the stopping condition
9. While there is improvement

Figure 8.11 The principle of local search [22]

When it comes to the problem of simultaneous formation of multigroup train, initial solution can be randomly generated by assigning numerical values of arbitrary binary input sorting for each individual
wagon from flow wagons or can be obtained on the basis of the traditional method for simultaneous formation of multigroup train [22]. The solution obtained elementary, triangular or geometric method is subsequently adjusted according to the technical and technological conditions and as such becomes the initial solution of search. Higher quality initial solution can be achieved if on the basis of applied sorting plan some of traditional methods simultaneously performs verification the fulfillment of technical and technological requirements.

Efficiency of local search method depends on the manner and number of defined environments. Environment is needed such defined that provide intensive search directed to finding how better solutions also and arbitrary choice of solutions targeting larger search space \( X \). In order to avoid the main problem method of local search i.e. search time of one big environment is carried out introducing a larger number of smaller environments \( N_k(x) \), \( k=1,...,k_{\text{max}} \). For the purpose of solving the problem of simultaneous formation of multigroup train may be used the following transformations in creating solutions adjacent environment \( N_k(x) \):

- \( k=1 \) (basic change): Changing the value of the binary records of sorting just only one selected wagon,
- \( k=2 \) (group change): Changing the value of the binary record of sorting the selected wagon and all subsequent wagon of flow wagons which have the same value of binary record,
- \( k=3 \) (block change): Changing the value of the binary record of sorting the selected wagon and all subsequent wagon of flow wagons which belong to the same block sorting,
- \( k=4 \) (arbitrary change): Changing the value of the binary record of sorting the selected wagon and an arbitrary number of subsequent wagon of flow wagons and
- \( k=5 \) (complete change): Changing the value of the binary record of sorting the selected wagon and all subsequent wagon of flow wagons.

The aim of the previously mentioned transformation is to generate adjacent solution and after that it is necessary to define the approach to search environmental solutions and mechanism of choice new starting solutions \( x \).

There are two approaches to generating adjacent solutions. First deterministic approach is implemented complete search environment and in the case of solving the problem of simultaneous formation of multigroup train are generated systematic changes sequences values of binary record sorting.

The second stochastic approach generating adjacent solutions is optionally in the context of the observed environment and limiting the number of adjacent sequences values of binary record sorting that will be generated. The simplest mechanism for selection of the starting solution \( x \) is random picking within the meaning an arbitrary decision whether to adjacent chosen solution become the new starting solution.

The selection mechanism of a new solution \( x \) can be improved if the selection is based on the quality of the obtained adjacent solutions. Depending on whether it solves the problem of operational, tactical or strategic planning simultaneous formation of multigroup trains, quality solutions can be expressed through the value of the appropriate objective function. One of the principal mechanisms which are based on the measurement values of the objective function is a mechanism the method of Iterative Improvement. This method only allows replacement of the starting solution neighbors who are "better" in terms of the value of the objective function [22]. Two forms of iterative improvements can be distinguished: Best Improvement and First Improvement. The basic disadvantage of these forms is the inability to overcome the local minimum that can be reached using only the steps that lead to a better solution.

The least efficient and simplest approach to overcome local minimums is if repeated iterative process improvements using arbitrarily generated initial solutions (Multistart Iterative Improvement). The
second approach is correcting mechanisms in a way that in certain cases allow to solutions with "worse" value of the objective function becomes the starting solutions of local searches. The third approach is the application of a large number of environments for the search space. This approach has been thoroughly developed and systematized using deterministic, stochastic or mixed forms of searching in the framework of method environments variables (VNS - Variable Neighborhood Search), which are defined and then applied for solving various combinatorial problems. Based on the conducted research the best results has shown the general method of variable environments (GVNS – General Variable Neighborhood Search). GVNS method is a combination of deterministic and stochastic method forms of variable environments (Figure 8.12).

<table>
<thead>
<tr>
<th>General VNS method</th>
<th>GVNS ((x_0))</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Initialization:</strong></td>
<td>Generate initial solution (x_0) and identify (f(x_0));</td>
</tr>
<tr>
<td></td>
<td>(x^* \leftarrow x_0) and (f^* \leftarrow (x_0))</td>
</tr>
<tr>
<td></td>
<td>(x \leftarrow x_0)</td>
</tr>
<tr>
<td><strong>Repeat the cycle of GVNS search:</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(l \leftarrow l)</td>
</tr>
<tr>
<td></td>
<td><strong># Stochastic form of VNS method</strong></td>
</tr>
<tr>
<td><strong>Repeat the cycle changes of starting solution (x):</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Choosing adjacent solution (x') from (N_l(x)) environment</td>
</tr>
<tr>
<td></td>
<td>(x \leftarrow x')</td>
</tr>
<tr>
<td></td>
<td><strong># Deterministic form of VNS method</strong></td>
</tr>
<tr>
<td></td>
<td>(k \leftarrow l)</td>
</tr>
<tr>
<td><strong>Repeat the cycle for search (N_k(x)) environment:</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>In environment (N_k(x)) find local suboptimal (x^*_k)</td>
</tr>
<tr>
<td></td>
<td><strong># Check solution</strong></td>
</tr>
<tr>
<td></td>
<td>If (f(x^<em>_k) &lt; f^</em>);</td>
</tr>
<tr>
<td></td>
<td>(x^* \leftarrow x^<em>_k) and (f^</em> \leftarrow f(x^*_k))</td>
</tr>
<tr>
<td></td>
<td>(x \leftarrow x^*)</td>
</tr>
<tr>
<td></td>
<td>(k \leftarrow l) and (l \leftarrow l)</td>
</tr>
<tr>
<td></td>
<td>otherwise: (k \leftarrow k+1)</td>
</tr>
<tr>
<td></td>
<td>while (k \leq k_{\text{max}})</td>
</tr>
<tr>
<td></td>
<td>(l \leftarrow l+1)</td>
</tr>
<tr>
<td></td>
<td>while (l \leq l_{\text{max}})</td>
</tr>
<tr>
<td></td>
<td>While there is improvement</td>
</tr>
</tbody>
</table>

**Figure 8.12 General Variable Neighborhood Search method [22]**

While solving the problem of simultaneous formation of multigroup train deterministic form performed systematic searches of smaller environments \(N_k(x), k=1,..., k_{\text{max}}\) and within them find the "best" strings values of binary record \(x_k^*\). In contrast to deterministic, stochastic form arbitrary changes in the value of the binary record at the level of wider environments \(N_l(x), l=1,..., l_{\text{max}}\) done the scrolling of the starting solution \(x\) in which environment will be repeated systematic searches. In the case of new local improvements record sorting wagon \(x_k^*\), the procedure returns to the beginning, and for question about internal search environments \(N_k(x)\) and for question about change starting solutions in the external environments \(N_l(x)\). This process allows an intensive search environment of "good" solutions, but also arbitrary environment in the space X. GVNS method stops after a failed systematic search of all the environments arbitrarily obtained centers search [22]. Most of the real problems of simultaneous formation of multigroup train can not be solved optimally in terms of limited time and memory of work the computer and it is necessary to examine the possibility of applying heuristic method for finding optimal solutions.
8.5 Conclusion

Multigroup trains increasingly gaining in importance for use in remote transport segment. They combine the profitability of rail transport in greater distances and flexibility transport of individual wagons consignments. From the aspect of the organization and management of transport of individual consignments, the biggest problem is the optimization of wagon flows and method of forming of multigroup train. The formation of multigroup train reduces the retention wagons due to accumulation, and therefore the total spent time of wagons in technical freight stations.

The formation of multigroup train can be done using conventional or the simultaneous methods. Classical methods in current practice frequently used and characterized by individual formation of trains. By these methods, the process of accumulation wagons fully separated from their sorting. The first wagons accumulate especially towards marshalling tasks multigroup train of forming plan, and then for each individual task shunting wagons are sorted according intermediate stations.

The required number of tracks to accumulation of wagons for all the classic method is the same and depends on the number of shunting tasks, while the number of tracks on which it is subsequently sorted wagons vary in relation to the applied method of forming and depending on the number of intermediate stations per trains. The main disadvantage of these methods can be seen in direct dependence of the total time of forming the number multigroup train, which restricts and precludes their effective use in case of a large number of trains.

Simultaneous method of forming multigroup train characterized by simultaneously formation of more multigroup trains, and can be realized by simple plan sorting wagons by hiring a larger number of tracks or a complex plan sort by hiring a small number of tracks. It is possible to form multigroup trains by methods of varying complexity sorting plan. Each simultaneous method has its own characteristics in terms of needed track capacity, and the possibility of applying the method should be assessed according to their basic characteristics.

The research conducted showed that limitations from the point of exploitation and the design of shunting installations greatly affect and change the final effects of the methods applied in relation to the theoretical formulations. Based on the results obtained through research can be given a unique response which method is most appropriate.

In Table 8.1 and Table 8.2 methods, their parameters, the basic characteristics and advantages and disadvantages are given. Number of group wagons on the formation and size of the wagons flow affects the process of sorting the wagons, which is particularly evident in terms of the large number of wagons on the formation.
9. CONCLUSION

In this deliverable D4.1, initial relevant information about train classification process and marshalling yard sorting methods are given. This Deliverable D4.1 is the first result of activities from WP 4 and presents the background for the second deliverable at the end of WP4 – D4.2 where detailed specification and list of requirements for real time marshalling yard management system will be given.

In the document, two important issues are presented and analyzed. One is analysis of the real marshalling yard and the second one is state of the art for marshalling yard sorting methods. The both issues are inevitable for good optimization of planning operations and managing of every marshalling yard in Europe.

Analysis of two selected real marshalling yards is done. There are specific reasons for selection Marshalling Yard Niš and Marshalling Yard Karnobat, explained in Chapter 3. Such a selection of real marshalling yards provides enough historical and real time data for analysis, specification, design, testing and implementation of real time marshaling yard management system to be built.

Two types of methods for formation of multigroup trains are described and analyzed. The first is analysis of methods for consecutive forming of multigroup trains and after that analysis of methods for simultaneous formation of multigroup trains is done. Comparative analysis is given for both groups of methods and short overview of heuristic approach for simultaneous formation of multigroup trains as an introductory of future SMART project work in that field. Finally, there are some conclusions for marshalling yard sorting methods analysis.
D4.1 - Identification of relevant information about train classification process and marshalling yard sorting methods

REFERENCE


[12] Internal documents of Marshaling yard Niš


