Rail to Digital automated up to autonomous train operation

D48.3 – Self-Driving Freight Wagon (SDFW) conceptual studies: use case list and concept definition

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EXECUTIVE SUMMARY

The present document constitutes the Deliverable D48.3 "Self-Driving Freight Wagon (**SDFW**) conceptual studies: use case list and concept definition" in the framework of the Task 48.3 of the WP48 contributing to the TE12 "Self-Driving Freight Wagons" of FP2-R2DATO. Since the work covered conceptual studies of the **SDFW** concept, with the aim of defining the **SDFW** concept, TRL3 is reached at this stage, as committed.

This deliverable presents a state of the art and defines use cases and an operational concept for the **SDFW.** The connection of the **SDFW** to TMS / YMS with the activities of the work packages related to Automation Processes, the activity of Self-Propelled Freight Wagon in Destination 5 and the TMS/YMS activities in Destination 1 is also considered. It also defined the **SDFW** concept description including by means of an architecture and different incremental **SDFW** types which enables to carry out a preliminary OPEX and CAPEX.

This deliverable, "D48.3 – Self-Driving Freight Wagon (**SDFW**) conceptual studies: use case list and concept definition" identifies and explores several use cases where the **SDFW** contributes. Among the most significant are autonomous yard operations (SS: Self Shunting), which allow **SDFWs** to operate within yard environments autonomously, thereby reducing the need for manual shunting operations and the need of shunting locomotives. Additionally, the deployment of **SDFWs** in an operation line (SD: Self-Driving) offers increased flexibility and reliability for freight services. By operating independently, **SDFWs** can reduce the number of main line locomotives. The complete list of the use cases is shown as follows:

Figure 1: SDFW updated use cases list

From the analysis done to FP1-MOTIONAL [4] and FP5-TRANS4M-R [5] the following topics related to **SDFW** have been found which contribute to the building blocks of the **SDFW** and the infrastructure elements to which the **SDFW** interacts.

- **FP1-MOTIONAL:** The management on the line of a **SDFW** by a TMS is considered to be similar to the operation a train equipped with ATO. However, yard operation on a **SDFW** will vary current procedures. FP1-MOTIONAL also covers Yard operations by introducing the **Yard Control System** (YCS), which is referred (WP10, WP11 and WP12). The YCS relates to the processes of the yard and its management and shall be linked to the **SDFW**.
- **FP5-TRANS4M-R:** The FDFTO includes elements that shall be considered in the **SDFW** architecture, on one hand, the Full Digital Freight Train with the DAC and the ASO /WP3, WP5 and WP12) to be integrated in a freight train and operated by the YCS, and on the other the Self-Propelled Freight Wagon elements to enable the movement of the wagon (WP22 and WP23).

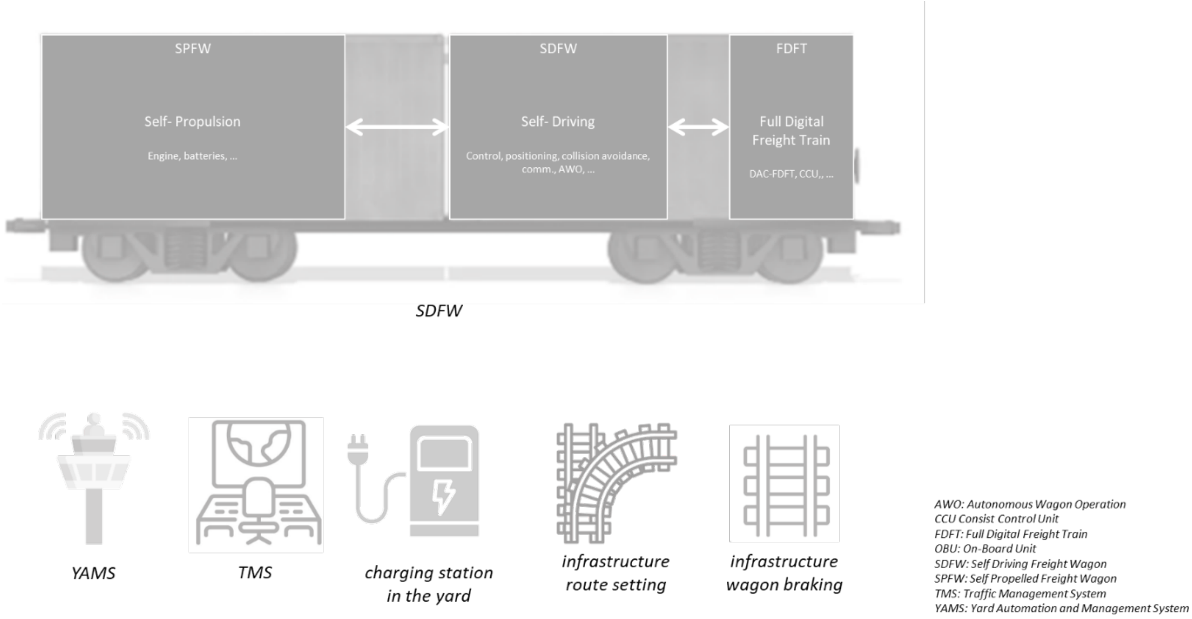

Figure 2: SDFW architecture and infrastructure elements

Five different evolutive types of the **SDFW** have been defined depending on the elements of the architecture and the application on the use cases of the **SDFW**.

Type 1	Type 2	Type 3	Type 4	Type 5
autonomous operations (movement) only in yards (SS), commanded by the YMS (yard) and within a yard that ensures the safety of the operation (avoids collisions and commands the emergency brake). For the last mile (<50 km) and operational line (>50 km) it operates within a consist.	autonomous operations (movement) only in yards (SS), commanded by the YMS (yard) and the own SDFW ensures the safety of the operation (avoids collisions and commands the emergency brake). For the last mile (<50 km) and operational line (>50 km) it operates within a consist.	autonomous operations (movement) only in yards (SS), and last mile (<50 km), commanded by the YMS (yard) and TMS (last mile), and the own SDFW ensures the safety of the operation (avoids collisions and commands the emergency brake). For the operational line (>50 km) it operates within a consist.	autonomous operations (movement) in yards (SS), Last Mile (<50 km), and operational line (>50 km), commanded by the YMS (yard) and TMS (last mile and operational line), and the own SDFW ensures the safety of the operation (avoids collisions and commands the emergency brake) in the yard and the last mile, and the ETCS (ATP) in the operational line.	autonomous operations (movement) in yards (SS), last mile (<50 km), and operational line (>50 km), commanded by the YMS (yard) and TMS (last mile and operational line), and the own SDFW ensures the safety of the operation (avoids collisions and commands the emergency brake) in the yard and the last mile, and the VCTS in the operational line.

Table 1: SDFW types definition

After the analysis it can be stated that the reference use cases SS1 forming train yards: **SDFW** moves to the track where the target train composition in order to couple to corresponding wagon of the train composition with type 1 and 2 **SDFW** and SD: autonomous operations into the operational line with type 3 **SDFW** shall be the more promising cases.

<table>
<tr><th colspan="2">Use case</th><th>SDFW Type</th><th>OPEX</th><th>CAPEX</th></tr>
<tr><td rowspan="2">SS: autonomous operations into the yard/terminal, it also includes last mile operation</td><td rowspan="2">SS1 forming train yards: SDFW moves to the track where the target train composition in order to couple to corresponding wagon of the train composition.</td><td>1</td><td>1st</td><td>1st</td></tr>
<tr><td>2</td><td>1st</td><td>1st</td></tr>
<tr><td>SD: autonomous operations into the operational line</td><td>SD2 transport regional line: SDFW travels in the regional line.</td><td>3</td><td>2nd</td><td>2nd</td></tr>
</table>

Table 2: SDFW reference use cases, SDFW types, CAPEX and OPEX summary

To sum up the document describes and defined the SDFW and emphasizes the importance of integrating SDFWs with existing Traffic Management Systems (TMS) and Yard Management Systems (YMS) to optimize scheduling and routing, ensuring seamless operations across various rail networks and yards. To achieve these objectives future work is required to further develop the SDFW concept. The three highlights are listed as follows:

- initiating pilot projects in selected yards and regional lines to validate the operational capabilities and benefits of SDFWs. These pilots will provide essential insights into the technical and logistical challenges that need to be addressed.
- standardization efforts to facilitate widespread adoption, including the development of standardized communication protocols and safety regulations for autonomous freight operations.
- continued research and development are also essential to enhance battery efficiency and obstacle detection systems, ensuring effective operation in diverse environments.

By focusing on these critical use cases and recommendations, this deliverable aims to pave the way for the successful integration of autonomous technologies in the rail freight sector, contributing significantly to the EU's sustainability and efficiency goals.

ABBREVIATIONS AND ACRONYMS

ADAS	Advanced Driver Assistance Systems
ANTS	Automated Nano Transport System
ARMG	Automated Rail Mounted Gantry Cranes
ASC	Automated Stacked Crane
AShC	Automated Shuttle Carriers
ASO	Automatic Shunting Operation
ATO	Automatic Train Operation
ATO-OB	Automatic Train Control – On board
ATO-TS	Automatic Train Control – Track side
ATP	Automatic Train Protection
B2B	Business to Business
CBA	Cost Benefit Analysis
C-DAS	Connected DAS
CAPEX	Capital Expenditure
CEO	Chief Executive Officer
CPU	Central Processing Unit
DAC	Digital Automatic Coupler
DAS	Driver Advisory System
EDDP	European DAC Delivery Programme
ERTMS	European Railway Traffic Management System
ETCS	European Train Control System
FDFTO	Full Digital Freight Train Operation
GNSS	Global Navigation Satellite System
GoA	Grade of Automation
GSM-R	Global System for Mobile Communications-Rail
HAZMAT	Hazardous Materials
HMI	Human Machine Interface
IVG	Intelligent Video Gates
JU	Joint Undertaking
LCC	Life Cycle Cost
LDCT	Lille Dourges Conteneur Terminal
OCR	Optical Character Recognition

OPEX	Operational Expenditure
PLC	Programmable Logic Controller
R2DATO	Rail to Digital automated up to autonomous train operation
R&I	Research and Innovation
RL	Relative Location
RS	Reach Stacker
RTG	Rubber-Tired Gantry Crane
SD	Self Driving
SDFW	Self Driving Freight Wagon
SERA	Single European Railway Area
SPE	Single Pair Ethernet
SPFW	Self Propelled Freight Wagon
SERA	Single European Railway Area
SP	System Pillar
SPFW	Self Propelled Freight Wagon
SRC	Short Range Communication
SS	Self Shunting
TE	Technical Enabler
TEU	Twenty-foot Equivalent Unit
TMS	Traffic Management System
TOS	Terminal Operation System
TRL	Technology Readiness Level
TTR	Timetable and Capacity Redesign
UX	User Experience
YAMS	Yard Autonomous Management System
YMS	Yard Management System
YCS	Yard Control System
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
VCTS	Virtually Coupled Train Set
WP	Work Package
WS	Work Streams

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1 INTRODUCTION

The present document constitutes the Deliverable D48.3 “Self-Driving Freight Wagon (**SDFW**) conceptual studies: use case list and concept definition” in the framework of the Task 48.3 of the WP48 contributing to the TE12 “Self-Driving Freight Wagons” of FP2-R2DATO. Since the work covered conceptual studies of the **SDFW** concept, no TRL is assigned at this stage.

This deliverable aims to define use cases and an operational concept for the **SDFW**, and connection of the **SDFW** to TMS / YMS in close collaboration with the activities of the work packages related to Automation Processes, the activity of Self-Propelled Freight Wagon in Destination 5 and the TMS/YMS activities in Destination 1. Moreover, it focuses on the conceptualisation of the **SDFW** looking at making use of the Short Range Communication (SRC) and Relative Localisation (RL) technologies developed in WP48 of FP2-R2DATO. For that, the following topics are foreseen:

- Study of prototypes already developed. -> *state of art from what it exists currently (chapter 2)*
- Initial list of use cases for **SDFW** analysing the extension to the use case of an inspection vehicle. -> *initial list of use cases (Chapter 3 section 3.1)*
- Update and review of use cases for **SDFW**, based on the initial list and validated e.g. by means of interviews of freight experts on this subject. -> *updated list of use cases (Chapter 3 section 3.2)*
- Operational concept description including the link to TMS/YMS defined in destination 1. -> *link to MOTIONAL (FP1) (Chapter 4 section 4.1)*
- Analysis of the integration with the vehicle concept for the SPFW from Destination 5. -> *link to TRANS4M-R (FP5) (Chapter 4 section 4.2)*
- Estimation of necessary investments -> *first approach for the Business Case including CAPEX and OPEX. (Chapter 5)*

In this context the content of the deliverables is structured as follows (Figure 3):

Executive Summary

1. Introduction
2. State of art
   - 2.1 Research projects
   - 2.2 Prototypes already developed
3. Use cases
   - 3.1 Initial list of use cases
   - 3.2 Update and review of use cases for **SDFW**, based on the initial list and validated e.g. by means of interviews of freight experts on this subject.
4. Relation to MOTIONAL and TRANS4M-R
   - 4.1 Operational concept description including the link to TMS/YMS defined in destination 1.
   - 4.2 Analysis of the integration with the vehicle concept for the **SDFW** from destination 5.

5. First approach to Business Case
5.1 **SDFW** types definition, architecture and operation
5.2 Approach to business case
6 Conclusions
7 Future work
References

Table 3: Structure of the deliverable

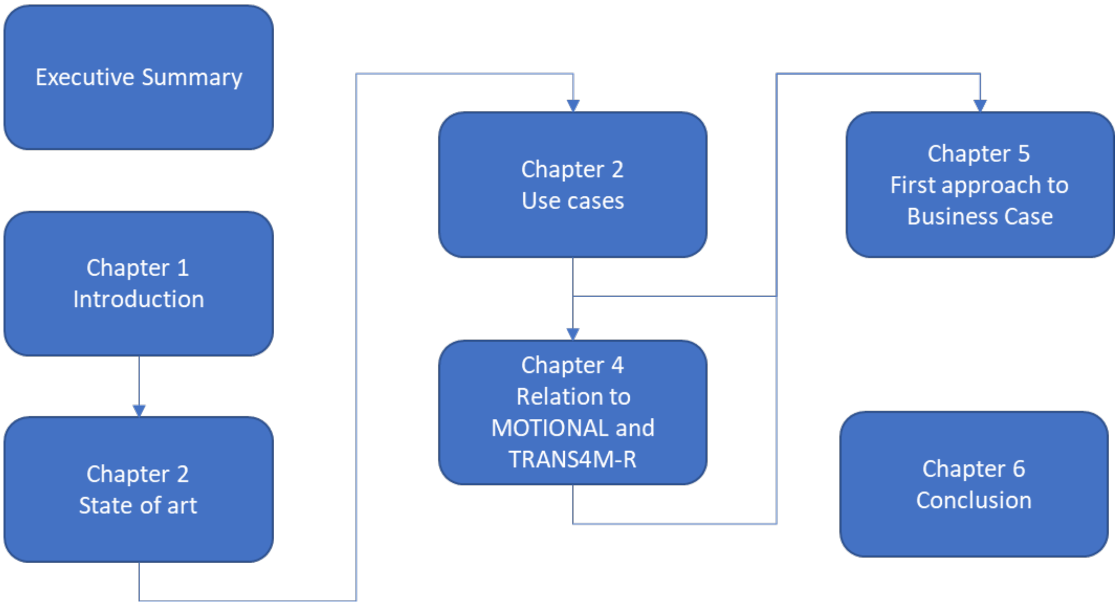


Figure 3: Structure of the deliverable

Rail freight transport in Europe plays a critical role in moving goods across the continent, but its market share lags behind road transport. In 2022, rail transport was not the main mode of transport in any of the countries in Europe. Among the countries that also have maritime transport, a relatively high share of rail freight transport was recorded in Lithuania (37.2 %), Slovenia (28.8 %), Latvia (26.0 %), Romania (21.0 %) and Poland (20.8 %). Among the countries without maritime transport, Slovakia had the highest share of rail transport, at 30.1 %, followed by Austria (30.0 %), Hungary (26.3 %) and Czechia (22.0 %) [1].Countries like Germany, Poland, and Austria are leaders in rail freight activity due to extensive rail networks, industrial hubs, and strong logistical integration. Germany, in particular, benefits from its central location and large industrial base, while Poland acts as a key transit country for goods moving between Western Europe and the East. Conversely, countries like Ireland and Luxembourg see minimal rail freight activity due to their smaller rail infrastructure, geographical constraints, and higher reliance on road or sea transport. Some nations, particularly in southern Europe, also face challenges related to aging rail infrastructure, regulatory fragmentation, and insufficient intermodal connections, which limit their ability to compete with road transport, showing lower market share as for example aprox. 10% in France [2] and 5% in Spain [3].

Rail freight offers several advantages that make it essential for Europe's sustainable economic growth and environmental goals. It is one of the most energy-efficient and environmentally friendly modes of transport, producing significantly lower greenhouse gas emissions compared to road or air freight. Rail is also highly effective for bulk goods, such as minerals, chemicals, and agricultural products, over long distances. As Europe intensifies its focus on decarbonization and achieving climate targets, increasing rail freight's share becomes critical to reducing transport emissions. Additionally, rail offers congestion relief on highways, enhances safety by reducing heavy truck traffic, and provides reliable schedules, which are key for integrated supply chains. Staying competitive in rail freight is vital for Europe, as other regions like China and the United States continue to invest heavily in modernizing their rail systems.

Emerging technologies are set to revolutionize rail freight transport, making it more efficient, cost-effective, and attractive. A key innovation for the freight rail transport is the development of the **SDFW**, autonomous units that can operate in the yard and through the rail networks independently. These wagons enable flexible, point-to-point freight delivery without the need for traditional locomotives, significantly improving operational efficiency. Autonomous wagons, combined with electrification and hybrid technologies also reduce emissions, reinforcing rail's environmental advantage. Digital platforms facilitating intermodal connectivity allow seamless integration of rail with road and sea transport, further increasing its competitiveness. These innovations, especially autonomous wagons, address current inefficiencies, making rail freight a more viable and attractive option for Europe's transportation future.

The conceptual study of the **SDFW** starts with the analysis of the state of the art, then it goes through its applications on different use cases and finally provides its definition looking at what it is defined for the Rail network and Yards management at FP1-MOTIONAL [4] and the Freight train digitalisation and wagon propulsion at FP5-TRANS4M-R [5].

The result of the study shows the potential use that the **SDFW** can have into the rail freight transport ecosystem, highlighting the need for a stepwise migration.

2 STATE OF ART

Vehicle technology is changing rapidly due to advancements in digitalization and automation. Other global trends like urbanization and increased connectivity are also playing a role. In the automotive industry, this is evident with the rise in research and development of electric vehicles and technologies for assisted, automated, and autonomous driving. Fully autonomous vehicles could make road transport much more appealing and safer than it is now. This poses a significant challenge for the rail industry, as autonomous road vehicles might replace some of the transport services that are currently rail-based. This is because benefits of rail transport, like being able to use travel time productively, could diminish. This applies to both passenger and freight transport.

To address this challenge, the rail industry needs to develop solutions that match or exceed the capabilities of future autonomous road transport. This means combining rail's current advantages, such as high comfort and freedom of movement, with the growing opportunities offered by digitalization and automation.

Within this context, the concept of the **SDFW** refers to a type of railway freight wagon designed to move autonomously with the aim of transporting goods without requiring a locomotive. This concept has been already addressed in previous works. This section summarizes the most relevant references found from research projects that result in scientific articles and from prototypes built by start-up companies.

In the following subsections the description of research projects and articles and prototypes/companies are included[1]:

- Research projects/Articles
  - **Automated Nano Transport System [6]:** Automatic Nano Transport System (ANTS): It was driven by Siemens and it is self-propelled and self-driving. There is a “Drive-board” and different types of “Life-Boards” – for Freight, too. It was planned to be able to carry a 40”-ISO-Container and is related to the idea of FP7-PODS4Rail.
  - **Wagon 4.0 [7]:** publication from Manfred Enning (et al.). He invented the concept in his time as Chief Engineer at the Institute of Control at the Rheinisch-Westfälische Technische Hochschule (RWTH) Aachen and continued with it after becoming Prof. at the FH Aachen. It is self-propelled and self-driving, too. Project is ongoing, but only in the FH Aachen (University of Applied Sciences).
  - **Intermodal Competition in Freight Transport - Political Impacts and Technical Developments [8]:** published by Joachim Daduna. It states that road freight transport dominates due to its widespread infrastructure, despite efforts to shift the modal split with subsidies and policy measures. Technological advancements will further boost road and maritime shipping, while rail and inland waterway freight currently lose market share.
- Prototypes already developed/Companies
  - **RAGV [9]:** was founded in 2014 by TS ONE in Netherlands. In 2019, a wagon prototype was ready, currently there are no further references to the evolution of the prototype.

[1] This study was carried out in 2023

- **Intramotev [11]:** was founded in Missouri (USA) in 2020. It developed two solutions for freight railcars with the objective of moving 100 tons of freight on a distance of 100 miles.
- **Parallel Systems [12]:** was founded in 2020 in California (USA). It developed an autonomous bogie that can be coordinated with a second one to move containers.

Finally, some conclusions are shown as a summary of the state of art. This state of art focuses on the **SDFW** and does not include other concepts such as Self Propelled Freight Wagon (SPFW), which is part of the **SDFW** due to the need of moving the wagon itself. Therefore, activities related to SPFW such as [13], [14], [15], [16], [17] and [18] are not addressed in the following subsections.

2.1 RESEARCH PROJECTS/ARTICLES

There are 700+ declared scientific works for the concepts of self driving (**SDFW**) and self propelled (SPFW) freight wagons in international journal and congresses. However, the filter for the relevant contributions on the self driving aspects (**SDFW**) reduces the list to almost 40 papers. There are listed below ordered by year of publication.

Figure 4: Publications related to SDFW ordered by year

Title	Year
AUTOMATIC WAGON LOADING CONTROL SYSTEM USING INDUSTRY 4.0 TECHNOLOGIES	2022
Freight Train in the Age of Self-Driving Vehicles. A Taxonomy Review	2022
Derivation of harmonised high-level safety requirements for self-driving cars using railway experience	2022
Self-Propelled Cars on Russian Railways	2021
Intermodal Competition in Freight Transport - Political Impacts and Technical Developments.	2021
Design of a modular solution for an autonomous vehicle for cargo transport and handling Design of a modular solution for an autonomous vehicle for cargo transport and handling	2020
Linear asynchronous traction drive in urban rail and maglev transport systems	2020
Automated and Autonomous Driving in Freight Transport - Opportunities and Limitations	2020
Improved public transportation in rural areas with self-driving cars: A study on the operation of Swiss train lines	2020
Shunt-E Autonomous Zero Emission Shunting Processes in Port and Hinterland Railway Operations	2019
Autonomous Vehicles and Freight Traffic: Towards Better Efficiency of Road, Rail or Urban Logistics?	2018
Automated Nano Transport System - Ansatz zur Entwicklung autonomer Schienenfahrzeuge	2018
The development of underground freight transport: An overview	2018
Scenarios for the development of self-driving vehicles in freight transport	2018
Automated rail wagon for new freight transport opportunities	2017
Connected freight rail rolling stock: a modular approach integrating sensors, actors and cyber physical systems for operational advantages and condition based maintenance	2017
Efficient autonomous driving freight trains in bidirectional crossing loop avoiding stops	2016
Towards inclusion of the freight rail system in the industrial internet of things-Wagon 4.0	2016
Impact of Automation on the Capacity of a Mainline Railway: A Preliminary Hypothesis and Methodology	2015
Potentials of Alternative Propulsion Systems for Railway Vehicles: A Techno-Economic Evaluation	2014
AGV self-propelled unloading transport cart	2013
Manually Guidable Freight Transport System for Urban Shipment and Delivery	2012
Electrically excited Wheel Hub Motors for High Speed Trains	2012
Freight transport system for urban shipment and delivery	2011
An Integrated Software Concept for Autonomous Driving in the Context of Intermodal Freight Traffic	2010
System Architecture and Risk Management for Autonomous Railway Convoys	2008
The scheduled waiting time on railway lines	2007
Advanced convoy control strategy for autonomously driven railway vehicles	2006
Using Real-Time Vision to Control a Convoy of Semi-Autonomous Unmanned Vehicles	2006
Drive control and position measurement of RailCab vehicles driven by linear motors	2006
Convoy Operation of Linear Motor Driven Railway Vehicles	2005
Design and implementation of a hybrid energy supply system for railway vehicles	2005
Cellular automaton model for railway traffic	2005
Radio-based control of a linear motor for the NBP railway system	2003
Railway capacity assessment, an algebraic approach	1999
COMPUTER-BASED OPTIMISATION TECHNIQUES FOR MASS TRANSIT RAILWAY SIGNALLING DESIGN	1992
23 Self steering bogies for freight and rapid transit applications	1982

Table 4: List of publications related to SDFW ordered by year

In the following subsections the most relevant ones for the definition of the **SDFW** are further described.

2.1.1 Automated Nano Transport System-Ansatz zur Entwicklung autonomer Schienenfahrzeuge [6]

Context: This entry is a paper published in Aachen, Germany, 28th-30th November 2017 in the proceedings of IRSA: 1st International Railway Symposium Aachen.

The author and his affiliation: Jürgen Schlaht, Siemens Mobility MLT ITE; Lukas Frink, Christian Schindler, Institute for Rail Vehicles and Transport Systems, RWTH Aachen University; Laumen, Peter, Andreas Schüttert, Nils Nießen, Institute of Transport Science, RWTH Aachen University.

Concept description: brainstorming and specification of a small, driverless rail vehicle that is intended to make rail transport more attractive, more cost-effective and safer, especially on low-load routes, and thus guarantee the system-related advantages of rail over road even after the advent of autonomous, electrically powered motor vehicles (Figure 5).

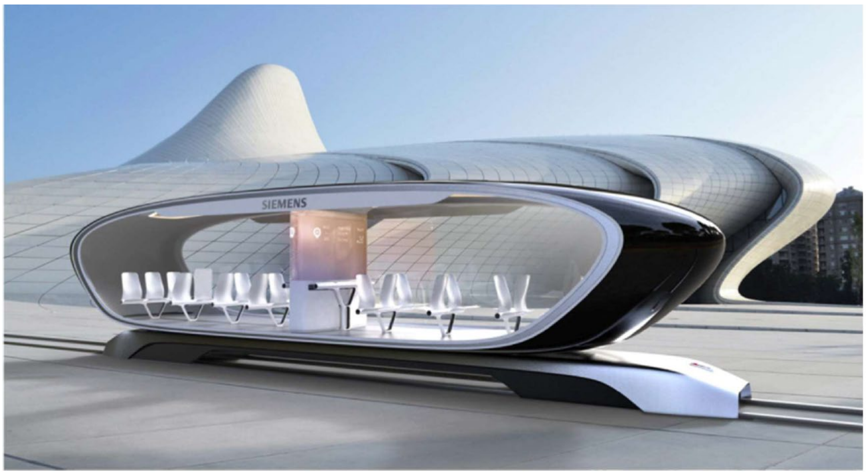


Figure 5: ANTS design study, autonomous micro-vehicle consisting of drive unit and life unit for the individualised transport of passengers (© SIEMENS AG) [6]

Inputs for SDFW: The aim is to design a driverless, fully autonomous and flexible rail transport system. A special feature of the vehicles is the strict separation between an independent chassis section (drive unit) and a flexible, customisable body aiming at using if as passenger unit and also a cargo unit. The main characteristics are listed as follows:

- **Geometric dimensions:** The vehicle length is initially set at 12 metres based on the standardised 40-foot containers used in freight transport. The vehicle height and width depend on the application: Considering EBO application, a width of 3 m and the height is limited to approx. 4.31 m above top of rail. The drive unit should be as low as possible to ensure maximum height for the passenger/cargo unit.
- **Energy requirement, power storage mass and drive power:** The proposed vehicle is powered purely electrically via an internal energy storage system (independent of the contact wire) and are therefore locally emission-free. Based on the geometric data and the maximum total vehicle mass, rough energy requirement calculations are shown. The scenarios for long-distance transport and freight transport (operating time of four hours in steady-state operation with five acceleration and braking processes) have the highest energy requirements: nominally around 700 kWh, if losses and ageing processes are also taken into account

approx. 1000 kWh must be able to be stored and transported. The 1000 kWh correspond to the state of the art according to an electricity storage mass of around 5 tonnes, without considering fastening and ventilation structure. The required volume for the electricity storage unit is therefore approx. 3 m³ without considering the technical design of the individual cells (electrical connections, mounting device, etc.).

- **Operational use:** In the cargo sector, it may be necessary to replace the drive unit due to the high masses to be transported with a high number of braking and acceleration processes. To this end, infrastructure requirements must be created and the battery set must be designed as a quick-change unit.
- **The maximum speed** of the autonomous micro-vehicles will be limited to 120 km/h.

The paper claims that the potential of autonomously operating small rail vehicles was demonstrated. It also asks to put particular attention to minimise or eliminate current obstacles to use railways by through this innovative type of rail operation. If finally declares that it represents an opportunity to shift the modal split towards rail transport.

It was also expected that further investigations could have specified the autonomous rail vehicles of the Automated Nano Transport in more detail up to a complete specification sheet. Based on a specification sheet, a concrete solution concept could have been developed to develop a prototype in order to validate the concept.

Use cases: the use cases referred are related to the rail scenarios where autonomous micro-vehicles could be used.:

- Urban Transport: Includes light rail, trams, and other urban light rail systems.
- S-Bahn / Metro Transport: For commuter services in large cities.
- Regional and Local Transport: Covers regional services.
- Long-Distance Transport: Intercity rail services.
- Cargo Transport: Focuses on cargo units instead of passenger units.

The main goal is to meet customer needs better than future competing products. Autonomous rail vehicles should offer clear advantages, such as increased flexibility and convenience, as for example:

- For **regional transpor**t, smaller, flexible vehicles could make the service more appealing compared to the current setup, which relies on fixed schedules and larger trains with longer intervals. These vehicles could potentially replace traditional "Life Units" (passenger units) with road-capable "Drive Units," allowing seamless door-to-door transport without transfers.
- For **long-distance travel**, autonomous micro-vehicles could eliminate the need for intermediate stops, providing direct routes from start to finish. Even with lower speeds due to route monitoring and required braking distances, the absence of stops could result in similar overall travel times compared to today’s high-speed trains. This setup would also lower the vehicle’s power requirements and the size of its energy storage unit.

2.1.2 Wagon 4.0 – the smart wagon for improved integration into Industry 4.0 plants and towards inclusion of the freight rail system in the industrial internet of things [7]

Context and Current Status: This entry is a conference paper published in June 2019, at the Conference International Heavy Haul Conference, hosted in Narvik, Norway.

The authors and their affiliation are as follows: R. Pfaff & B.D. Schmidt & D. Wilbring & M. Enning, from Aachen University of applied sciences, Aachen, Germany. And J. Franzen from Ruhr Universität Bochum, Bochum, Germany

Concept description: As described in the abstract and core of the paper, in many instances, freight vehicles exchange load or information with plants that are or will soon be Industry 4.0 plants. The Wagon 4.0 concept, as developed in close cooperation with e.g. port or mine operations, offers a maximum in railway operational efficiency while providing strong business cases already in the respective plant interaction. This is equally relevant for the logistic operations in the railway yards.

Inputs for SDFW: The Wagon 4.0 presented in this paper consists of main components, a power supply, data network, sensors, actuators and an operating system, the so called Wagon OS. The Wagon OS is implemented in a granular, self-sufficient manner, to allow basic features such as WiFi-Mesh and train christening/inauguration in remote areas without network connection. Furthermore, the granularity of the operating system allows to extend the familiar app concept to freight rail rolling stock, making it possible to use specialised actuators for certain applications, e.g. an electrical parking brake or an auxiliary drive. In order to facilitate migration to the Wagon 4.0 for existing fleets, a migration concept featuring five levels of technical adaptation was developed. The present paper investigates the benefits of Wagon 4.0 implementations for the particular challenges of heavy haul operations by focusing on 5 use cases, introduced below.

The Wagon 4.0 is based on conventional freight wagons, with conventional bogies and couplings according to local standard. It generates much of its added value thanks to its local control hardware and software, supplied by wheelset generator with buffer battery as well as sensors, actuators, communication units and a shunting drive. The Wagon 4.0 is self-sufficient, self-aware and recognizes other Wagon 4.0 in its vicinity. Thanks to a battery that is charged during mainline operation, it is also smart when stationary. Due to the operating system and other interfaces to the power supply, it can be optimized for various applications. The next figure shows the system architecture and the elements of the 6 key structural elements:

- Power supply
- Data Network
- Sensors
- Actuators
- Algorithms
- Operating System

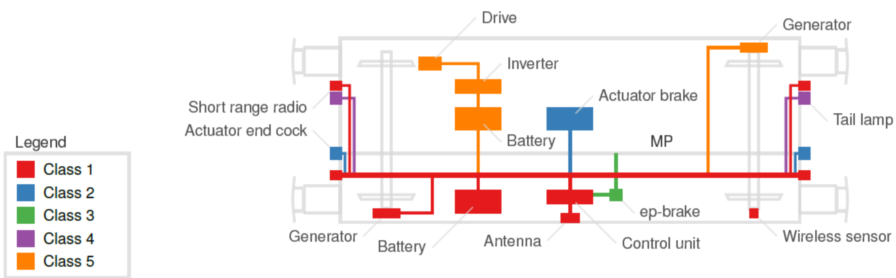


Figure 6: Wagon 4.0 system architecture [19]

Use cases: There are 5 use cases introduced in this paper:

- train inauguration

- ep-assisted braking
- autonomous last mile
- traction boost operation
- improved maintenance schedules

However, the paper on the chapter 2 only details the use cases of harbour interaction (section 2.1), Industry 4.0 plant (section 2.2) and shunting (section 2.3):

- **Harbour interaction:** in many harbours, a train consist is broken down into small groups of wagons, with distances introduced between these groups to allow for passing of container carriers. Using the local control and shunting drive, the related uncoupling and motion can be achieved by the wagons autonomously, speeding up preparation for loading. (Figure 7)
- **Industry 4.0 plant:** using the Industry 4.0 feature self-organisation, it is possible that container crane and the wagon communicate on the sequence of containers to be loaded, allowing for an automatic adjustment of the wagons' trunnions. After loading, the train can be formed again autonomously, while communicating with the container carriers and other automated vehicles in the harbour. The train can leave almost immediately thanks to the automated brake assessment and train inauguration. For Industry 4.0, the wagons can be used as an unmanned transportation system within the plant, yielding benefits over the traditional lorry logistics. The wagons can interface the smart machinery as well the smart storage in a self-organising fashion, paving the way towards logistics 4.0. (Figure 8)

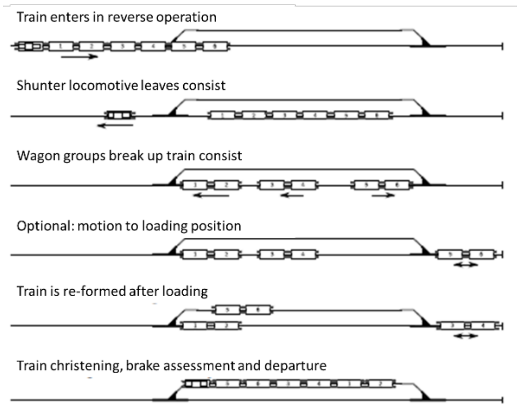


Figure 7: Wagon 4.0 use case example harbout operation steps [20]

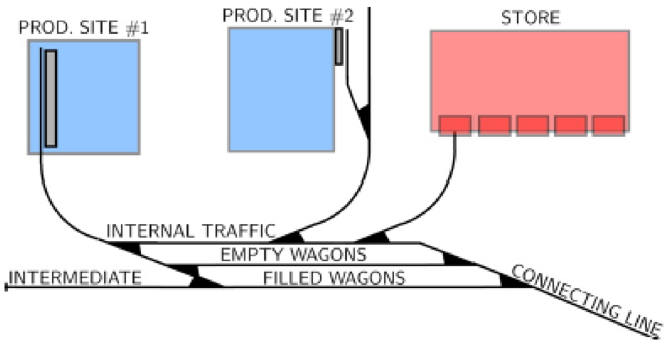


Figure 8: Wagon 4.0 use case example Industry 4.0 plant [19]

- **Shunting:** the freight Wagon 4.0 can be helpful when shunting and, in addition to the possible shunting drive, can also assist in train composition. Information from previous journeys simplifies technical wagon handling, load changes, brake settings and brake calculations. This saves time and staff. The automatic immobilisation brake eliminates the need for shoes or other rugs. This reduces sources of failure, but above all ensures smoother operation because they no longer have to be collected. The power supply also makes it possible to equip the last car with a camera and other sensors. This makes it possible to drive with the train end monitored, even without shunting assistants, and at the same time provides a more ergonomic and pleasant workplace for the locomotive driver. The preparation of coupling and separation points enables faster train dispatch with coupling field operations.

Finally, the potential benefits explained for heavy haul are threefold: condition monitoring and maintenance, remote train inauguration and brake calculation, and autonomous last mile operation.

2.1.3 Intermodal Competition in Freight Transport - Political Impacts and Technical Developments [8].

Context and Current Status: This entry is a conference paper published in 2020, at the International Conference on Computational Logistics ICCL2020. This is also part of the Lecture Notes in Computer Science book series (LNTCS, volume 12433).

The author and his affiliation is as follows: Joachim Daduna, Berlin School of Economics and Law

Concept description: The development of mobility has always had a considerable influence on economic, social and political structures. Without efficient transport systems, the industrial revolutions of the last centuries would not have been possible or only to a much lesser extent. With the advancing digitalization and the development of automated and autonomous vehicles, new framework conditions are emerging, which are leading to far-reaching changes in the transport sector. In this contribution, the discussions regarding the existing automated and autonomous vehicles in the field of the main freight transport modes as well as possible developments will be presented and considered in the light of future demand structures.[8]

Inputs for SDFW

This paper provides information about the technical basis and applications of autonomous driving in both general and rail transportation.

<u>General and road Transportation:</u>

- Main Technical Basis: The main technical components for autonomous driving on roads are Advanced Driver Assistance Systems (ADAS), including radar and sensor systems for environment recognition and evaluation. These systems are critical for safe driving.
- Positioning: Accurate satellite-based positioning is achieved through the Global Navigation Satellite System (GNSS) and digital maps.
- Communication Infrastructure: Information and communication structures, such as vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication, play a crucial role in enabling autonomous driving.
- Platooning: Platooning of trucks on higher-level road networks is an essential step, allowing vehicles to travel closely together in a coordinated manner.

<u>Rail Transportation:</u>

- Grade of Automation (GoA): Railways are transitioning to automated driving with two main forms: GoA 3 (driverless train operations with conductor intervention) and GoA 4 (unattended train operations).
- Technical Equipment: To achieve high market penetration of automated driving on railways, vehicles need Automatic Train Control - Onboard (ATO-OB) systems to communicate with track infrastructure (ATO-TS) and control centers.
- Communication Infrastructure: Communication is facilitated by the Global System for Mobile Communications-Rail (GSM-R) based on G2 mobile radio technology, up to now.
- Positioning: Current train positions are determined using odometric procedures, with potential enhancements through the integration of GNSS and other sensors.

- Applications: In rail freight transport, autonomous driving can make operations more efficient. Concepts like the CargoMover aim to operate the last leg of the trip autonomously. Virtual coupling of autonomously driving units to form quasi-trains has also been explored.
- Autonomous Driving in Defined Networks: Autonomous control of locomotives within marshalling yards and industrial rail yards is being tested in various projects, including successful implementations in places like the Bremerhaven harbour rail yard.

Overall, the transition to autonomous driving in any transportation and particularly in railways, relies on advanced technology, communication infrastructure, and specific applications tailored to the unique needs of each mode of transport.

2.2 PROTOTYPES ALREADY DEVELOPED/COMPANIES

In this subsection three prototypes are described: RAGV [9], Intramotev [11] and Parallel Systems [12]. The two latter ones belong to two start-up companies that are still in operation.

2.2.1 RAGV [9]

Context: RAGV was founded in 2014 by TS ONE in Netherlands. It was in 2012 when Paul van Bers was in an airport looking at the luggage belt and had the idea of using a similar mechanism to transport wagons (tsone.nl/The-team). [10]

Current status: In 2019, the wagon was ready and developed by a group of people that Paul van Bers gathered thanks to a subsidy and with a software provided by Container Shift2Rail. No further recent references to the development of the wagon have been found.

However, the wagon was still not on track due to the fact that there were some hurdles. For example, the software system that allows the wagon operating in the available train paths needs to be marketed and, moreover, the industry would have to accept this new concept.

Concept description: This concept is based on an autonomous wagon, which can move by itself and is equipped with integrated navigation and obstacle avoidance systems, including Galileo satellite navigation and radar. It offers advantages compared to other means of transportation:

- **Compared to trains**: more efficient use of the railway network and more flexible, call-off on a unit-by-unit basis, no prolonged waiting times for loading/formation of trains, no need for intermediate stacking.
- **Compared to trucks:** a lower cost per kilometre, a 70% reduction in emissions per container, is driverless, eliminates traffic jams, reduces pressure on the road network, eliminates intermediate stacking, lowers the risk of theft, and improved cargo integrity.

Inputs for SDFW: The next picture shows the RAGV configuration where different component of the wagon are shown:

- **PLC**: responsible for control of the wagon.
- **Communication and navigation equipment**: wireless communication and on-board positioning based on Galileo satellite navigation.
- **Obstacle detection sensors:** radars are employed to detect obstacles to avoid collision.
- **Battery pack:** required for the on-board electronics and power train
- **Power train:** propulsion system to move the vehicle.

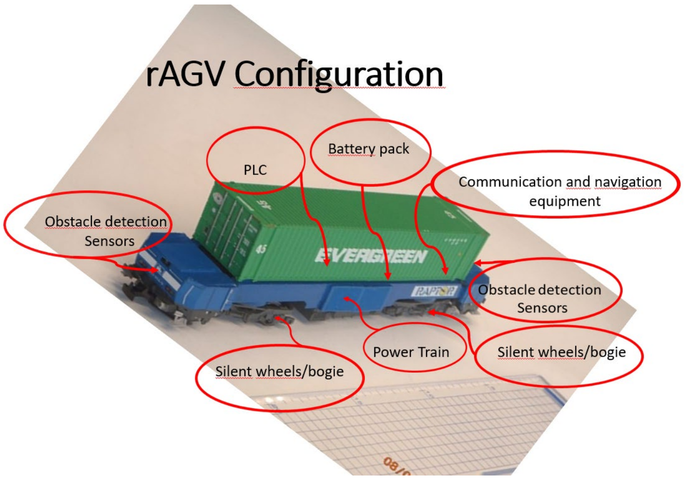


Figure 9: RAGV concept [9]

Use cases: These new wagons could be used for both transporting goods and for transporting people in a much more efficient and cost-effective way. Additionally, these wagons could be used for both long and short distances.

2.2.2 Intramotev [11][21][22][23]

Context: Intramotev was founded in January 2020 by Timothy Luchini (current CEO), Alex Peiffer and Corey Vasel. It is based in Saint-Louis, Missouri. Since its creation, the company received a total of 14 M$ of funding throughout six financing rounds.

Current status: The Cumberland mine in Waynesburg, Pennsylvania owned by Iron Senergy has ordered 3 ReVolt battery-electric wagons to be deployed on its 17 mile private line used to transport coal. Since a few months, Intramotev has successfully deployed a self–propelled battery electric car in a traditional freight train on this line. This is the first time in the world such a deployment is done. Moreover, current wagon proposal is not compatible with the European wagons due to the location of the traction system on the wagon and the connection with the axle.

Concept description: On a technical point of view, the company developed two solutions for freight railcars with the objective of moving 100 tons of freight on a distance of 100 miles:

- The ReVolt freight car is a self-propelled battery electric rail car using battery technology and regenerative braking. It reduces the locomotive fuel consumption as it can be deployed in a traditional freight train.
- The TugVolt freight car is the primary product of the company (fully independent freight and material movement). This freight car has the same characteristics as the ReVolt freight car but is also a self-driving wagon. It offers the opportunity to operate independently on first and last mile legs.

Inputs for SDFW: The current INTRAMOTEV technology puts forward

- The two systems (ReVolt and TugVolt) can be adapted by retrofit to existing wagons.
- Vehicles can energy share when they are coupled (for instance, if a wagon goes further than 100 miles, it can preferentially use the energy of the vehicle that needs to go to a shorter distance).

- Braking regenerates the battery.

Use cases: First, the safety and the reliability of the wagon will be tested in captive use cases such as mining railways, ports, intra terminal movements and very short return trips. As a second step, the wagon could be used on short distances (branch lines and intermediate movements and interchange points to customer and vice versa). Finally, Intramotev freight cars would be deployed on long haul traffic.

Figure 10: Intramotev prototypes [11]

2.2.3 Parallel Systems [12]

Context: The company was founded in 2020 by three former engineers from Space X. It is based in Los Angeles, California. After 200 years of almost no innovation in the freight train industry, these three engineers have thought a new idea for the world of freight railroads, using two vehicles to move the containers.

Current status: In August 2023, Georgia Central Railway, L.P. (GC) and Heart of Georgia Railroad, Inc. (HOG), subsidiaries of Genesee & Wyoming Inc. (G&W) have asked permission to the Federal Railroad Administration (FRA) to make test on their rail lines with Parallel System.

Concept description: The way it works is the following, placing two vehicles far enough apart to support the container which is placed by a crane. The two Parallel Systems vehicles use the container to complete the "car" and it has everything it needs to move so it can go from the origin to the destination by itself. These "cars" can move individually so it is not needed group them, but they will end up travelling in platoons. Parallel Systems´ vehicles have an expected maximum range of 500 miles on a single charge, and a two-vehicle team can transport either a single or a double stack of containers, each holding 29.000 kg (64.000 pounds)

Inputs for SDFW: The Parallel Systems technology can be used to transport platoons of 10 to 50 "cars", so it will be a problem in case of larger platoons. One of the main problems is that Parallel Systems builds and controls their vehicles, they don't manufacture and control the train tracks that their vehicles need. These tracks are controlled by other companies that may have other ways of distribution.

Use cases: The idea is that once trains decrease in size, railroads will have the capability to transport goods that might otherwise be managed by trucks.

https://moveparallel.com/
Location: LA, US
What they do: autonomous battery-electric rail cars as an alternative to trucking.
Timing:

Figure 11: Parallel systems prototype [12]

2.3 CONCLUSIONS - SUMMARY

The state of art of the **SDFW** showed that the concept has been created some few years ago, predecessor related concepts are dated in the 80s (e.g. *Self steering bogies for freight and rapid transit applications* from 1982) and the idea from the SDFW is dated in the last decade (e.g. *Automated rail wagon for new freight transport opportunities* from 2017). There have been some works around the **SDFW** concept and currently it is time to make the concept reality due to the technology matureness and the needs of the sector.

From the three research papers analysed a definition of the **SDFW** specification can be obtained including energy requirements of aprox. 1000kWh, maximum speed of 120km/h, components required include power supply, data network, sensors, communications, positioning, …

The analysis of the prototypes, all designed only for freight transport, is summarized in the next table:

Prototype	Advantages	Drawbacks
RAGV [9][10]	• Fully autonomous wagon. • Efficient use of the rail network. • Reduction in emissions. • Transport of both goods and people.	• Lack of control over the infrastructure.[2] • Acceptance of this new model. • Commercialisation of the software.
Intramotev [11]	• Reduction in CO_2 emissions, thanks to the use of batteries. • Reduction in OPEX (between 30% and 80%). • Predictive maintenance thanks to its technology.	• Lack of control over the infrastructure. • Current only deployment in closed areas even though due to the distance it able to travel, it could be used as intercity transport. • Current wagon proposal not compatible with the European wagons.
Parallel System	• Reduction in the space needed to store them.	• Lack of control over the infrastructure.

[2] No reference to the interaction with TMS and/or YMS for the control of the vehicle.

Prototype	Advantages	Drawbacks
[12]	• Individual movement and in groups of up to 50.	

Table 5: Description and drawbacks of the prototype analysed.

Additionally, the concepts from the state of art analysed that can be useful for WP48 (T48.4) can be highlighted. The next table shows the type of communications and positioning is employed in each when it applies.

Section	Project/Article/Prototype/Company	Positioning	Communications
2.1.1	Automated Nano Transport System-Ansatz zur Entwicklung autonomer Schienenfahrzeuge [6]	Absolute	Long range
2.1.2	Wagon 4.0 – the smart wagon for improved integration into Industry 4.0 plants and towards inclusion of the freight rail system in the industrial internet of things	Absolute	Long range
2.1.3	Intermodal Competition in Freight Transport - Political Impacts and Technical Developments [8].	-	-
2.2.1	RAGV	Absolute	Long range
2.2.2	Intramotev [11]	Absolute	Long range
2.2.3	Parallel Systems [12]	Absolute	Long range

Table 6: Type of communication and positioning employed in the paper/prototype analysed.

Finally, it can be stated that the **SDFW** concept is promising, the benefits it will bring to the sector can be assessed by amount of funding received by the on-going companies. Moreover, it is considered that, for the success of the **SDFW** concept, there is a need for considering current technology maturity, current evolution of the sector beyond the **SDFW**, e.g. future Traffic Management System (TMS) and Yard Management System (YMS), Full Digital Freight Train (FDFT), …. Finally, the **SDFW** will contribute to the objectives of EU white book 50% which aims to reduce the emissions by 2050.

3 USE CASES

This section is dedicated to the potential use cases enabled by the Self-Driving Freight Wagon (**SDFW**). To guarantee the success of the acceptance of the sector of the innovative concept of the **SDFW** it is necessary to address the need of the sector that the **SDFW** could cover. The definition of the use cases shall help to find the appropriate use cases for the **SDFW**.

The methodology followed covers three steps. First, a description of the operations and the processes on different types of freight wagon terminals (terminal yard, the flat yard and the hump yard) is included. After that, an initial list of use cases is presented, including a description of how those are applied in a specific yard. Finally, the use cases listed are updated after different interviews conducted with stakeholders of the sector.

3.1 OPERATION OF FREIGHT WAGON TERMINALS

This subsection briefly describes three types of freight wagon terminals, as well as some of the processes carried out in them.

3.1.1 Terminals

In this subsection the terminal yard, flat yard and hump yard are explained.

3.1.1.1 Intermodal Terminal

An "Intermodal Terminal" is generally known as a facility for the storage and management of intermodal transport units (containers and swap bodies). These facilities are used to store, maintain, and manage intermodal transport units that move through loading and unloading ports, often used in the rail and maritime sectors.

A terminal yard performs several functions:

- **Container storage**: A terminal yard can temporarily store freight containers. These containers are grouped into specific zones designated for their subsequent distribution.
- **Sorting and organization**: Containers are organized and sorted according to their final destination or shipping schedule. This simplifies the efficient loading and unloading of ships and freight trains.
- **Inspection and maintenance**: A terminal yard can perform inspections and basic maintenance on containers to ensure they are in good condition before shipping.
- **Intermodal transfer**: These terminals are typically connected to different modes of transport, such as railways, roads and waterways. This allows for the loading and unloading of containers between different types of transport.
- **Registration and tracking**: Within a terminal yard, precise registration and tracking of the location and status of containers can be carried out using various container management systems.

In conclusion, a terminal yard is an important part of the container supply chain because it facilitates the efficient transfer of goods between different modes of transport and enables the proper management and organization of these containers. These facilities are essential for the proper functioning of seaports and railway stations.

3.1.1.2 Flat Yard

"Flat Yards" are considered classification or shunting yards built in an area where the terrain is flat, requiring the use of locomotives to move containers from one track to another. These terminals are more cost-effective to build; however, they are slower due to the use of locomotives for wagon movement and require personnel to manage these movements.

Figure 12: Flat Yard [24]

3.1.1.3 Hump Yard

A "Hump Yard" (also known as a "rail yard" or "gravity classification yard") is a railway facility designed to sort and organize freight wagons efficiently. These facilities are used in large terminals and are essential for managing freight trains. Hump Yards operate as follows:

- **Wagon reception**: Freight trains arrive at the Hump Yard, where the wagons are uncoupled and aligned on reception tracks.
- **Hump (hill or mound)**: The "hump" is the main feature of these facilities—an artificial mound on a hill designed to create a height difference between classification and reception tracks.
- **Gravity sorting**: The wagons are moved to the top of the mound using a shunting locomotive. Once at the top, the wagons are released and gently descend along the classification tracks due to gravity.
- **Classification tracks**: The Hump Yard has several classification tracks, each representing a different destination. As the wagons roll down, they are directed towards the classification tracks according to their destination.
- **Separation and sorting**: As the wagons descend, they are automatically directed to their classification tracks using a series of switches and control systems.
- **Train formation**: Once all the wagons have been sorted into their respective tracks, they are reconnected to form new trains.

Hump Yards allow wagons to be efficiently separated and grouped with minimal environmental impact. They also reduce transit times and optimize cargo management and train organization [6].

Figure 13: Hump Yard (Maschen, Germany) [25]

3.1.2 Processes within Terminals

This section explains several processes that take place in the previously described terminals.

3.1.2.1 Train Wagon Composition

The composition of train wagons is a key part of freight transport and involves a specific process to ensure the efficiency, safety, and stability of the train. The following steps are typically followed when forming the composition of train wagons:

1. **Documentation Review**: Staff review the documentation detailing each wagon's characteristics, including content, weight, destination, and other important data. This step is crucial for correctly planning the train's composition.
2. **Wagon Classification**: Wagons are classified based on their final destination and contents, among other factors. This helps make the loading and unloading processes more efficient.
3. **Wagon Placement**: The position of each wagon within the train is determined, deciding which wagons will be at the front, rear, and middle sections.
4. **Load Capacity**: The total load capacity of the train is checked to ensure it does not exceed the weight limits of the railway line and that the load is evenly distributed along the train.
5. **Wagon Inspection**: Before being incorporated into the train, a thorough inspection is carried out to ensure all wagons are in good condition and free from damage that could affect transportation.
6. **Wagon Coupling**: Wagons are securely and precisely coupled to each other to prevent potential detachment or issues during transit.
7. **Braking and Safety Systems**: Braking and safety systems are checked to ensure they are functioning correctly and are properly connected.
8. **Weight Control**: The weight of the train is verified again to ensure compliance with established limits, making adjustments if necessary.

9. **Brake Test**: A brake test is conducted on the entire train to confirm that the braking system is functioning correctly.
10. **Authorization**: Once the composition process is complete and everything is verified to be in order, the train receives authorization to depart to its destination.

It is important to note that this process may vary depending on the company, type of cargo, and other factors. Efficiency and safety are the primary considerations, and these procedures are conducted to ensure a successful and safe journey.

3.1.2.2 Container Classification in a Terminal

The classification of freight containers in a railway station or terminal yard is carried out in an organized and efficient manner to facilitate handling and transport. Containers are primarily classified based on the following criteria:

1. **Container Size**: Containers come in standard sizes, such as 20 feet (approximately 6 meters) and 40 feet (approximately 12 meters). The initial classification is often by size, as larger containers may require special equipment for handling.
2. **Container Type**: Containers can be of various types, such as Dry Van containers, refrigerated containers (Reefers), tank containers, or bulk containers. Classification is also done by type to ensure proper handling and necessary equipment.
3. **Destination**: Containers are often classified by their final destination or transport route. This simplifies the efficient loading of containers onto the correct modes of transport, typically trains or trucks, which will deliver them to their final destination.
4. **Condition and Status**: Containers in good condition can proceed directly to their respective transports, while damaged ones are diverted to service areas for repair and maintenance.
5. **Load and Contents**: This criterion is often used for containers with hazardous materials (HAZMAT) or special cargo that requires specific handling.
6. **Priority**: Sometimes speed is crucial, so containers are loaded and unloaded based on priority.

Classification is usually performed using container management systems and handling equipment, such as cranes and forklifts. This enables efficient movement of containers through the terminal yard or railway station and ensures they are loaded onto the appropriate transport for subsequent shipment.

3.1.2.3 Wagon Movement within a Terminal

Within a yard, three levels of automation can be highlighted:

1. **Manual Transport and Manual Handling**

   The transfer of containers between the yard and the railway system, as well as loading and unloading operations on the railway, are carried out manually. The transportation process begins at the truck loading area. In the container yard, loading and unloading are conducted using yard cranes that operate in a semi-automatic mode remotely controlled. For railway transport, terminal tractors equipped with U-shaped trays are used instead of trucks, manipulated by lifting and lowering platforms pulled by these terminal tractors.

   The previous system separates the management of trays used for container transport from tractor operations. This improves efficiency by allowing a tractor to start a new cycle after dropping off a tray while the first tray awaits loading or unloading. Reach Stackers (RS), which are manually operated and can work on both the first and second train lines, are used for loading and unloading trains.

Figure 14: Reach Stacker operating on the 2nd train line. [26]

When a Reach Stacker cannot be used on the second line, two options are available: precise planning to keep the second line clear or using an RTG (Rubber-Tired Gantry Crane) operating on central and lateral tracks. Reach Stackers work on the first lines and assist the RTG by loading containers from the temporary rail area as shown in the next figures.

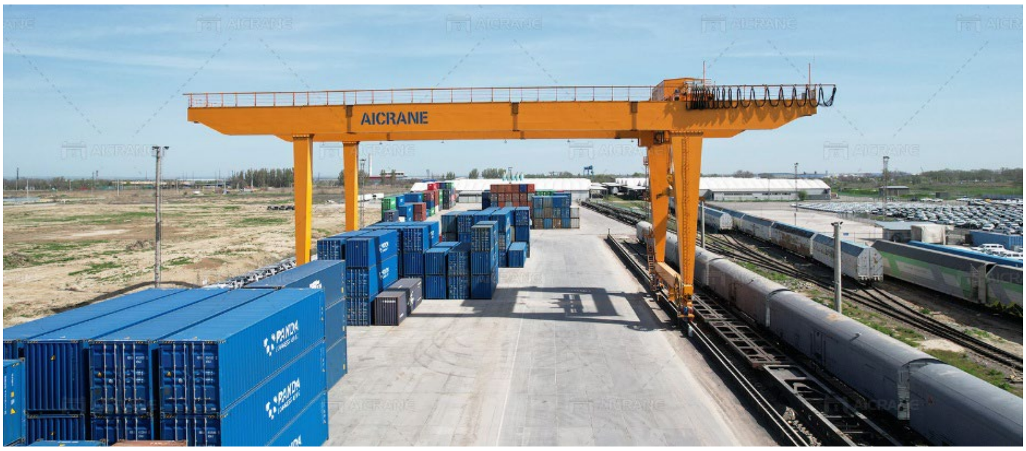


Figure 15: RTG operating on the railway [27]

Figure 16: RTG operating on the railway [28]

2. **Manual Transport and Semi-Automatic Handling**

   Containers are moved between the yard and the railway using terminal tractors and platforms, with loading and unloading carried out semi-automatically using ARMG (Automated Rail Mounted Gantry Cranes). The rail cranes are remotely controlled via an individual control system for each crane. This controller, through the Terminal Operation System (T.O.S.), coordinates the dispatch of containers to the railway and the reception of new containers arriving by train at the terminal. The recognition and reception of containers from the railway are automated. Most loading and unloading operations are automated, except for the manoeuvring of containers. The T.O.S. also supervises and prevents unplanned crane movements.

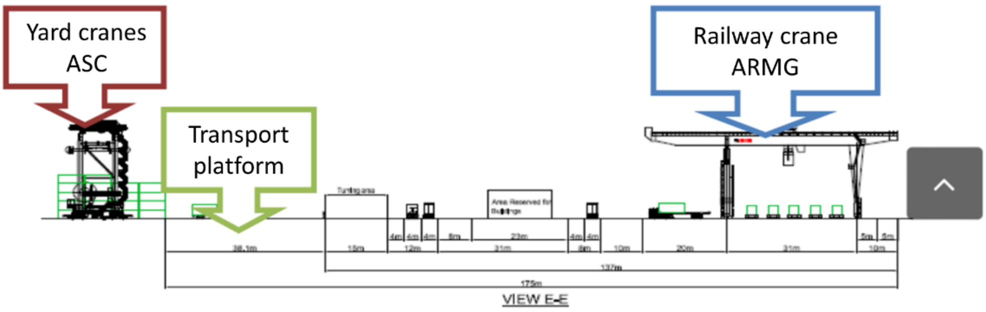


Figure 17: Cycle of Containers from Yard to Railway and Vice Versa. [29]

Figure 17 shows the route of a container starting from the ASC (Automated Stacked Crane) yard cranes, which are responsible for placing containers on platforms. These platforms, moved by terminal tractors, transport containers to the railway section. ARMG cranes then lift containers from the platforms and place them on wagons. If loading onto the train is not possible immediately, they are stored temporarily between the crane's legs. This type of machinery is similar to that used in the previous section on manual transport and handling.

ARMG cranes are more complex than Reach Stackers (RS), as they can achieve full automation if circumstances permit. This crane is equipped with cantilevers at both ends, facilitating loading from both ends if needed.

3. **Automated Transport and Semi-Automatic Handling**

In this scenario, ARMG cranes are also used, as in the previous case, but transport is automated. Automated Shuttle Carriers (AShC) are used as the model for transport from the container yard to the railway. These automated vehicles can grab and release a container automatically.

Figure 18: AShC Transporting a Container [32]

Figure 19: Automated Transport from Yard to Railway. [29]

However, this option has a drawback: automated vehicles cannot be mixed with road vehicles (trucks) in the same area. Therefore, a series of physical barriers must be established to prevent the mixing of both vehicle types.

The previous image shows areas designated in yellow for containers destined for export and transshipment. The orange or brown areas represent zones assigned for import containers and the initial storage phase for containers arriving by truck for export. Finally, the blue areas represent sectors dedicated to containers linked to the railway when their horizontal movement is automated [29].

3.1.2.4 Description of the Wagon Entry-Exit Process in a Terminal

The entry-exit process of a wagon in a terminal follows these steps:

1. **Wagon Reception**:
    - The process begins when a freight train arrives at the terminal.
    - Staff verify the documentation and identify the contents, origin, and destination of each wagon.
2. **Classification in the Reception Area**:
    - Wagons are uncoupled from the freight train and sent to the reception area.
    - Once in the reception area, they are organized according to their origin and type of cargo.
3. **Inspection and Maintenance (Optional)**:
    - If necessary, wagons undergo inspections and maintenance to ensure they are in good condition.
4. **Classification for Departure**:
    - Wagons are classified for their subsequent departure to their destination. Wagons with similar destinations may be grouped on the same classification track.
5. **Wagon Coupling**:
    - Selected wagons are coupled and placed in the correct order.
6. **Brake Test**:
    - A brake test is performed on the entire train to ensure that all braking systems are functioning correctly.
7. **Train Departure**:
    - Once the train is complete and all safety protocols have been fulfilled, departure is authorized.
    - The train then departs towards its destination.

3.2 Initial List of Use Cases

To begin, some members of the working group provided several lists of use cases from various origins. After review and discussion, seven use cases have been defined grouped into yard/terminal autonomous operations (SS) and autonomous operations into the operational lines (SD).

Moreover, these use cases are applied, as example, to the operations of specific terminals: classification yard-hump yard, multimodal terminals (LDCT-Lille Dourges Conteneur Terminal, France) and a port terminal (JadeWeserPort, Germany).

3.2.1 Use cases

Seven use cases have been defined grouped into yard/terminal autonomous operations (SS) and autonomous operations into the operational lines (SD).

- SS – Self Shunting: autonomous operations into the yard/terminal
    - SS1 forming train yards: once uncoupled from the incoming train, the **SDFW** moves to the track where the outgoing train is located in order to couple to the corresponding wagon of the train.
    - SS2 stabling yards: **SDFW** moves to the track where **SDFW** will be parked.
    - SS3 loading/unloading: **SDFW** moves from/to the track for loading/unloading.
    - SS4 workshop: **SDFW** moves to the workshop.
- SD – Self Driving: autonomous operations into the operational line
    - SD1 transport in main line: **SDFW** travels in the main line.

- SD2 transport regional line: **SDFW** travels in the regional line.
- SD3 stabling: **SDFW** moves to a siding/station track where it will be parked.

Figure 20: SDFW use cases list

3.2.2 Use case application

The following subsections show how the SS[3] use cases can be applied to terminal operations. Three practical cases are presented:

- Classification yard: ex. hump yard
- Multimodal terminal: LDCT (Lille Dourges Conteneur Terminal), France
- Port terminal: JadeWeserPort (Germany)

3.2.2.1 Use case application: Hump yard

As a reference, a general definition of a hump yard is taken to analyse how the use cases are applied on their processes. A hump yard consists of:

- a **reception** beam where the trains to be classified arrive
- a disconnection **hump** where the wagons are pushed after having been uncoupled and diverted to the track of the forming train beam corresponding to the train with which they must be associated, according to their intermediate or final destination
- a **forming trains** beam of classified trains where wagons with the same destination accumulate and which are then coupled.
- in certain stations, in order not to clog the training beam, the trains formed but waiting for their machines are moved by a manoeuvring machine to the **departure** beam

Representation of a hump yard:

[3] It is considered that the automation of freight wagons should start from the terminal operations, moreover, operational line operations relate to the ATO. Therefore, as first step, only SS use cases are considered.

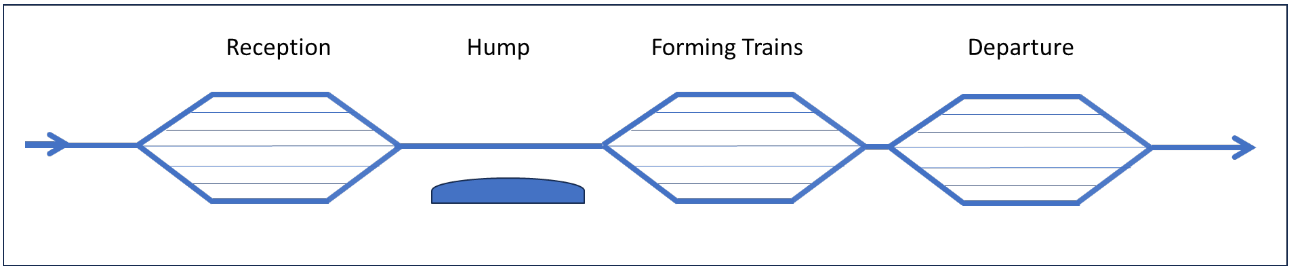


Figure 21: Classification yard

The current processes of the classification yard are included in the next diagram in green boxes. Additionally, the processes brought by the **SDFW** are included in blue boxes.

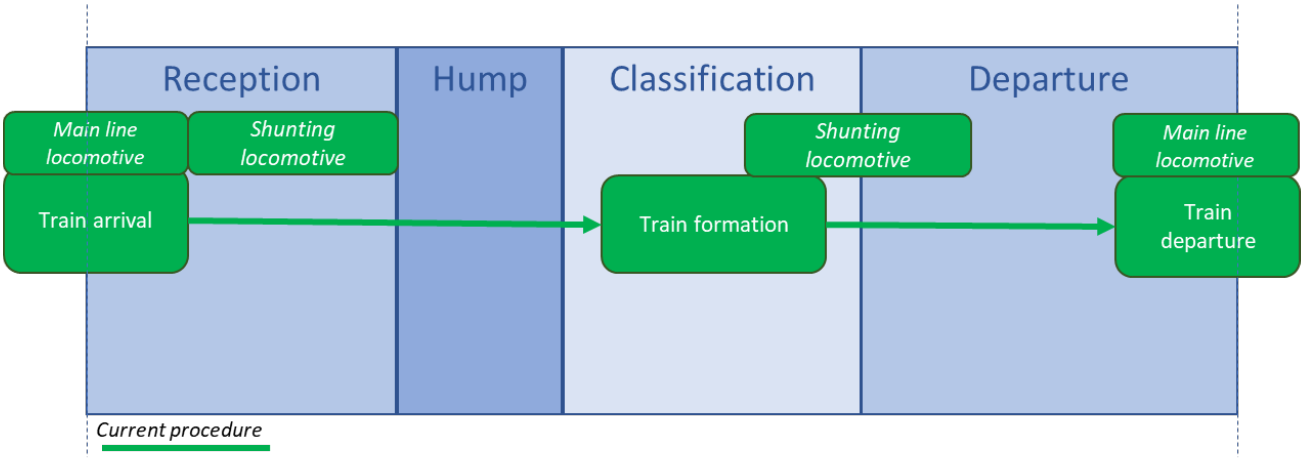


Figure 22: Current procedures of the classification yard

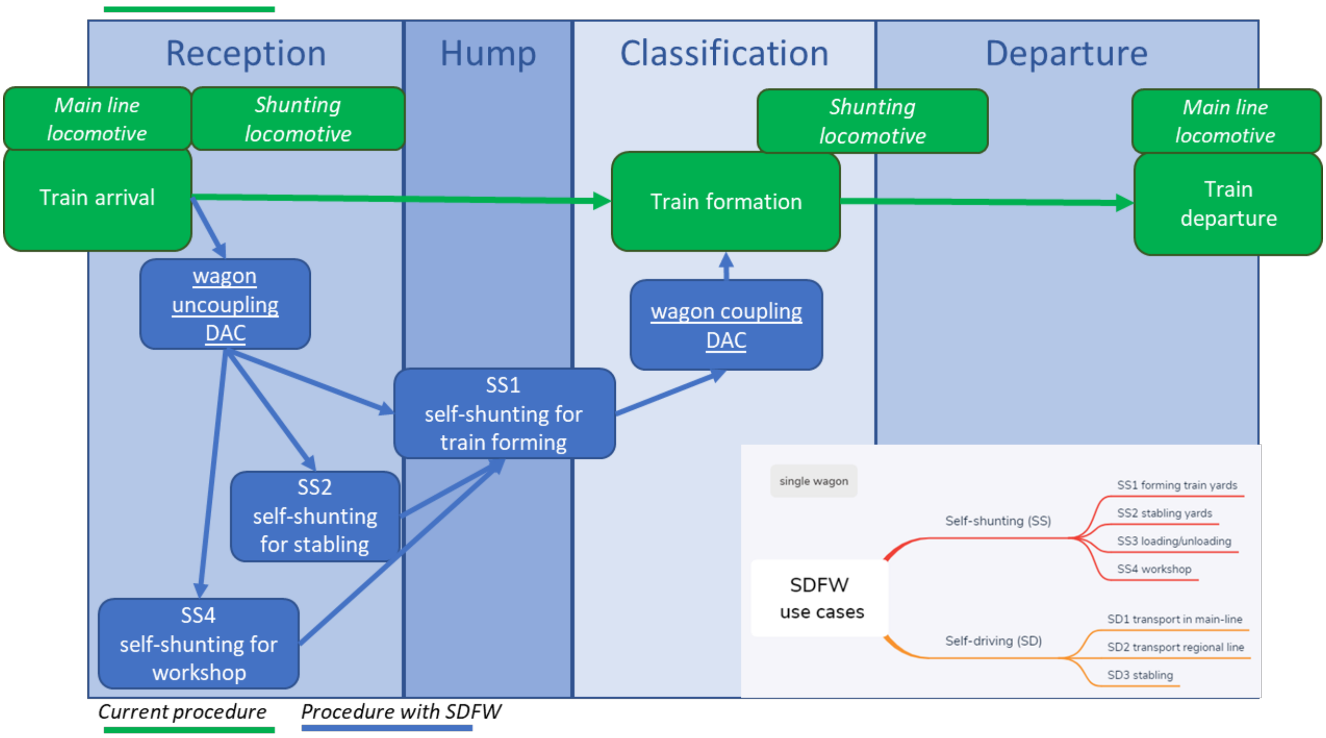


Figure 23: Current and SDFW procedures of the classification yard

3.2.2.2 Use case application: Combined transport terminal

Lille Dourges Container Terminal (LDCT) [30] is taken as an example of combined transport terminal. Lille Dourges Container Terminal (LDCT) manages the trimodal terminal of the DELTA 3 logistics platform. It is located at 20 kilometres south of Lille. LDCT is a dry port and a continental multimodal platform. It offers to all multimodal actors a full terminal services.

Figure 24: LDCT Lille Dourges Conteneur Terminal (France) [31]

Figure 25: LDCT Lille Dourges Conteneur Terminal (France) [32]

The current processes of the terminal are included in the next diagram in green boxes. Additionally, the processes brought by the **SDFW** are included in blue boxes.

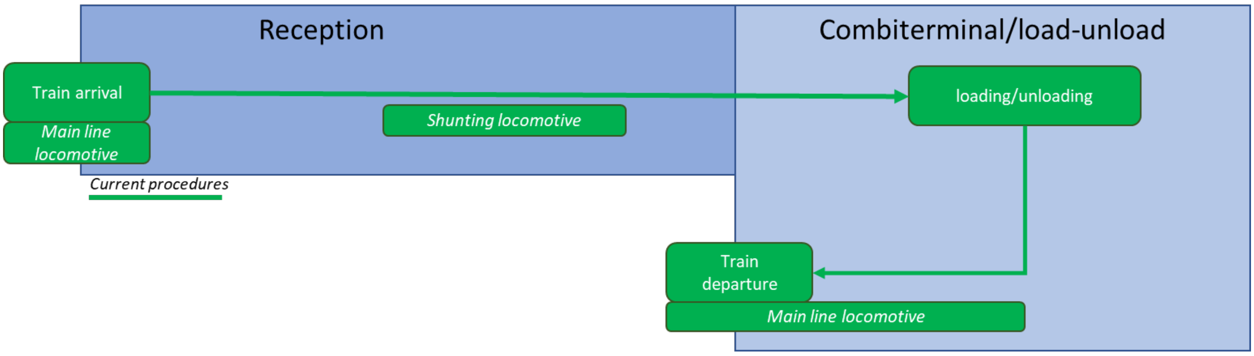


Figure 26: Current procedures of LDCT (France)

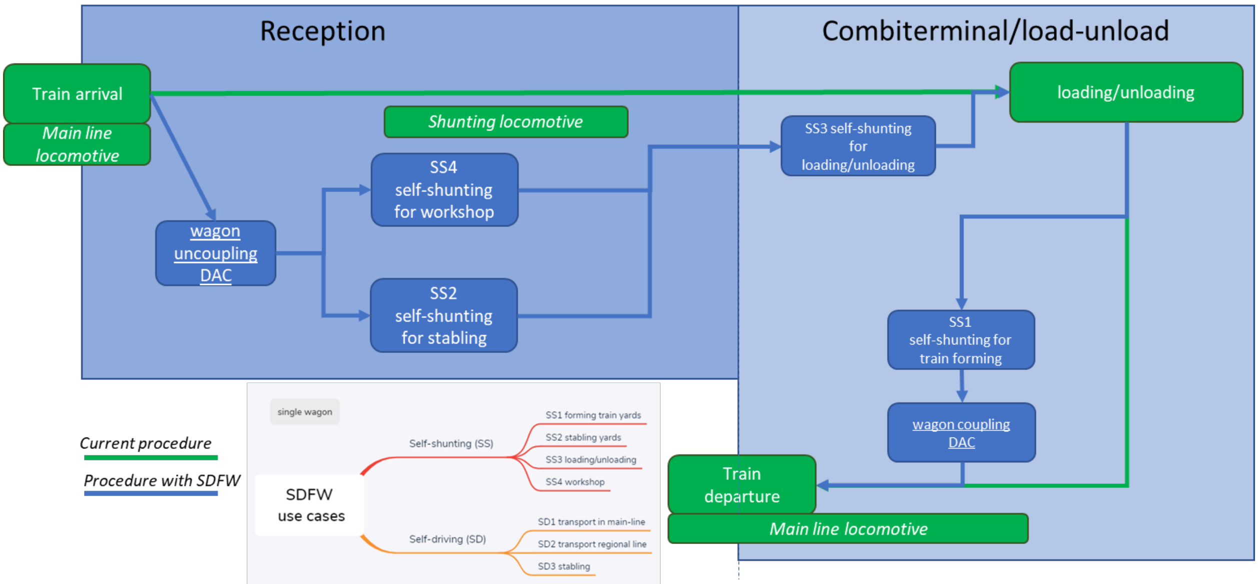


Figure 27: Current and SDFW procedures of LDCT (France)

3.2.2.3 Use case application: Port terminal

As example of a Germany's largest harbour project port terminal JadeWeserPort (Germany) has been taken as reference. This new container port is located at Wilhelmshaven at the Jade Bight, a bay on the North Sea coast. It has a natural water depth in excess of 18 m. Container ships with a length of 430 metres (1,410 ft) and 16.5 metres (54 ft) draught will be able to call the JadeWeserPort at any tide. Currently container handling could be raised from 60,000 in 2014 to 426,700 twenty-foot equivalent unit in 2015 [33]. The yearly capacity of the port is 2,700,000 TEU.

Figure 28: JadeWeserPort (Germany) [34]

Figure 29: JadeWeserPort (Germany) [35]

The current processes of the classification yard are included in the next diagram in green boxes. Additionally, the processes brought by the **SDFW** are included in blue boxes.

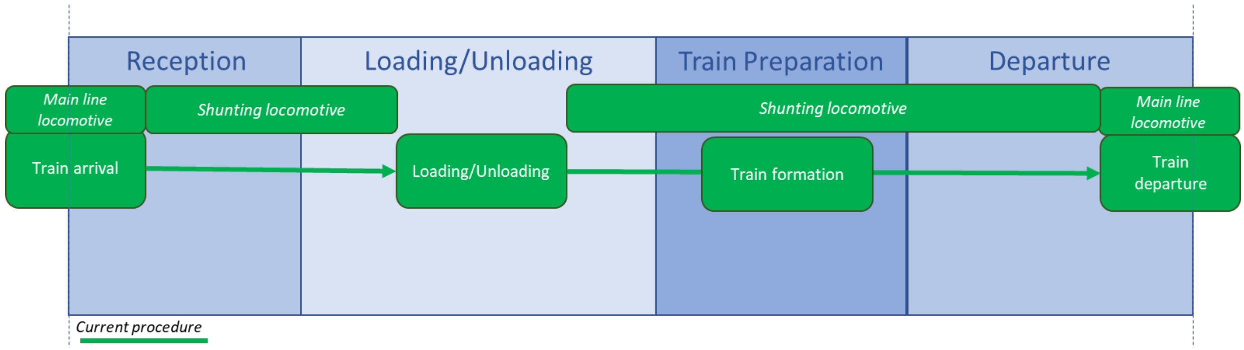


Figure 30: Current procedures of JadeWeserPort (Germany)

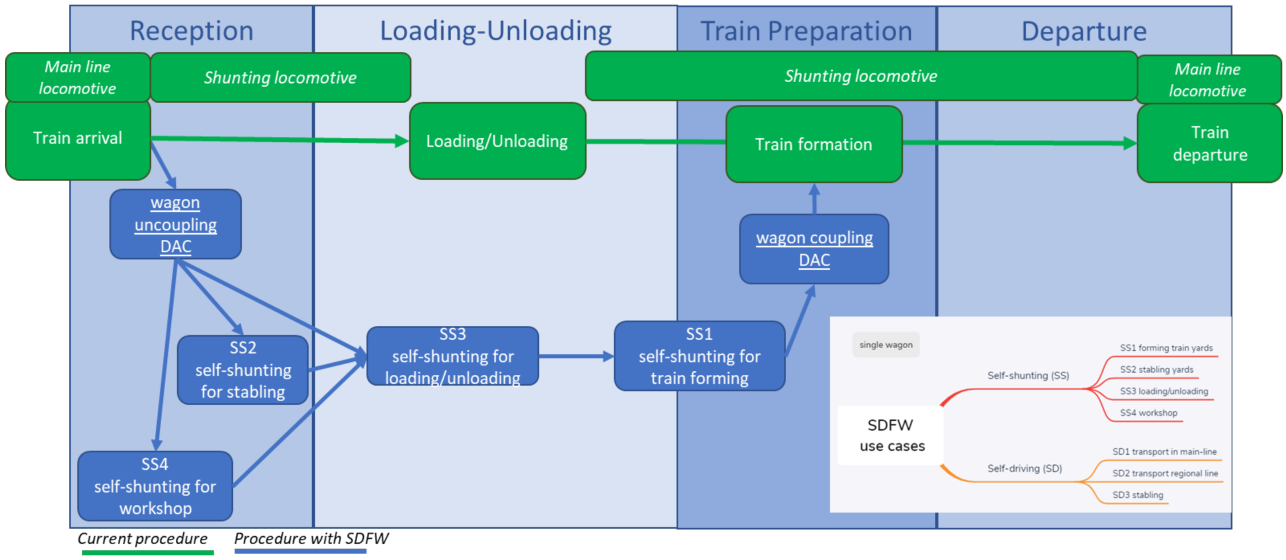


Figure 31: Current and SDFW procedures of JadeWeserPort (Germany)

3.3 UPDATE AND REVIEW OF USE CASES FOR SDFW

The strategy to update and review the initial list of use cases defined in the previous section was based on interviews with experts based on the questionnaire shown in this section. The results of the interviews included in this section, led to the final use cases of this document.

3.3.1 Questionnaire

The questionnaire consists of four differentiated parts as shown in Figure 32:

- **SDFW** definition
- Generic questions about the **SDFW** concept
- **SDFW** use cases
- Specific check-list about **SDFW** use cases

R2DATO

Guide for interview of Freight/Rail experts

Adapt questions to the role of the interviewed

1. SELF DRIVING FREIGHT WAGON (SDFW)

The Self Driving Freight Wagon (SDFW) concept embraces the idea of a saleable and modular automation system for the movement of the Freight Wagon for Automating Operations. The SDFW takes care about waking up, starting-ending the operation, controlling the movement and stabling.

The SDFW concept focuses on the operations that can be covered by the operation of a single wagon, both at Yards/Terminals and on the operational lines. Once the SDFW takes part of a consist, the operation is lead by the locomotive.

2. GENERIC OPEN QUESTIONS SDFW

1. Have you ever heard about SDFW? Have you ever seen a SDFW? In which context?
2. What would be for you the "perfect SDFW"? Why?

3. Staff needed: specific needs in comparison with "classic freight operation"?
4. What could be the main challenges to put in service a SDFW in terms of Fleet Management, Security rules, Rail Service Organisation, Yard operations, …?
5. Biggest opportunity for the SDFW? Biggest risk for the SDFW?

1

R2DATO

3. SDFW USE CASES

Seven use cases have been defined grouped into yard/terminal autonomous operations (SS) and autonomous operations into the operational lines (SD).

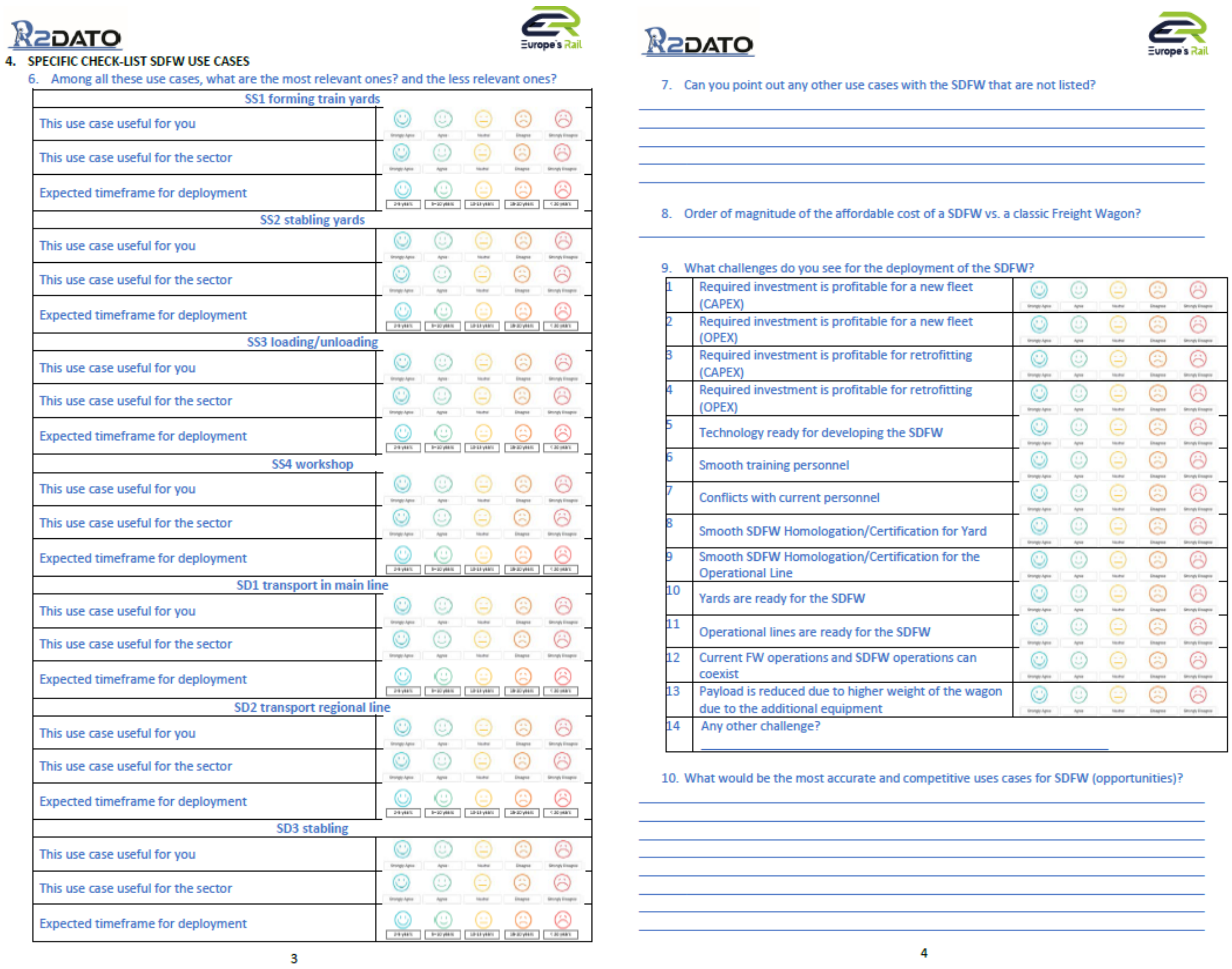
SS – Self Shunting: autonomous operations into the yard/terminal

- SS1 forming train yards: SDFW moves to the track where the target train composition in order to couple to corresponding wagon of the train composition.
- SS2 stabling yards: SDFW moves to the track where SDFW will be parked.
- SS3 loading/unloading: SDFW moves from from/to the track for loading/unloading.
- SS4 workshop: SDFW moves to the workshop.

SD – Self Driving: autonomous operations into the operational line

- SD1 transport in main line: SDFW travels in the main line.
- SD2 transport reginal line: SDFW travels in the regional line.
- SD3 stabling: SDFW moves to a siding/station track where it will be parked.

2



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Europe's Rail

4. SPECIFIC CHECK-LIST SDFW USE CASES

6. Among all these use cases, what are the most relevant ones? and the less relevant ones?

SS1 forming train yards	
This use case useful for you	
This use case useful for the sector	
Expected timeframe for deployment	
SS2 stabling yards	
This use case useful for you	
This use case useful for the sector	
Expected timeframe for deployment	
SS3 loading/unloading	
This use case useful for you	
This use case useful for the sector	
Expected timeframe for deployment	
SS4 workshop	
This use case useful for you	
This use case useful for the sector	
Expected timeframe for deployment	
SD1 transport in main line	
This use case useful for you	
This use case useful for the sector	
Expected timeframe for deployment	
SD2 transport regional line	
This use case useful for you	
This use case useful for the sector	
Expected timeframe for deployment	
SD3 stabling	
This use case useful for you	
This use case useful for the sector	
Expected timeframe for deployment	

3

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7. Can you point out any other use cases with the SDFW that are not listed?

8. Order of magnitude of the affordable cost of a SDFW vs. a classic Freight Wagon?

9. What challenges do you see for the deployment of the SDFW?

1	Required investment is profitable for a new fleet (CAPEX)	
2	Required investment is profitable for a new fleet (OPEX)	
3	Required investment is profitable for retrofitting (CAPEX)	
4	Required investment is profitable for retrofitting (OPEX)	
5	Technology ready for developing the SDFW	
6	Smooth training personnel	
7	Conflicts with current personnel	
8	Smooth SDFW Homologation/Certification for Yard	
9	Smooth SDFW Homologation/Certification for the Operational Line	
10	Yards are ready for the SDFW	
11	Operational lines are ready for the SDFW	
12	Current FW operations and SDFW operations can coexist	
13	Payload is reduced due to higher weight of the wagon due to the additional equipment	
14	Any other challenge?	

10. What would be the most accurate and competitive uses cases for SDFW (opportunities)?

4

Figure 32: Questionnaire related to the use cases

3.3.2 Interviews responses summary

11 interviews have been conducted with experts from different countries in Europe, namely, Sweden, Norway, Spain, Germany, Austria and France. These experts include the following profiles: wagon and digital transformation manager, account manager for freight wagons maintenance, security Expert for autonomous train, freight rolling stock responsible, rail freight performance deputy director, rail freight infrastructure manager, rail freight operators and researcher. The summary of the responses gathered for each of the questions are included as follows:

1. Have you ever heard about **SDFW**? Have you ever seen a **SDFW**? In which context?
    - The concept was new just for one of the experts.
    - One expert claims to have seen a **SDFW** in videos and photos.

2. What would be for you the **"perfect SDFW"**? Why?


2 bogies carrying a container


a complete wagon


other

Figure 33: Types of SFDW

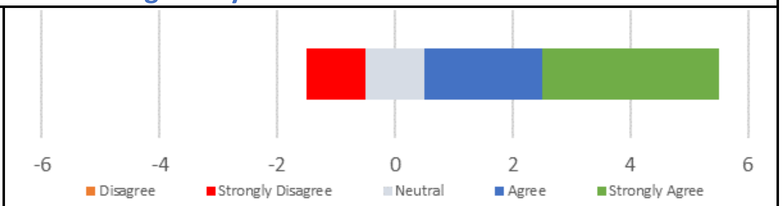
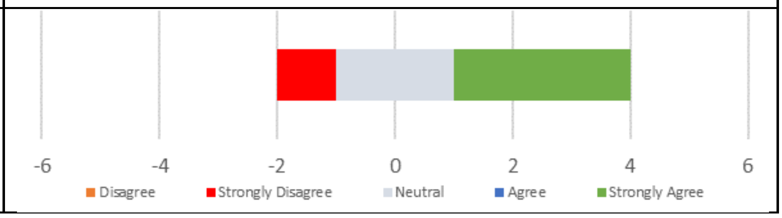
- Single wagon with bogies preferred by all.

3. **Staff needed:** specific needs in comparison with "classic freight operation"?
   - Less personnel
   - Need to be trained in other technologies/procedures (equipment, maintenance, ...)
   - Safety procedures to be updated

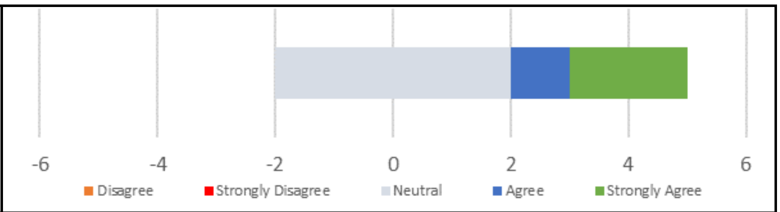
4. What could be the **main challenges** to put in service a **SDFW** in terms of Fleet Management, Security rules, Rail Service Organisation, Yard operations, …?
   - Safety - less staff
   - Cost - investment, ROI, effective use.
   - Procedures - Interface between **SDFW** and the Yards, Rail connected terminal

5. Biggest **opportunity** for the **SDFW**? Biggest **risk** for the **SDFW**?
   - Opportunity
     - Cost: save money
     - Yards-terminal-private lines (non mainline)
   - Risk
     - Costs: high investment
     - Safety
     - Incompatibility with current wagons

6. Among all these use cases, what are the most relevant ones? and the less relevant ones?

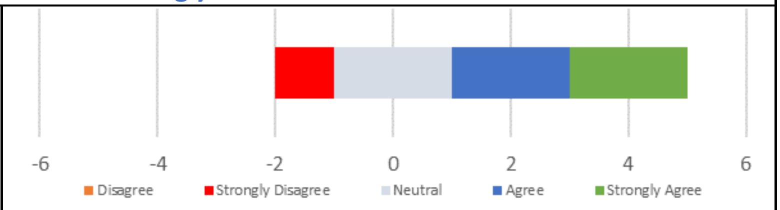
SS1 forming train yards	
This use case useful for you	
This use case useful for the sector	

Expected timeframe for deployment

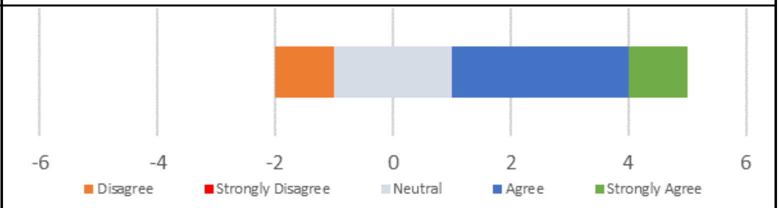


SS2 stabling yards

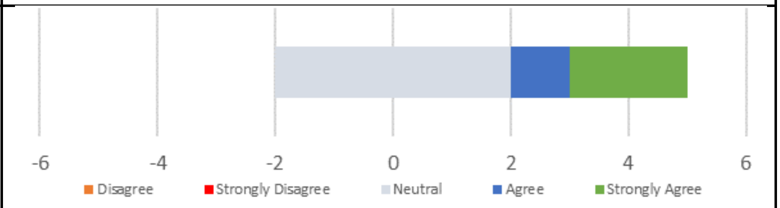
This use case useful for you



This use case useful for the sector

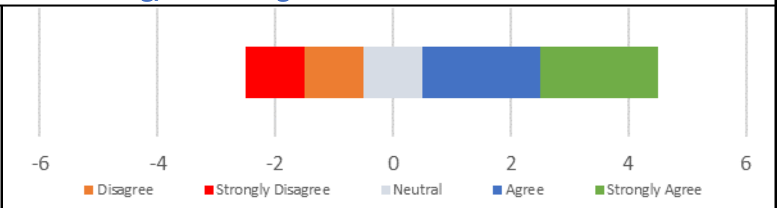


Expected timeframe for deployment

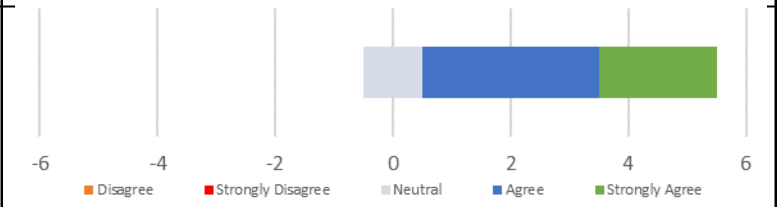


SS3 loading/unloading

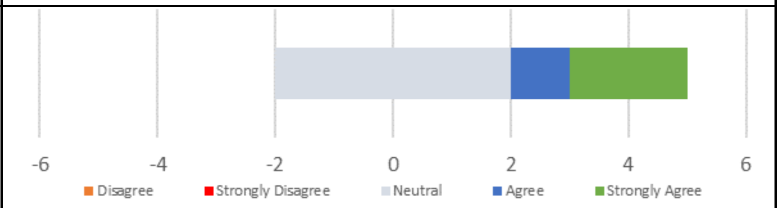
This use case useful for you



This use case useful for the sector

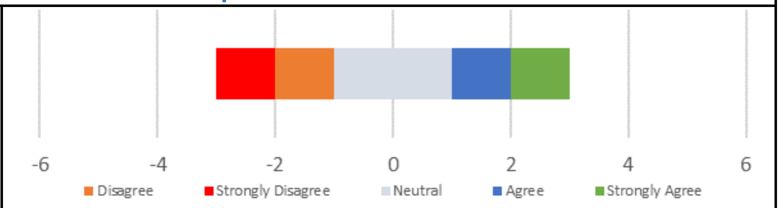


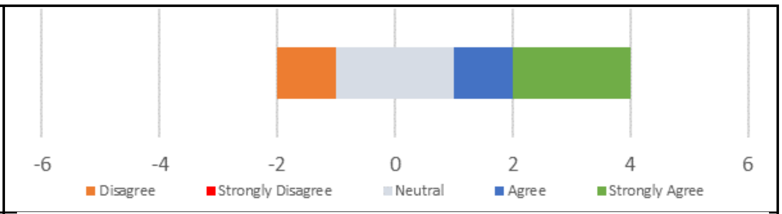
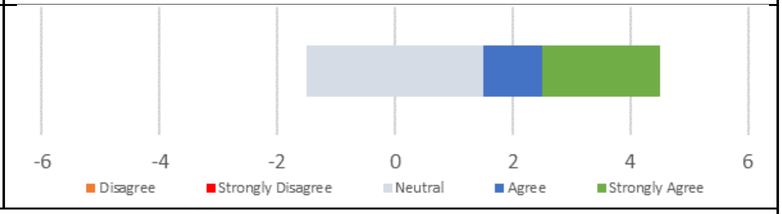
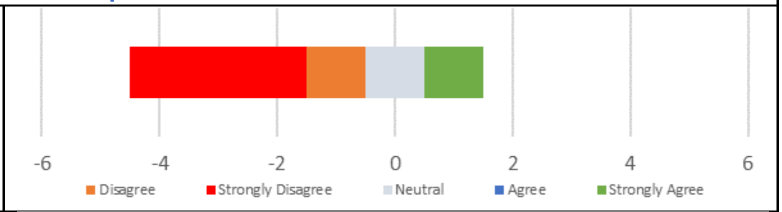
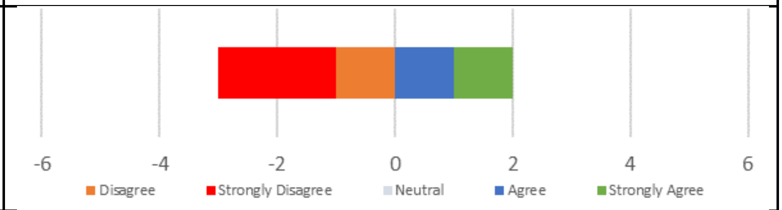
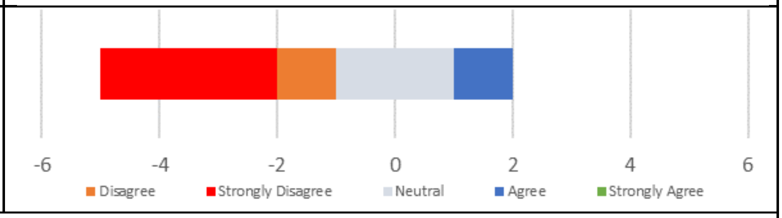
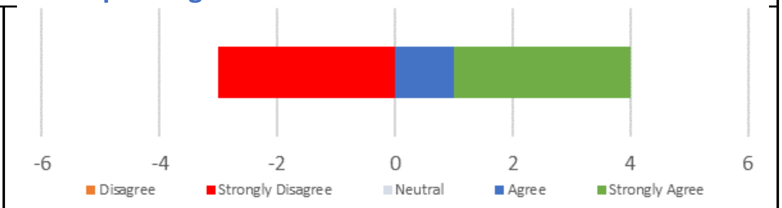
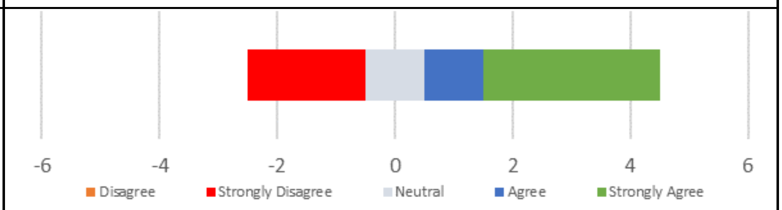
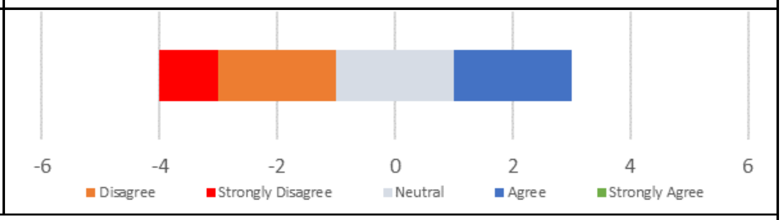
Expected timeframe for deployment



SS4 workshop

This use case useful for you



This use case useful for the sector	
Expected timeframe for deployment	
SD1 transport in main line	
This use case useful for you	
This use case useful for the sector	
Expected timeframe for deployment	
SD2 transport regional line	
This use case useful for you	
This use case useful for the sector	
Expected timeframe for deployment	
SD3 stabling	

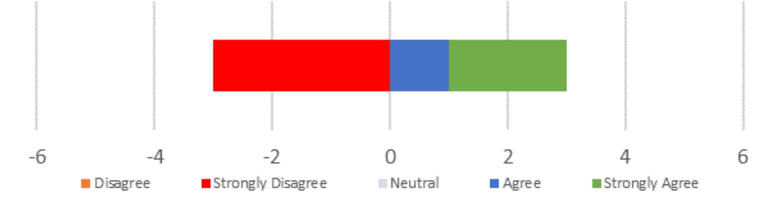
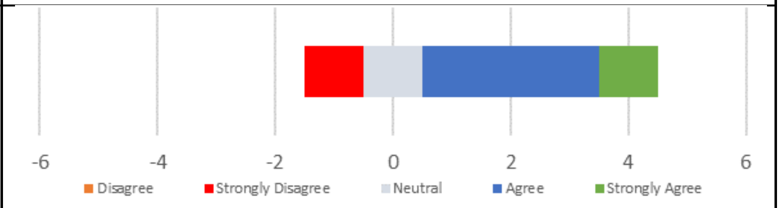
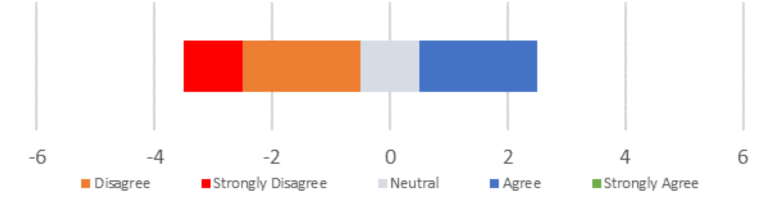
This use case useful for you	
This use case useful for the sector	
Expected timeframe for deployment	

Table 7: Responses of the question #5: Among all these use cases, what are the most relevant ones? and the less relevant ones?

7. Can you point out any other use cases with the **SDFW** that are not listed?

- Public railway network
  - Snow removal
  - Last mile operation (up to 50km)
  - Transporting material for railways work - maintenance
  - Transporting material for railways construction
  - Military purposes
- Private railway network / track
  - Customer private lines
  - Tunnel operations in mines
  - Movement inside the workshop
  - Snow removal
  - Last mile operation (up to 50km)
  - Transporting material for railways work - maintenance
  - Transporting material for railways construction
  - **SDFW** as "shunting loco" for other FWs

8. Order of magnitude of the affordable cost of a **SDFW** vs. a classic Freight Wagon?

- Min. range: +25% (purchasing)- +50% (purchasing)
- Max. range: x3 (purchasing + maintenance)
- Affordable price depends on budget available with depends on whether locomotives are replaced by buying a new one.

9. What challenges do you see for the deployment of the **SDFW**?

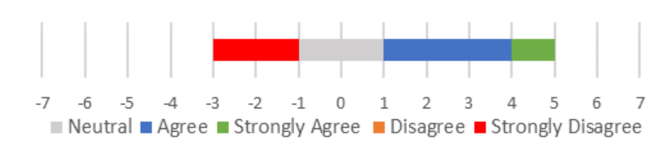
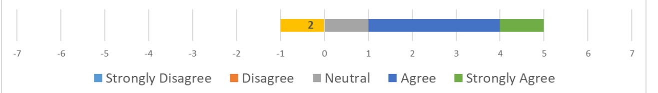
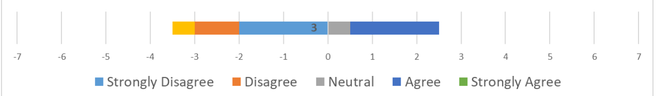
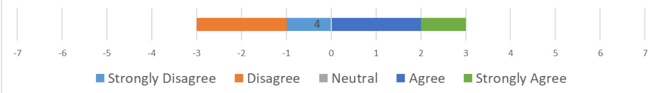
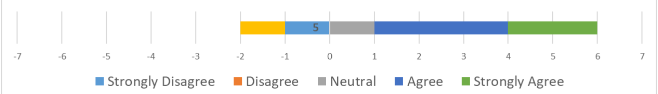
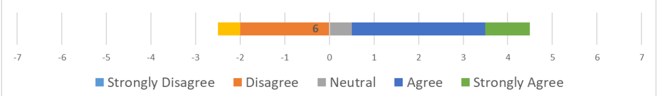
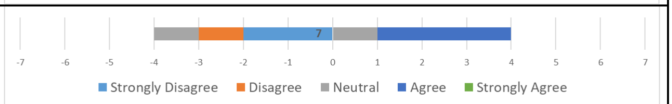
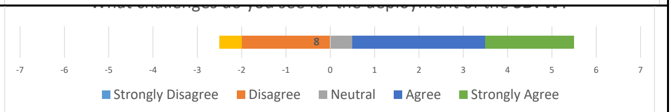
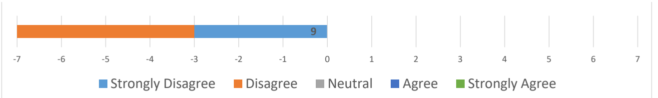
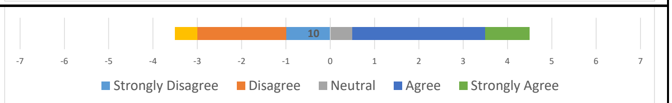
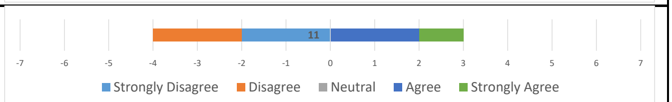
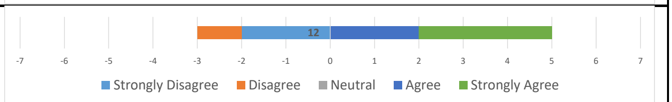
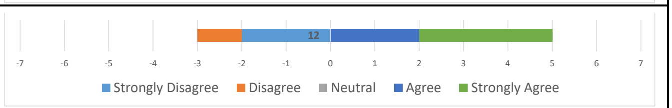
1	Required investment is profitable for a new fleet (CAPEX)	
2	Required investment is profitable for a new fleet (OPEX)	
3	Required investment is profitable for retrofitting (CAPEX)	
4	Required investment is profitable for retrofitting (OPEX)	
5	Technology ready for developing the **SDFW**	
6	Smooth training personnel	
7	Conflicts with current personnel	
8	Smooth **SDFW** Homologation/Certification for Yard	
9	Smooth **SDFW** Homologation/Certification for the Operational Line	
10	Yards are ready for the **SDFW**	
11	Operational lines are ready for the **SDFW**	
12	Current FW operations and **SDFW** operations can coexist	
13	Payload is reduced due to higher weight of the wagon due to the additional equipment	
14	Any other challenge? ____	

Table 8: Responses question #9: What challenges do you see for the deployment of the SDFW?

10. What would be the most accurate and competitive uses cases for **SDFW** (opportunities)?

- Wagon classification
- Last mile operation
- Movement in private yards

3.3.3 Conclusion of the interviews leading to the updated list of use cases

Seven initial use cases (section 3.2) have been defined grouped into yard/terminal autonomous operations (SS) and autonomous operations into the operational lines (SD).

- SS – Self Shunting: autonomous operations into the yard/terminal
  - SS1 forming train yards: **SDFW** moves to the track where the target train is located in order to couple to the corresponding wagon of the train.
  - SS2 stabling yards: **SDFW** moves to the track where **SDFW** will be parked.
  - SS3 loading/unloading: **SDFW** moves from from/to the track for loading/unloading.
  - SS4 workshop: **SDFW** moves to the workshop.
- SD – Self Driving: autonomous operations into the operational line
  - SD1 transport in main line: **SDFW** travels in the main line.
  - SD2 transport regional line: **SDFW** travels in the regional line.
  - SD3 stabling: **SDFW** moves to a siding/station track where it will be parked.

From the responses of question #6 (see Table 9) where the interest of the use cases to the interviewed, and for the sector and the expected timeline for deployment has been asked, the score for all the use cases can be obtained. It can be seen that for the SS use cases, SS1, SS2 and SS3 obtained similar scores, while SS4 had a lower score, and for the SD use cases the SD2 obtained a higher score than SD1 and SD3.

	SS1	SS2	SS3	SS4	SD1	SD2	SD3
All	75	76	75	63	46	65	54
Sector	22	25	25	22	15,5	24	21
Sector and time deployment	48	51	51	45	30,5	43	37
Time deployment	26	26	26	23	15	19	16

Table 9: Responses question #6: classification of relevant use cases

From questions #7 a list of additional use cases has been obtained and from question #10 the most accurate and competitive can be identified. Some of the use cases mentioned are included in the current list. The next table shows the updated list of use cases where 4 new SS and 4 new SD use cases are included, and its traceability to the use cases of the initial list.

	SS1	SS2	SS3	SS4	SD1	SD2	SD3	SS5	SD4	SD5	SD6	SD7	SS6	SS7	SS8
Most accurate and competitive use cases															
Wagon classification	x														
Last mile operation[4]	x		x		x	x									
Movement in private yards	x	x	x	x											

[4] Last mile operation is considered up to 50km

	SS1	SS2	SS3	SS4	SD1	SD2	SD3	SS5	SD4	SD5	SD6	SD7	SS6	SS7	SS8
Public railway network: under the TMS control, ATP required															
Snow removal									X						
Last mile operation (up to 50km)					X	X									
Transporting material for railways work - maintenance										X					
Transporting material for railways construction											X				
Military purposes												X			
Private railway network / track: under the YAMS control, ATP non required															
Customer private lines	X	X	X	X											
Tunnel operations in mines	X	X	X												
Movement inside the workshop				X											
Snow removal								X							
Last mile operation (up to 50km)	X		X												
Transporting material for railways work - maintenance													X		
Transporting material for railways construction														X	
***SDFW** as "shunting loco" for other FWs*															X

Table 10: The next table shows the updated list of use cases where 1 new SS and 5 new SD use cases are included, and its traceability to the uses cases of the initial list.

The next figure shows the updated list of use cases with eight use cases for the SS and seven use cases for the SD.

Figure 34: SDFW updated use cases list

3.4 REFERENCE USE CASES

From the analysis done, the following use cases are selected as reference use cases for the next sections. This is done due to the score obtained in question #6 (Table 9) and the traceability to the number of use cases gathered in the responses to the questionnaire (Table 10).

- SS: autonomous operations into the yard/terminal, it also includes last mile operation
  - SS1 forming train yards: **SDFW** moves to the track where the target train composition in order to couple to corresponding wagon of the train composition.
- SD: autonomous operations into the operational line
  - SD2 transport regional line: **SDFW** travels in the regional line.

4 RELATION TO FP1-MOTIONAL AND FP5-TRANS4M-R

This section is dedicated to the description of FP1-MOTIONAL and FP5-TRANS4M-R projects and extract those aspects linked to the **SDFW**.

4.1 Relation to FP1-MOTIONAL

This subsection briefly describes FP1-MOTIONAL project [4] and provides the topics related to the **SDFW**.

4.1.1 Flagship Project 1: MOTIONAL - mobility management multimodal environment and digital enablers [4]

The project FP1-MOTIONAL aims at improving planning and operational management of rail services and offers to meet the European goal of making rail the preferred mode of transport. Thanks to the potential of digitalization, the project aims at developing a future European Traffic Management System (TMS) that is interoperable, resilient and able to adapt the capacity and integrate all involved services. It also includes last mile operations provided by other transport modes.

The project is divided into two major workstreams (WS). WS1 is focusing on planning and operation activities, as well as integration activities.WS2 is delivering transversally across the programme a set of digital enablers to support the development of destination-specific digital solutions such as Digital Twins.

4.1.2 Project objectives, WPs and technical enabler [4]

Improved planning and operational management of services and offers is of paramount importance to meet the European ambitious target to make rail the preferred mode of transport in the future. The future European railway system will be interoperable, resilient, able to adapt capacity and able to integrate all involved services including last mile operations, exploiting the opportunities provided by digitalisation. The development of the future European Traffic Management is key for achieving the foreseen Single European Railway Area (SERA).

Today, rail traffic is managed on national or regional level, supported by legacy systems with a poor level of digitalisation and weak integration with systems of other actors participating in the overall traffic planning and management process.

Through the development of functional requirements, associated specifications and operational or technological solutions and by taking advantage of the potential of digitalisation, the Project "FP1-MOTIONAL" is paving the way towards the implementation of the future European Rail Traffic Management System to make rail the backbone of a multimodal transport system for passengers and freight.

The planned activities to achieve the objectives of Flagship Area 1 are carried out in two major workstreams.

- Workstream 1 (WS1) is focused on Planning and Operation activities (dealing with the future interactively linked timetable planning and operational traffic management systems) and Integration Activities (dealing with railway centred door-to-door mobility service offers).

  Digitalisation is a fundamental transformational process encompassing the rail system as a whole, affording greatly expanded opportunities for innovation in the form of machine 'intelligence' injected in the system through advanced information sharing and processing solutions. These new solutions, which will be developed in all of Europe's Rail (EU-RAIL) Flagship Areas, will allow tackling long-standing hard technical and operational issues in the rail system, e.g. interoperability. But even more importantly, they will provide the potential for the creation of new added value from the rail system physical and technical assets, and from its organisational and human knowledge.

- Workstream 2 (WS2) will deliver a set of digital enablers for all EU-RAIL Flagship Areas (i.e. "transversal") to support them in the development of destination-specific digitalisation solutions with:
  - a common scalable, reliable and interoperable data sharing and communications infrastructure,
  - a common machine-readable semantic and syntactic description of the data, and
  - a common digital assets planning, engineering and Digital Twin support development and run-time environment.

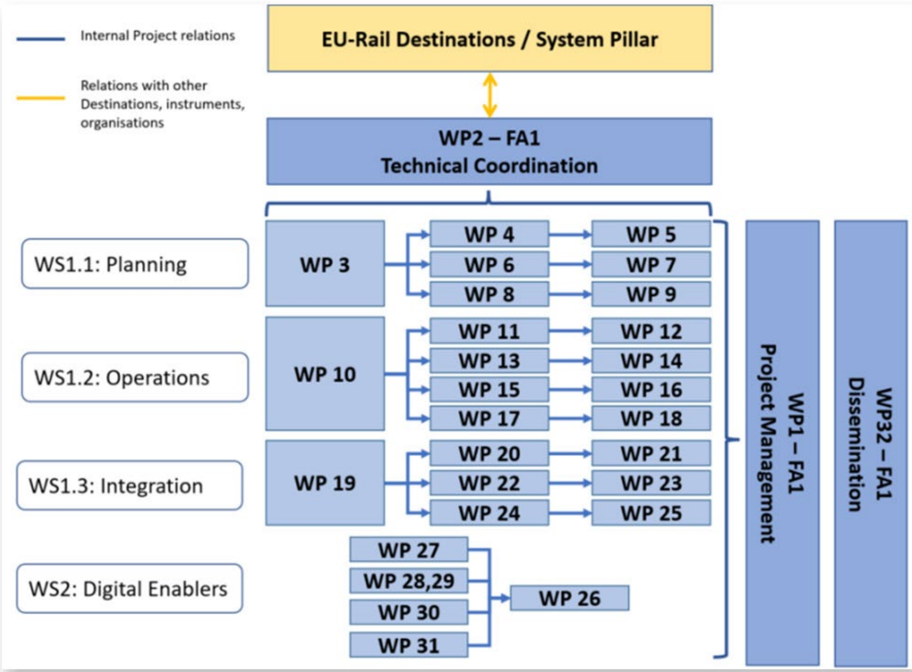


Figure 35: FP1-MOTIONAL WP structure

WP#	Title	Brief description
WP01	Project Management	
WP02	Technical Coordination	
WP03	Specifications of demonstrators for improved strategic and tactical planning of the rail network	To align, prepare and deliver the high-level (Workstream 1.1) specifications of requirements, high- level design and high-level use cases for development of the Technical Enablers 1 to 7.
WP04	Development - Integration of planning systems and processes including cross-border planning The objectives of this work package are to provide detailed design and use case definitions for the development of Technical Enablers 1, 2 and 6.	Enabler 1: European cross-border scheduling with international train path planning [TRL 6/7] Enabler 2: Improved capacity allocation using rolling planning and TTR [TRL 6/7] Enabler 6: Integration of planning systems and TMS with a) yard capacity planning and b) station capacity planning [TRL5/6]
WP05	Demonstration - Integration of planning systems and processes including cross-border planning	The overall objective of WP5 is to demonstrate and further develop the demonstrator modules in WP5, to ensure to reach

		the target TRLs that allow the verification of the achievement of the goals of WP4 and WP5
WP06	Development- Decision support for planning and timetable optimisation	The objective of this WP is to improve long-term and short-term timetabling of the railway network. The activities aim at increasing infrastructure and transport utilisation capacity through optimised and robust timetables, synchronized with rolling stock planning, among others. In WP6, advanced algorithms are developed for the generation and adjustment of timetables and rolling stock planning.
WP07	Demonstration - Decision support for planning and timetable optimisation	The objective of this WP is to further develop and demonstrate the algorithms developed in WP6, also by the creation of a testbed and a benchmark methodology for conducting rigorous, transparent, and replicable testing for comparing both the algorithms and the plans/timetables generated by them. Finalisation of development and demonstrations for Technical Enablers 3, 4 and 6 will be performed at target TRL 5/6 using decision support systems on short-term planning, algorithms for long-term timetabling, integrated network and station planning as well as rolling stock planning.
WP08	Development - Simulation and operational feedback for improved planning	The objective of this work package is to develop and improve railway traffic simulation methods, models and knowledge to enable more reliable and effective capacity and punctuality evaluations and predictions of the railway network. The developed methods and models will be used to improve feedback loops between operations and planning and to increase knowledge about the potential capacity impact of new technologies like C-DAS, ATO, ETCS L2 with optimised braking curves and ETCS Hybrid Level 3. This WP covers the following enablers: Enabler 5: Improved rail traffic simulation models for selected Use Cases to forecast punctuality in the network (e.g., simulating proportion primary and secondary delays, simulations drivers vs. ATO over ETCS …). [TRL6/7] Enabler 7: New planning and operational processes using feedback loops from ERTMS ATO and C-DAS [TRL5/6].
WP09	Demonstration - Simulation and operational feedback for improved planning	To validate and demonstrate the models and methods developed in WP8 regarding both technical enablers 5 (TRL6/7) and 7 (TRL5/6). The potential capacity impact of new technologies such as C-DAS, ATO, ETCS L2 with optimised braking curves and ETCS Hybrid Level 3 will be evaluated to get a better understanding on how these new technologies can contribute to improved capacity and punctuality.
WP10	Alignment of specifications	The objectives of this work package are to align, prepare and deliver the high-level specification of requirements, high-level design and high-level use cases based on a state-of-the-art analysis undertaken in conjunction with Technical Enablers 8 to 17
WP11	Development - Integration of TMSs and processes including cross-border traffic management	The overall objectives of WP11 are linked to Technical Enablers 8, 9 and 10 covering specification, and development of use-cases, processes and interfaces needed to achieve a much higher integration level of functions and decision processes including increase of the precision of the traffic prediction. In focus are also the alignment between different TMS areas including cross-border and integration of TMS with yard station and energy management systems as well as crew and rolling stock planning and management systems.

WP12	Demonstration - Integration of TMSs and processes including cross-border traffic management	Much higher integration level of functions and decision processes including an increase of the precision of the traffic prediction.
WP13	Development - Improved resilience and efficiency of disruption management	The overall objective is to develop prototypes for a cooperative multi-actor optimisation and decision support system for incidents and disruption management, with human-in-the-loop through an advanced HMI, to increase system resilience and efficiency.
WP14	Demonstration - Improved resilience and efficiency in disruption management	Development of the demonstrators that will allow the verification of the achievement of the goals of WP13 validating the integration of the DSS in a Control Center and HMI, to automate tasks, reduce operators' workload, improve efficiency of disruption management and to promptly inform the involved actors.
WP15	Development - Linking TMS to ATO/C-DAS for optimised operations	Seamless integration between TMS and ATO/C-DAS.
WP16	Demonstration - Linking TMS to ATO/C-DAS for optimised operations	Demonstration of seamless integration from TMS and ATO by testing them in an emulated "live" environment by human-in-the-loop demonstration and test bench.
WP17	Development - Automated decisions and decision support for traffic management optimisation	Specify the requirements and implement the algorithms providing decision support and whenever possible automatic decisions for traffic management optimisation as well as to verify their suitability for different applications.
WP18	Demonstration - Automated decisions and decision support for traffic management optimisation	Demonstrations of the developments performed in WP 17.
WP19	Alignment of Specifications for Enabler 18 - 27	Development specifications, requirements, Gathering information, Definition of planned work in the development and demonstration WPs, Design high level architecture and Use Cases and Analyse the available data sets and information
WP20	Development: Integrate Rail with other transport modes	Development of improved rail integration using B2B intermodal services and harmonised interfaces between rail operators and other transport modes, leveraging existing European standards when applicable to enhance collaboration between mobility providers and support B2B integration including the objective to deliver an enhanced end-user experience.
WP21	Demonstration: Integrate Rail with other transport modes	Demonstration of improved rail integration using B2B intermodal services and Harmonised interfaces between rail operators and other transport modes.
WP22	Development: Services for inclusive rail-based mobility	Services and solutions that improves the quality of the travel and it is focused on the support to PRM and passengers with special needs.
WP23	Demonstration: Services for inclusive rail-based mobility	Demonstration of a set of services and solutions associated with inclusive rail-based mobility.
WP24	Development: Anticipate demand leading to improved resource utilisation	Solutions associated with demand anticipation in order to improve resource utilisation.
WP25	Demonstration: Anticipate demand leading to improved resource utilisation	The objective is to demonstrate a set of services and solutions developed in WP 24, associated with the anticipation forecasts of the demand for mobility in the different modes, and rail capacity optimisation and management/information of the disruptions across modes.
WP26	Digital Process Scenarios from all FA	Coordination of the work performed in the development of common digital enablers (Workstream 2), connecting it to the MOTIONAL project's workstream 1, to all other Destinations and to System Pillar activities.

WP27	Digital Asset Engineering (Multidisciplinary Process)	Digitise and automate the whole planning phases to ease engineering work, reduce costs of development and testing, and reduce time to deployment.
WP28	Digital Twin Environment Preparation	Design of an environment for building up and using Digital Twins and Digital Twin assemblies, which are defined as virtual representations able to imitate the behaviour of the physical railway system, its multiple heterogeneous subsystems and interactions during their lifetime.
WP29	Digital Twin Environment Implementation	Digital Twins that are capable of digitally representing the behaviour of the physical railway system, its multiple heterogeneous subsystems and interactions during their lifetime.
WP30	Conceptual Data Model and semantic dictionary evolution	Conceptual Data Model offering, a project independent railway system model with rich semantics based on a federation of UML source models. A railway semantic dictionary has been subsequently built which collects ontologies extracted from the conceptual models and allows their interlinking.
WP31	Federated Data Space	Deliver data federation services for building a trusted, reliable, cybersecure federated data space for the rail ecosystem - the Rail Data Space.
WP32	Communication, dissemination and exploitation of results	

Table 11: FP1-MOTIONAL WP list [4]

To achieve the operational outcomes targeted in this Flagship Area, several technical capabilities were identified by FP1. To develop flagship demonstrations, some functions must be delivered with enough maturity, with a target TRL indicated for each enabler.

Enabler 1	European cross-border scheduling with international train path planning [TRL6/7]
Enabler 2	Improved capacity allocation using rolling planning and TTR [TRL6/7]
Enabler 3	Decision support for short term planning [TRL5/6]
Enabler 4	Train path and schedule optimisation methods and strategies for capacity efficiency, punctuality and energy saving for different parts of the network and different traffic situations (level of punctuality). [TRL5/6]
Enabler 5	Improved rail traffic simulation models for selected Use Cases to forecast punctuality in the network (e.g., simulating proportion primary and secondary delays, simulations drivers vs. ATO over ETCS). [TRL6/7]
Enabler 6	Integration of planning systems and TMS with a) yard capacity planning and b) station capacity planning [TRL5/6]
Enabler 7	New planning and operational processes using feedback loops from ERTMS ATO and C-DAS [TRL5/6]
Enabler 8	Real-time connection of rail networks as managed by TMSs and involved actors [TRL6/7]
Enabler 9	Modelling and decision support for cross-border traffic management [TRL5/6]
Enabler 10	Integration of TMS with a) yard management system and processes; b) station management system and processes; c) energy management (Electric Traction System); d) real-time crew / rolling stock dispatching [TRL6/7]
Enabler 11	HMI for TMS based on User Experience (UX) Design and user input [TRL8];
Enabler 12	Real-time convergence between planning & feedback loop from operations [TRL4/5] and Technical Enabler 15; TMS speed regulation of trains, precise routes and target times for ATO and dynamic timetables [TRL4/5].
Enabler 13	Cooperative planning multi-actors within rail [TRL4/5]; and

Enabler 14	Integration of incident management and customer information, with IM and RU interaction and Decision Support for Disruption management [TRL4/5]. Feedback-loop with traffic simulation (Technical Enabler 12) verifying the algorithms of Technical
Enabler 15	TMS speed regulation of trains, precise routes and target times for ATO and dynamic timetables
Enabler 16	Automation of very short-term train control decisions [TRL5]
Enabler 17	Real-time conflict detection & resolution for main line and optimisation [TRL4/5] All of the developments regarding both technical enablers have a TRL 4.
Enabler 18	Improved rail integration using B2B intermodal services. This covers aspects of cross-operator information, sharing on e.g. sales and distribution, traffic information, end-user experience.
Enabler 19	Harmonised interfaces between rail operators and other transport modes, leveraging existing European standards when applicable to enhance collaboration between mobility providers and support B2B integration including the objective to deliver an enhanced end-user experience. The TRL 5 developments within this WP will be based on the specifications and analysis done in WP19. Within this WP TRL5 will be reached in order to be used for the demonstrators.
Enabler 20	Focused on services and solutions that improves the quality of the travel and it is focused on the support to PRM and passengers with special needs
Enabler 21	Dedicated to the development of delivering hands free experience for travellers using rail services and transferring between rail operators, other mobility modes and developing a Wi-Fi Roaming setup, which will allow travellers using different rail operators to seamlessly stay online
Enabler 22	Focused on the development of smart solutions for better passenger flow and guidance that is based on real-time provided in different channels adapted to the different user's capabilities in order to allow the data Exchange between smart phones and infrastructure that would improve guidance. The developments within this WP are based on the specifications and analysis done in WP19. This WP will reach TRL4 for Enabler 20 and 22 and TRL 5 for Enabler 21, results will be used for the demonstration in WP23.
Enabler 23	Short term demand forecast calculation using run time data (e.g. ticketing data, short term weather forecast, passenger density, ….)
Enabler 24	Long term demand forecast with focus on data analytics based on a variety of sources (e.g., public events, holiday calendar) and operators' data (e.g., fare, passenger density data) and historical information for predictive models related to passenger clustering
Enabler 25	Integrated traffic simulation and demand forecast in a Digital Twin to optimise offer, passenger occupancy, connection time and other service-related elements
Enabler 26	Optimised rail capacity to better match the demand; Synergy between short term and long-term forecast (e.g. weather forecast for an airport line) combined with Digital Twins in order to provide optimisation guidance
Enabler 27	Disruption management across different mobility modes enabling operators to collaboratively solve the disruption and properly inform passengers The developments within this WP are based on the specifications and analysis done in WP19 and will reach TRL 4-5. All results developed are used for the demonstrations in WP25. The demonstrations take place in a set of hubs or labs (depending on the task or sub-task details) where the adequate equipment and infrastructure is made available.
Enabler 28	Federated data space
Enabler 29	Conceptual data model (CDM)
Enabler 30	Digital Twin Design-time environment
Enabler 31	Digital Twin run-time environment

Table 12: FP1-MOTIONAL Technical Enablers list [4]

4.1.3 Relation to the SDFW

The TE10 includes yard management system and processes, which is included in WP10 Specification, WP11 Development and WP12 Demonstrator.

Enabler 10	Integration of TMS with a) **yard management system and processes**; b) station management system and processes; c) energy management (Electric Traction System); d) real-time crew / rolling stock dispatching [TRL6/7]

Table 13: FP1-MOTIONAL Technical Enabler 10 [4]

The TE10 will help to improve traffic management decisions by integrating TMSs with the systems and processes mentioned in the TE10 title and being external to traffic management. This will lead to more realistic train running forecast as a basis for traffic management decisions and induced changes to the Operational Plan. As a result, the Operational Plan managed by the TMS anticipates and addresses very short term or dynamic variations of resource availability or other dependencies made available through the integrated systems in conjunction with train operation.

In Europe, the today's traffic management process using national TMSs is focused on freight and passenger trains as operating on the railway lines' tracks. Based on experience, timing allowances or supplements in the timetables are used to cover non-knowledge of factors influencing the timing of trains with respect to their arrival or departure at stations or handling points. Up to a certain extent, the additional time granted also covers unawareness of different activities or constraints of resource usage impacting train operation on the lines. Today, there is no transparency about how much of the additional time will effectively be used for these activities or constraints and if these would even cause delays. As a result, any already known delay in these activities will not be communicated technically to the TMS to consider it for the forecast calculation which itself leads to less realistic forecast and finally non optimum traffic management decisions. In some situations, a very short-term change of the linked activities or resource constraints and their impact could even lead to a non-compliance of operational rules in conjunction with the current operational plan. In this case, the operational plan needs to be substantially changed in terms of e.g., train cancellation or exchanges of rolling stock/crew.

In most of the above situations, the problems are due to there is no or only insufficient integration with systems and processes related to yard or station management, asset/maintenance planning and management, real-time crew/rolling stock dispatching and electric traction systems. Moreover, these systems are lacking early information about delay or operational plan changes being required for providing a high-quality information back to the TMS.

The needs identified at a general level related to **SDFW** are to improve the quality of manual or automatic traffic management decisions, the train running forecast of the TMS needs to be improved by integration of TMS with systems and processes related to yard or station management. This includes the Req. 10.1 related to the interface with yards and stations. This is in line with to the Use-case UC-FP1-WP10-15: Sending and Receiving track allocation information between TMS and YCS, where the interaction between TMS and YCS is defined.

The TMS operator has an updated view on track allocation that has impact on interaction with neighbouring area supervised and controlled by an YCS, where the YCS operator has an updated view on track allocation that has impact on interaction with neighbouring TMS area.

4.2 RELATION TO FP5-TRANS4M-R

This subsection briefly describes FP5-TRANS4M-R project and provides the topics related to the **SDFW**.

4.2.1 Flagship Project 5: TRANS4M-R - Sustainable Competitive Digital Green Rail Freight Services [5]

Flagship Project 5: TRANS4M-R aims at enhancing the attractiveness and competitiveness of rail freight will also increase the greening of European logistic and its resilience, by improving capacity, cross-border operations, and multimodal customer services. An essential enabler is the Digital Automatic Coupler (DAC) together with the implementation of full digital rail freight train and integrated / seamless rail freight operations. The project follows three working streams: WS1: full digital Freight Train Operations with DAC as an enabler, WS2: Seamless Freight with easy access and reliable (intermodal) transport service offering digital solutions and WS3: Innovative Freight Assets. The third one has been created recently and it is not presenting the official images that illustrate this flagship project 5.

4.2.2 Project objectives, WPs and technical enabler [5]

FP5-TRANS4M-R's overall goal is to establish rail freight as backbone of the lowest emission and most resilient logistics chain in Europe, fulfilling the end customer requirements to their full satisfaction. Therefore, the project builds upon the goals and vision of the European Commission addressing the needs to significantly boost the rail freight transport through increased capacity, strengthened cross-border coordination and cooperation between rail infrastructure managers, better overall management of the rail network, and the deployment of new technologies such as digital coupling and automation. These goals set the foundation, frame, and ambition for the project.

- Objective 1: Higher throughput and shorter transportation duration: Develop, validate, and demonstrate the FP5-TRANS4M-R technologies and thereby enabled train functions and operational procedures leading to:
  - at least 40% decrease of train formation/decomposition time,
  - train preparation time of at least 45%, while
  - enabling freight train compositions up to 1500 meters
- Objective 2: Maximize flexibility and reliability of rail freight services: Develop, validate, and demonstrate the FP5-TRANS4M-R digital rail freight services and software solutions significantly contributing to achieve in 2030 the MAWP objectives:
  - Reduce average transportation time on reference corridor by 10-20%.
  - Reduce operational dwell time at borders and other handover points by 50%.
  - Reduce the number of additional operational stops (also limiting the energy consumption) by 20%.
  - Reduce handling/response time for ad-hoc cross-border path requests by 70%.
  - Reduce handling/response time for connected comprehensive intermodal offers by at least 50%.
  - Reduced energy consumption and reduced footprint through less stops at borders by a minimum of 10%
- Objective 3: Mitigating demographic change: With the demographic change not only the average age of employees is increasing but also less people are available for physically demanding work especially in yards, such as train preparation, coupling, uncoupling and

further operational processes. FP5-TRANS4M-R provides the necessary technologies to automate/digitalise operational processes, but also instructions and guidelines to maximise the acceptance of the newly developed digital technologies.

FP5-TRANS4M-R is focussing on the key innovation drivers for the rail freight system to shift transport volumes to rail, reducing substantially the related greenhouse gas emissions. To speed up the innovation availability the project's activities are split in two distinct clusters "Full Digital Freight Train Operation" and "Seamless Freight Operation" (Figure 36). These clusters are fundamental to achieve the European Green Deal objectives of the European Union and will only collaboratively secure a significant improvement of rail freight.

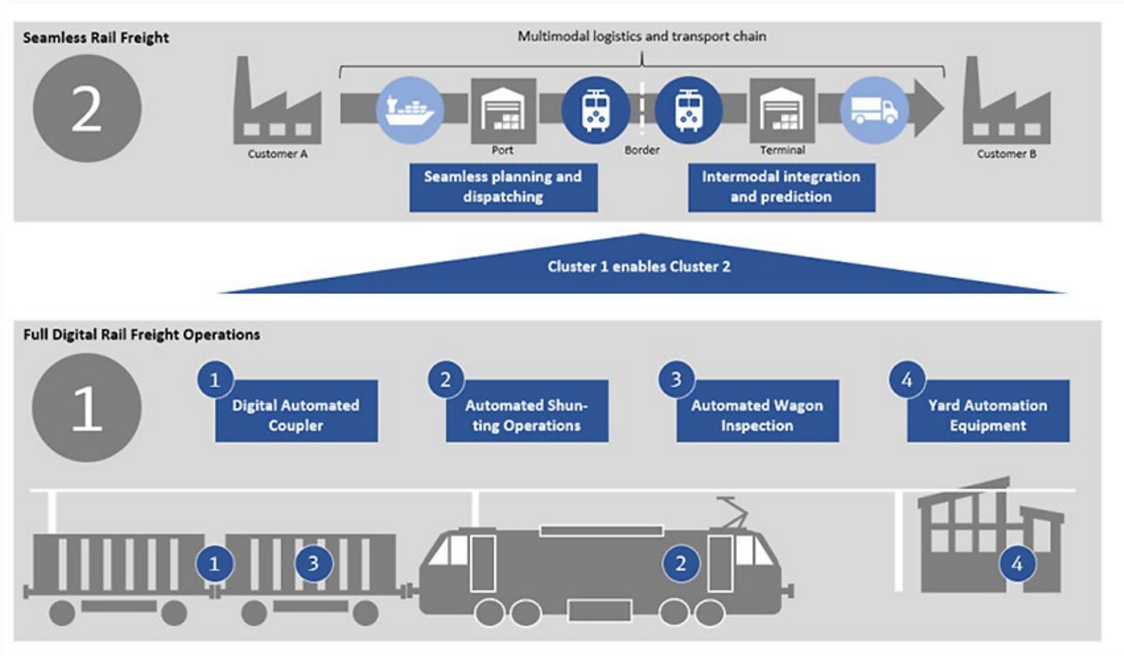


Figure 36: FP5-TRANS4M-R clusters [5]

The detailed project breakdown structure is hereinafter illustrated.

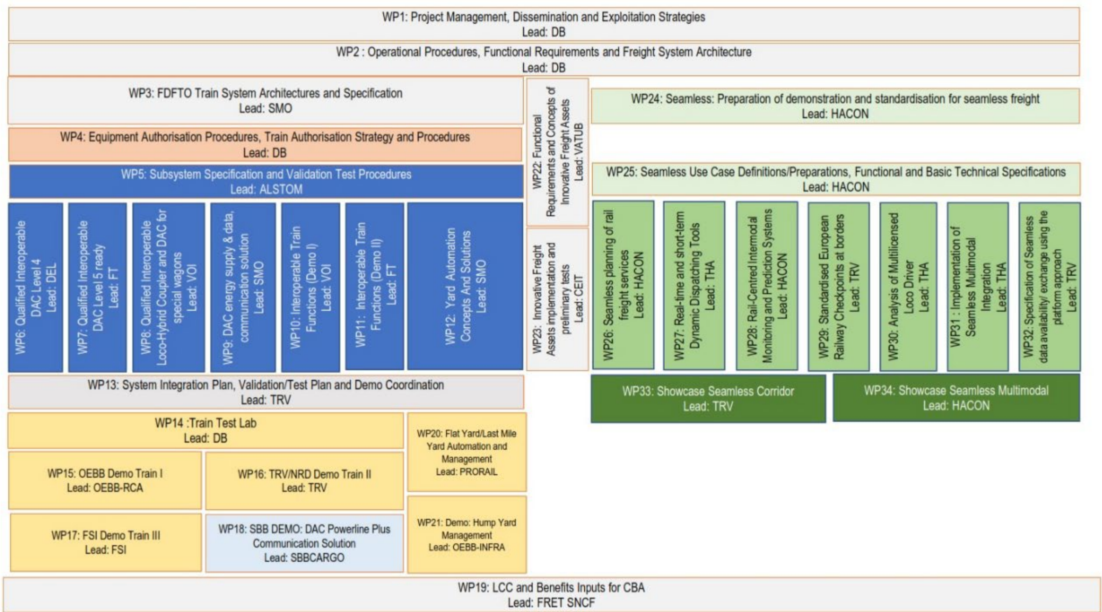


Figure 37: FP5-TRANS4M-R WP structure [5]

WP#	Title	Brief description
WP01	Project Management, Dissemination and Exploitation Strategies	
WP02	Operational Procedures, Functional Requirements and Freight System Architecture	The process flow for European seamless rail freight and a future automated full digital freight train operation with all relationships must be described within its physical (such as locomotive/wagon and its subsystems) and a digital (data) layer as a foundation for the specification of the requirements of the technical enablers for a digital-rail-based logistic systems. Target operational processes for all areas in all relevant scenarios (situations/sites/locations) shall be defined.
WP03	FDFTO Train System Architectures and Specification	A common approach for fully functional interoperable and homologated Digital Freight Train Operation (FDFTO) shall be ensured by means of a fully integrated reference system architecture comprising of the various technological advances and developments of the project. The system architecture shall build a foundation for all interconnected tasks: requirement management, variant management, validation tests, RAMS analysis. The work package aim is designing and harmonization of a functional reference system for the FDFTO architecture with a focus purely on functionality not on the technical solution: Both a physical reference system architecture (layout of physical entities and interfaces) and a digital reference system architecture (data and digital interface design).
WP04	Equipment Authorisation Procedures, Train Authorisation Strategy and Procedures	The main objective of WP4 is to prepare the procedures and the necessary requirements for vehicle authorisation to bring DAC up to functional Level 5 into the EU railway system. This includes procedures and requirements to assess and certify the DAC as well as procedures and requirements to assess the integration of the related energy provision, vehicle control and train functionalities into (new or retrofitted) freight wagons and locomotives.
WP05	Subsystem Specification and Validation Test Procedures	The foundation provided by the EDDP, prepared for the TSI and CEN/CENELEC Working Groups for fully digitalized freight transport operational procedures enabled by a harmonized interoperable DAC system up to Level 5 functionality, for the European rail freight industry will be narrowed down to detail the common interfaces, protocols between subsystems, interoperable functions and technical specifications enabling full EU interoperability. A standardized European FDFTO verification and validation test plan on subsystem level (equipment, required HW and train function) for full digital freight operations shall be developed providing step-by-step integration and test procedures.
WP06	Lead Beneficiary Qualified Interoperable DAC Level 4	The main objective of WP6 is reaching a full compatibility and EU-interoperability of DAC Level 4 of functionality. WP6 partners will provide interoperable DAC Level 4 systems. The aim is to test and demonstrate the interoperability of the systems in laboratory environments & provide qualified technology for train tests under controlled environment and large-scale validation and demonstration with TRL8.
WP07	Qualified Interoperable DAC Level 5 ready	The main objective of WP7 is reaching a full compatibility and EU-interoperability of DAC Level 5 readiness functionality. WP7 partners will provide interoperable DAC Level 5 ready couplers

		based on the upgrade of WP6 DAC Level 4 couplers. The aim is to test and demonstrate the interoperability of the couplers in laboratory environment & provide qualified technology for train tests under controlled environment and large-scale validation and demonstration.
WP08	Qualified Interoperable Locomotive-Hybrid Coupler and Wagon DAC for special wagons	The main objective of WP8 is reaching a full compatibility and EU-interoperability of a Locomotive-Hybrid Coupler Level 4 with a Wagon DAC Level 5 system and a full compatibility and EU-interoperability of a Wagon DAC Level 5 ready for special wagons, based on couplers provided within WP6 and WP7. WP8 partners will provide interoperable Locomotive-Hybrid Coupler Level 4, though upgradable to Level 5, enabling the Level 5 functionality on a train system level. In addition, WP8 partners will provide interoperable Wagon DAC Level 5 ready for special wagons (e.g., T3000). The aim is to test and demonstrate the interoperability of the systems in laboratory environment and provide qualified technology for train tests under controlled environment and for demonstration with TRL8.
WP09	DAC energy supply & data, communication solution	The interoperable solutions, which are developed and delivered in WP9 shall supply the freight-wagons with electrical energy from the locomotive and/or from the stationary power-supply in the yards. On-board electronics and consumers for the wagons need to be supplied. The communication channel shall allow messages to be exchanged between the wagons and the locomotive via the DAC, but also to a server on the landside (especially the yards, WP12 involved) and/or in the cloud. Therefore, the energy supply and communication channel represent the basis of interoperability for implantation of train wide functions, which will be developed in (WP10 & WP11).
WP10	Interoperable Train Functions (Demo I)	WP10 will focus on the adjustments and bringing the different existing solutions across system suppliers and across technologies to a higher maturity level with the main objective to enable/ensure a fully functional interoperability of future software defined technologies: train composition detection (train inauguration), automated brake test, automatic coupling and uncoupling (controlled from a locomotive), and train integrity monitoring and train length determination will be enhanced, adjusted, and tested in a laboratory environment fulfilling the functional requirements incl. safety and interoperability with the aim of reaching TRL8 during the project.
WP11	Interoperable Train Functions DEMO II	WP11 will focus on the adjustment of the different solutions across system suppliers and across technologies with the main objective to enable/ensure a fully functional interoperability of future software defined technologies. Automated parking brake control function (controlled from locomotive), Distributed Power System – DPS (multi-traction control via train network of up to 4 locomotives in a train) Train brake control & monitoring (via train network parallel; EP-Brake) will be tested in a laboratory environment fulfilling the functional requirements incl. safety and interoperability with the aim of reaching TRL7 during the project
WP12	Yard Automation Concepts and Solutions	Yard processes shall be highly to fully automated by introducing the DAC Level 5 capabilities. WP12 objective is to develop and deliver safe and secure automated shunting solutions ensuring

		functional interoperability across technologies and suppliers. Procedures in departure section such as train preparation shall be supported by trackside equipment for automatic brake & line test. Movements of shunting locomotives can be carried out automatically in dedicated areas even without ETCS with unequivocal mapping/positioning. The focus of WP12 lies in developing of novel software defined technologies aiming to embed new functionalities - not yet available - into automated yard management and yard automatization systems – both for flat and hump yards. This WP will implement the following technical enabler: 4 with the aim to reach TRL 6 - 8
WP13	System Integration Plan, Validation/Test Plan and Demo Coordination	The aim of WP13 is to support and coordinate WP14-21 by providing a test concept, system integration plan and holistic FDFTO assessment. The objective of WP13 is to ensure integration of the technical enablers to a functional FDFTO train and delivery of the demonstrators.
WP14	Train Test Lab	The objective of WP14 - Train Test Lab is to enable and execute the validation of the FDFTO requirements in a centralized FDFTO lab and in a harmonized way. The aim is to establish a joint, cocreational, one-of-its-kind environment for the project and the railway freight sector to move up across the envisaged TRLs in a cost-efficient and effective way. Test procedures of the technical enablers, both on component/subsystem and on train level, according to the developed validation and test plan shall be possible. By using the train test lab specific operational procedures can be pre-tested, and on the other hand retrofitting efficiency, maintainability and serviceability assessments shall be possible. Also, developer- tests will be carried out to ensure the suitable system-approaches for the FDFTO-energy- and communication-system for locomotives and wagons.
WP15	OEBB Demo Train I	The WP15 main objectives are: To prepare "Demo Train I", To demonstrate the "Demo Train I" based on the technical enablers (WP6-WP11) of the flagship project reaching at least TRL7/8 To assess and validate the functionalities and impact the FDFTO train set "Demo Train I" on the transformation of FDFTO operational procedures. As a result, this WP should prove that technical enabler solutions are capable to demonstrate defined full functionality under relevant operational conditions incl. defined operational contingency scenarios. "Demo Train I" will cover EU-Corridors crossing Austria. (TRL8)
WP16	TRV/NRD Demo Train II	Testing and validation of DAC and selected enablers (e.g., EP-brake, train composition, automated brake test etc.) in harsh winter conditions with low temperatures down to - 25 degrees Celsius (T1), a lot of snow and snow smoke adverse weather conditions. This will contribute to input and data for LCC analysis of DAC, full interoperability, and the functionality of the selected enablers (e.g., EP-brake, train composition, brake test etc). The WP16 will set up three (3) demo trains in these DAC tests and selected train functions (e.g., EP-brake, train composition, automated brake test). (TRL8)
WP17	FSI Demo Train III	The WP17 main objectives are: To prepare "Demo Train III" To demonstrate the "Demo Train III" based on the technical enablers (WP6-WP12) of the flagship project reaching TRL7/8 To assess and validate the functionalities and impact of the

		"Demo Train III" on the transformation of FDFTO operational procedures. As a result, this WP should prove that technical enabler solutions are capable to show defined full functionality under relevant operational conditions incl. defined operational contingency scenarios. "Demo Train III" will cover EU-Corridors crossing Italy. (TRL8)
WP18	SBB DEMO: DAC Powerline Plus Communication Solution	Based on the foundation provided by the EDDP WP1 SG 3, Powerline PLUS is one of two shortlisted communication technologies for the data backbone of the future freight train. The primary focus from FP5 will be on the technology SPE, due to the limited resources in the project and the challenging time plan. As none of the technologies has been fully tested and qualified in the target environment and to minimize the risk in the project, it´s recommended to continue the development and testing with both technologies, meanwhile in parallel. If Powerline PLUS will be selected instead of SPE it needs to be further pursued, in this WP an interoperable Powerline plus based DAC communication systems, will be brought to a higher maturity (TRL8), and integrated into ERJU demonstrators. The aim is to provide standardized interoperable set of solutions. The functionality and performance shall be demonstrated and validated against the requirements and documented in test-reports for interoperability readiness. Mechanical, electrical, and SW integration into rail vehicles shall be made possible by providing integration instructions and required documentation of the individual components and sub-systems. (TRL8)
WP19	LCC and Benefits Inputs for CBA	The objective of this work package is to support EDDP. This work package aims at providing input for the EDDP CBA work package. ERA involvement will be actively requested for validation purposes, so values can be accepted for a global CBA.
WP20	Demo: Flat Yard/Last Mile Yard Automation and Management	In most cases, except for "hand-over" tracks between main-line and yards, flat yards/last mile infrastructure are un- signalled areas. Automatization of these yards is hampered by crucial signalling components not having conflict-free, safe route setting and, in most cases, non-automated movement of switches. The main objective of the WP20 is to validate, implement and showcase the practical application of the developments of WP12 for an automated flat yard/last mile in a real operational environment. Enabler 4 will be addressed in this work package. (TRL6-8)
WP21	Demo: Hump Yard Management	Well organized yards are essential for an excellent performance of SWL-traffic throughout Europe. The change management of operational and organizational procedures going from a non- or semi-automated environment towards a digitalized and fully automated yard area needs detailed planning; this also applies for test and demonstrator purposes, using real hump yard environment. The main Objective of WP21 is to validate, implement and showcase the practical application of the developments of WP12 for an automated hump yard in a real operational environment.
WP22	Functional Requirements and Concepts of Innovative Freight Assets	WP22 objective is to enable the introduction of technical enablers developing concepts on three levels: - energy efficiency: train aerodynamics concepts and efficient driving. multimodality: combined container including wagon concepts for efficient loading/unloading for end-2-end optimized logistic process, and automation: self-propelled wagons complementing

		operational procedures and WP22 goal is to define the functional requirements of the enablers while iterating on preliminary concepts that at the end shall lead to technical specifications, validation plans and preliminary designs feeding into WP23.
WP23	Innovative Freight Assets implementation and preliminary tests	WP23 main objective is to provide deployable, cost-efficient solutions based on the requirements and architectures developed in WP22. Implementing and pre-testing of the concepts demonstrating: multimodality: wagon concept carrying a high-pressure hydrogen storage system with optimized cascading of single storage units, fully equipped with instrumentation and sensors embedded in a new defined logistics model and concept; automation: demonstrate the functionality of a preliminary design of a traction system for the self-propelling capability; energy efficiency: characterize the real-world aerodynamics of freight-train operation in order to provide applicable recommendations for the aerodynamic optimization of freight-trains operating in real-world conditions on one hand and on the other: Adapt the efficient driving strategies to the freight convoys and evaluate the feasible energy savings. This WP aims to reach TRL 4-.
WP24	Preparation of demonstration and standardisation for seamless freight	The goal of WP24 is to prepare the activities for the demonstration efforts of WP 33 and WP 34. This is done via a continuous alignment of planning, timing execution and evaluation between all involved partners. Since this is a continuous and regularly updated process, the WP will run for the entirety of the first call. In addition, this WP also aims to provide input for standardisation, including a possible extension of the existing standards.
WP25	Seamless Use Case Definitions/Preparations, Functional and Basic Technical Specifications	To match the market requirements, the goal of this WP is to establish the functional and technical specifications of the necessary developments to achieve the vision of the seamless freight cluster of Destination 5. The actual development is done in WP 26-32, or in the respective work packages of the Destination 1 project, which is focussed on mainline network planning and management, as well as the FP3 project regarding the development of CBM.
WP26	Seamless Planning of Rail Freight Services	As the development of freight specific planning functions for the main lines and the network including cross-border, which were analysed and specified in WP25. Two will be performed in the Destination1 flagship project, the main objective of this WP is to develop the necessary functions, tools or supporting systems to ensure that the seamless planning covers the complete end-to-end rail service including the sections, processes and actors of the first and last mile and the terminals/yards. Therefore, the developments include the enhancement of yard and terminal planning systems, so that they can interact with network planning systems in an efficient and agile way and can process the data for a better internal planning of the resources. Additionally, also the planning and management processes of the Railway Undertakings for freight services will be improved by standardised data exchange and new functions for asset/capacity management to ensure a better use of scarce resources. Another objective is to provide easy access to information about available network capacity / capacity restrictions via a web portal, so that the transport planning departments of shippers and LSPs can use

		this information for an improved mid- to long-term logistic planning.
WP27	Real-time and short-term Dynamic Dispatching Tools	Implement a harmonised real-time interface between Railway Traffic Management System and the yard/terminal management systems, to dynamically adapt planning and tasks in yards/terminals according to real-time evolution of traffic and availability of assets. Overall objective to enable harmonised yard/terminal operations across Europe to further ease interaction between different yards/terminals.
WP28	Rail-Centred Intermodal Monitoring and Prediction Systems	The goal of this WP is to develop key functions for intermodal monitoring and prediction systems which cover(s) the entire European intermodal transport chain by developing several rail-focused algorithm models as well as integrating other (prediction) systems for the first and last mile processes in a harmonised way. These intermodal prediction systems shall achieve a high and reliable performance in terms of pre-specified quality evaluation criteria.
WP29	Standardised European Railway Checkpoints at Borders and Other Operational Stop Points	The main objective of this WP is to develop Railway Checkpoints that will partially automate Freight Train Transfer Inspections at borders or other operational stop points. This includes digitalising and automating processes using emerging technologies in specialised adapted “Intelligent video gates” (IVG), using OCR, sensors and other detection and identification technologies. The technological objectives are combined with evaluation of data sharing and exploitation possibilities as well as harmonized procedures and regulation across the European rail network. Apart from enabling improved operations these checkpoints can also contribute to improved maintenance processes and safety performance e.g., in freight train preparation phase and monitoring safe attachments on wagons. Thus, this WP will focus on: Digitalisation and partial automation of manual processes through innovative sensors, video gates and handheld devices, based on a process analysis (TRL 7) Interoperable IT-systems for data management and processing (TRL 7) Harmonized procedures and regulations.
WP30	Analysis of Multilicensed Loco Driver	As there are numerous initiatives and projects ongoing or planned to support an international cross-border deployment of loco-drivers it is important, to analyse in a first step the current state of the art of the connected technology and the developments ongoing, as well as to merge/analyse the different customer requirements so that in a project in future calls of ERJU the respective missing technologies can be developed which should reach then TRLs of 8-9. The analysis and resulting implementation concept are covering Multi licensed loco driver, cross border rostering concepts and cross border line simulation tools. This WP covers Enabler 13 reaching TRL 3-4.
WP31	Implementation of Seamless Multimodal Integration	The main objective of the WP is to combine multimodal services (incl. short and deep-sea-shipping, barges, and road transportation) in/for harmonised transport planners with easy booking functions. It shall allow users to increase the modal split of railway freight transport by means of demand-responsive transport network planning, optimized loading and capacity management algorithms with ad-hoc dynamic capacity allocation functions based on resource availability. The WP will implement software solutions for innovative and integrated multimodal

		transport planning, management and operation system including innovative routing engines on loading unit level (e.g., Container, Trailer, etc.). By standardising the formats and the services descriptions and adapting the transport planers, services from various/all service providers could be combined and a European overview of rail freight services is enabled. This WP covers Enabler 10, 11 and 14 with targeted TRLs 6-8.
WP32	Specification of Seamless data availability/ exchange using the platform of platform approach	This work package shall provide an overall framework to allow a seamless and harmonised exchange of data, not only for the activities within Destination 5 Seamless Freight, but also for the connection to Cluster 1: FDFTO. The Conceptual Data Model (CDM) which will bring everything under a common federation will be developed within Destination 1 and used to share data. The cooperation with Destination 1 will be considered to explore opportunities of using standards with the CDM as well as contributing to it. This framework shall facilitate an increased availability and quality of data by reducing technical and administrative barriers for the generation and exchange of data. To achieve this goal, the framework will govern the data exchange processes (developing interfaces, data converters, the facilitation of a common data structure and the use of standardised formats etc.). This work package will cover Enabler 15 reaching TRL 7-8.
WP33	Showcase Seamless Corridor	The objective is via a seamless operation part of destination 5 integrate both physical flow (wagons, locos, and trains) and not at least the information flow in a corridor using the enabling technologies that Seamless operations established in destination 5. The corridor set up shall be supported by use cases from the relevant corridor enablers and as a result the various use cases should be united in a comprehensive corridor approach. The ScanMed corridor will be the base for the showcase with complementary use cases in other corridors that mirror solutions that can be used in every generic set up of a corridor. In the field of network management, a collaboration with Destination 1 (FA1) is necessary including potential cooperation also with RNE. In parallel to this showcase also a customer showcase is established in destination 5 Seamless operations in order show capabilities in supply chain management and customer orientation. Technical Enabler 9, 10, 11, 14 and 15 shall be validated and demonstrated in this work package (TRL 6-8).
WP34	Showcase Seamless Multimodal	The objective of this work package is to demonstrate a seamless multimodal transport service. This will be made possible by the developments implemented in WP 28, WP 31, and WP 32. The seamless integration of multimodal transport services will be realised and showcased by using a multimodal transport planning, management and operation system including innovative routing engines (WP 31). Using for example joint data services like KV4.0, multimodal services will be integrated and harmonised in transport planners with easy booking support. The seamless multimodal transport chain shall feature international, multimodal transport relations of two and more operators. Enabler 11, 14 and 15 shall be validated and demonstrated in this work package with the aim to reach TRL 6-8.

Table 14: FP5-TRANS4M-R WP list [5]

To achieve the operational outcomes targeted in this Flagship Area, several technical capabilities were identified by FP5. To develop flagship demonstrations, some functions must be delivered with enough maturity.

Enabler 1	Development of an EU-harmonized DAC, plus the necessary freight consist of backbone system including a solution for both the energy supply as well as data/communication (setting the right conditions towards modular – standard interfaces-expected to be scalable, of plug & play integration, etc. solution). As needed by the demonstrator the enabler must be able to drive complete train sets and the DAC shall be upgradable to Type 5. There is also the need to develop a coupler solution for locomotives and a type 5 coupler.
Enabler 2	Developing a train composition detection/management system, automated/automatic brake test system, on asset side DAC wagon retrofitting solutions.
Enabler 3	Automated parking brake system, digital wagon inspection, DAC based telematics applications, distributed power system, electropneumatic brake and cover important preparatory works incl. train dynamics with higher TRL for the future set of demonstration foreseen in the Multi- annual Work programme in view of the evolutions of the solutions
Enabler 4	Development of systems and solutions for basic autonomous shunting operations. Development of solutions for yard automation including digitalization that enable automated train composition and dispatching (Automated Shunting Operations), including necessary wagon identity system for automated shunting and cover important preparatory works with higher TRL for the future set of demonstration foreseen in the Multi- annual Work programme in view of the evolutions of the solutions
Enabler 5	Integrative deployment of video gates, wayside check points, visual recognition methodologies and AI-Tools for yard automation
Enabler 6	Achieving expected consolidation of the expected new freight capabilities, providing requirements and giving feedback to Destination 2 for new automation technology solutions for the automated driving and decision-making as well as automating functions, such as train preparation and basic automatic yard shunting.
Enabler 7	Developing DAC based wagon concepts incl. multi-modal transport applications (retrofitting needs for combined traffic T3000 kind of wagons) and cover important preparatory works with higher TRL for the future set of demonstration foreseen in the Multi- annual Work programme in view of the evolutions of the solutions
Enabler 8	Specify and deliver freight specific requirements for integrated cross-border timetable planning, management and path ordering systems (including requirements for covering also the last mile) suitable for development in destination 1
Enabler 9	Setting up the respective models and systems to test and demonstrate the destination 1 developments for integrated timetable planning on selected part of a European corridor and cover important preparatory works with higher TRL for the future set of demonstration foreseen in the Multi- annual Work programme in view of the evolutions of the solutions
Enabler 10	Develop dynamic yard/terminal management systems and test their integration with dynamic TMS based on agreed interfaces– that will be specified among destination 1 and the TMS development will come from destination 1 and cover important preparatory works with higher TRL for the future set of demonstration foreseen in the Multi- annual Work programme in view of the evolutions of the solutions
Enabler 11	Specify and develop intermodal monitoring and prediction systems, which shall work in combination with dynamic TMS and other resource management systems using AI based models, accuracy and computational learning functions and cover important preparatory works with higher TRL for the future set of demonstration foreseen in the Multi– annual Work programme in view of the evolutions of the solutions
Enabler 12	Specify and develop Railway Checkpoints that will automate Freight Train Transfer Inspections at borders or other operational stop points, digitalising and automating processes through innovative sensors, specialised adapted video gates and handheld devices, in combination with harmonized procedures and regulation across European rail network and cover important preparatory works with higher TRL for the future set of demonstration foreseen in the Multi- annual Work programme in view of the evolutions of the solutions

Enabler 13	Finalise R&I development of certified secured translation tools100 to enable in combination with multi-country driver licensing and appropriate rostering concepts a harmonised cross-country operation and cover important preparatory works with higher TRL for the future set of demonstration foreseen in the Multi- annual Work programme in view of the evolutions of the solutions
Enabler 14	Specifications for the development of integrated multimodal transport planning, management and operational systems enabling easy access to rail-base (intermodal) services and dynamic demand responsive service offering, network planning and capacity management based on agreed interfaces with TMS – _with Destination 1 – and the specific freight development to support this functionality. And cover important preparatory works with higher TRL for the future set of demonstration foreseen in the Multi- annual Work programme in view of the evolutions of the solutions
Enabler 15	Analysis and coordination of requirements for seamless data exchange / data availability for the various Destination 5 developments and planned demonstrations, considering existing/proposed data standards (if applicable) and regulations e.g., TAF TSI. Specification and development of required processes/tools (e.g., interfaces/ converters.) and cover important preparatory works with higher TRL for the future set of demonstration foreseen in the Multi- annual Work programme in view of the evolutions of the solutions
Enabler 16	Analysis and coordination of required technology upgrades of legacy/national systems to be able to provide/consume/process harmonised data from/for international (European) applications/innovations. Development of an implementation plan.

Table 15: FP5-TRANS4M-R Technical Enablers list [5]

4.2.3 Relation to the SDFW

The TE4, 5, 6 and 10 are related to the FDFTO, ASO and SPFW wagon with are covered in WP3, WP5, WP12, WP22 and WP23.

- FDFTO: Full Digital Freight Train Operation architecture that affects to the wagon architecture.
- ASO: automated shunting solutions ensuring functional interoperability across technologies and suppliers. Procedures in departure section such as train preparation shall be supported by trackside equipment for automatic brake & line test. Movements of shunting locomotives can be carried out automatically in dedicated areas even without ETCS with unequivocal mapping/positioning. Novel software defined technologies aiming to embed new functionalities - not yet available - into automated yard management and yard automatization systems – both for flat and hump yards.
- SDPW: which complements operational procedures.

4.3 Conclusions

From the analysis done to FP1-MOTIONAL [4] and FP5-TRANS4M-R [5] the following topics related to **SDFW** have been found.

- **FP1-MOTIONAL:** the project aims to improve planning and operational management of rail services. It does not only focus on the operational line, but also on the yard. The management on the operational line of a **SDFW** by a TMS is considered to be similar to the operation a train equipped with ATO. However, yard operation on a **SDFW** will vary current procedures. FP1-MOTIONAL also covers Yard operations by introducing the **Yard Control System** (YCS), which is referred (WP10, WP11 and WP12). The YCS relates to the processes of the yard and its management, and shall be linked to the **SDFW**.

- **FP5-TRANS4M-R:** the project aims to establish rail freight as the backbone of a low-emission, resilient European logistics chain, which fulfils end-user requirements to full satisfaction by means of the 'Full Digital Freight Train Operation (FDFTO)' and 'Seamless Freight Operation'. The FDFTO includes elements that shall be considered in the **SDFW** architecture, on one hand, the Full Digital Freight Train with the DAC and the ASO (WP3, WP5 and WP12) to be integrated in a freight train and operated by the YCS, and on the other the Self-Propelled Freight Wagon elements to enable the movement of the wagon (WP22 and WP23).

5 First approach to business case

This section is dedicated to a first approach to business case. It aims at bringing some elements about the potential profitability of the use cases selected in the former chapter. For that, this section includes the **SDFW** types, definition, architecture and operation, and the approach to business case by analysing the CAPEX and OPEX together with a summary and a conclusion.

5.1 SDFW TYPES DEFINITION, ARCHITECTURE AND OPERATION

This subsection describes a classification of five types of **SDFW** depending on the scope of its use and their corresponding architecture.

5.1.1 SDFW Types

This subsection describes a classification of five types of **SDFW** depending on the scope of its use. Starting from autonomous operations in a yard without much intelligence at the wagon (**SDFW** Type 1) up to autonomous operations of a single wagon in the main line (Type 4 and Type 5).

The ASO is defined in FP5-TRANS4M-R D5.5 [36], which is the ATO counterpart for the Yard operations (Figure 38). While the ASO interacts with the Yard Management System, the ATO interacts with the Traffic Management System, therefore the **SDFW** shall interact with both, depending on where the operations are being taken place.

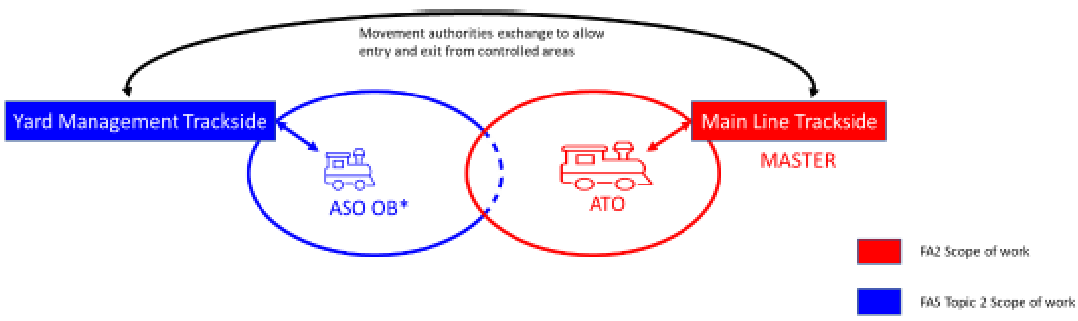


Figure 38: ASO-ATO FP5-TRANS4M-R D5.5 [36]

Taking into account the yard operation and the main line operations, the definition of the **SDFW** types is listed as follows and shown in the Table 16:

- **Type 1:** it allows autonomous operations (movement) only in yards (SS), commanded by the YMS (yard) and within a yard that ensures the safety of the operation (avoids collisions and commands the emergency brake). For the last mile (<50 km) and operational line (>50 km) it operates within a consist.
- **Type 2:** it allows autonomous operations (movement) only in yards (SS), commanded by the YMS (yard) and the own **SDFW** ensures the safety of the operation (avoids collisions and commands the emergency brake). For the last mile (<50 km) and operational line (>50 km) it operates within a consist.
- **Type 3:** it allows autonomous operations (movement) only in yards (SS), and last mile (<50 km), commanded by the YMS (yard) and TMS (last mile), and the own **SDFW** ensures the safety of the operation (avoids collisions and commands the emergency brake). For the operational line (>50 km) it operates within a consist.

- **Type 4:** it allows autonomous operations (movement) in yards (SS), Last Mile (<50 km), and operational line (>50 km), commanded by the YMS (yard) and TMS (last mile and operational line), and the own **SDFW** ensures the safety of the operation (avoids collisions and commands the emergency brake) in the yard and the last mile, and the ETCS (ATP) in the operational line.
- **Type 5:** it allows autonomous operations (movement) in yards (SS), last mile (<50 km), and operational line (>50 km), commanded by the YMS (yard) and TMS (last mile and operational line), and the own **SDFW** ensures the safety of the operation (avoids collisions and commands the emergency brake) in the yard and the last mile, and the Virtually Coupled Train Set (VCTS) in the operational line.

It should be noted that Type 4 are Type 5 are not expected to be equipped with a coupler. Therefore, a migration phase where intermediate Types of the couplable to a consists Type 4 and Type 5 **SDFW** with might exist.

SDFW	Type 1	Type 2	Type 3	Type 4	Type 5
Route (A to B)	YAMS	YAMS	YAMS/TMS	YAMS/TMS	YAMS/TMS
Scope (Yards, Last Mile (50km), Operational line (>50 km))	Yards	Yards	Yards & Last Mile	Yards & Last Mile & Operational line	Yards & Last Mile & Operational line
Use case applied (SS1, SD2)	SS1	SS1	SS1	SD2	SD2
DAC-FDFT (Coupleable electronically to a consist)	Yes Type 5	Yes Type 5	Yes Type 5	No	No
On-board propulsion capacity	*	*	***	*****	*****
Max. Speed	*	*	***	*****	*****
Charging on motion in the consist	Yes	Yes	Yes	No	No
Regenerative braking	No	No	Yes	Yes	Yes
Remote driving	Yes (back-up)	Yes (back-up)	Yes (back-up)	Yes (back-up)	Yes (back-up)
Safety functions on-board	No	Yes	Yes	Yes	Yes
Emergency stop	-on-board commanded by YMS - on the side of the vehicle for slow speeds	on-board commanded by SDFW	on-board commanded by SDFW	on-board commanded by SDFW	on-board commanded by SDFW
Obstacle detection on-board	None	Yes (front, back detection)	Yes (front, back detection)	Yes (front, back detection)	Yes (front, back detection)
Collision avoidance	on the infrastructure	on-board	on-board	on-board	on-board
Short Range Wireless Communication	on-board equipment for local comm. (short range)	on-board equipment for local comm. (short range)	on-board equipment for local comm. (short range)	-	-
Long Range Wireless Communication	-	-	on-board equipment PLMN (long range)	on-board equipment PLMN (long range)	on-board equipment PLMN (long range)
Absolute localisation	on-board equipment	on-board equipment	on-board equipment	on-board equipment	on-board equipment
Relative localisation	on-board equipment	on-board equipment	on-board equipment	on-board equipment	on-board equipment
ATP	none	none	Regional ATP	ETCS L2-L3	VCTS
Battery size (wagon travelling autonomy)	*	*	***	*****	*****
Charging station in the yard	No	No	**Yes**	Yes	Yes
Number of charging stations	-	-	***	*****	*****
Cost SDFW	*	**	***	*****	****

Table 16: SDFW types definition

5.1.2 SDFW Architecture

FP5-TRANS4M-R project defines the ASO, the SPFW and the FDFT concepts that are applicable for the **SDFW**.

- The SPFW is defined in FP5-TRANS4M-R D22.3 [37] (Figure 39), which is responsible for the movement of the Freight Wagon. It includes the traction elements, braking elements, Battery and the controller among others. The **SDFW** requires all these elements for the movement of the wagon.

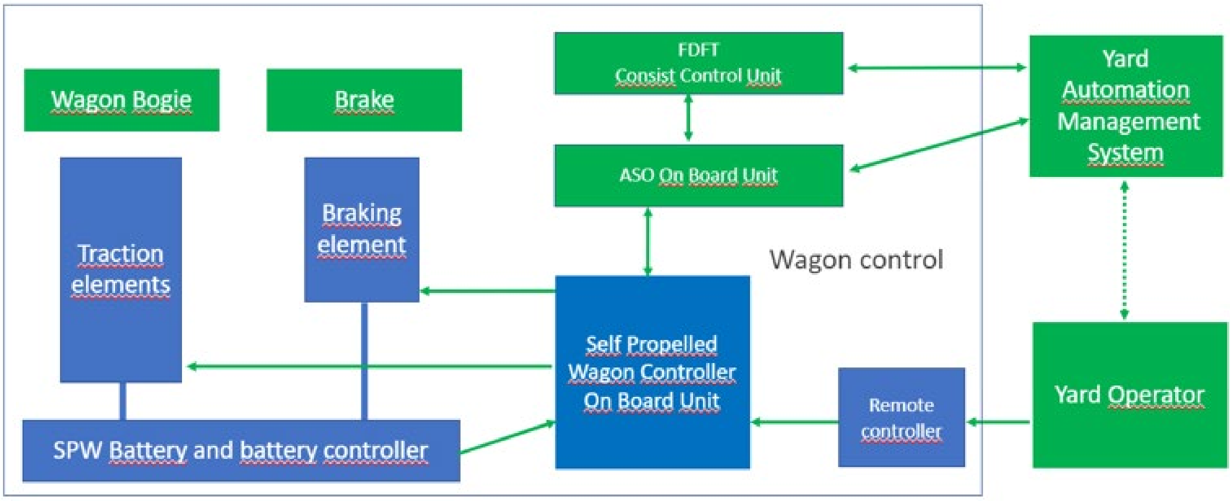


Figure 39: SPFW FP5-TRANS4M-R D22.3 [37]

- The FDFT is defined in FP5-TRANS4M-R D3.1 [38] (Figure 40), Full Digital Freight Train Operations are enabled by the Digital Automatic Coupler (DAC). The **SDFW** requires these elements in order to couple and uncouple from/to a consist.

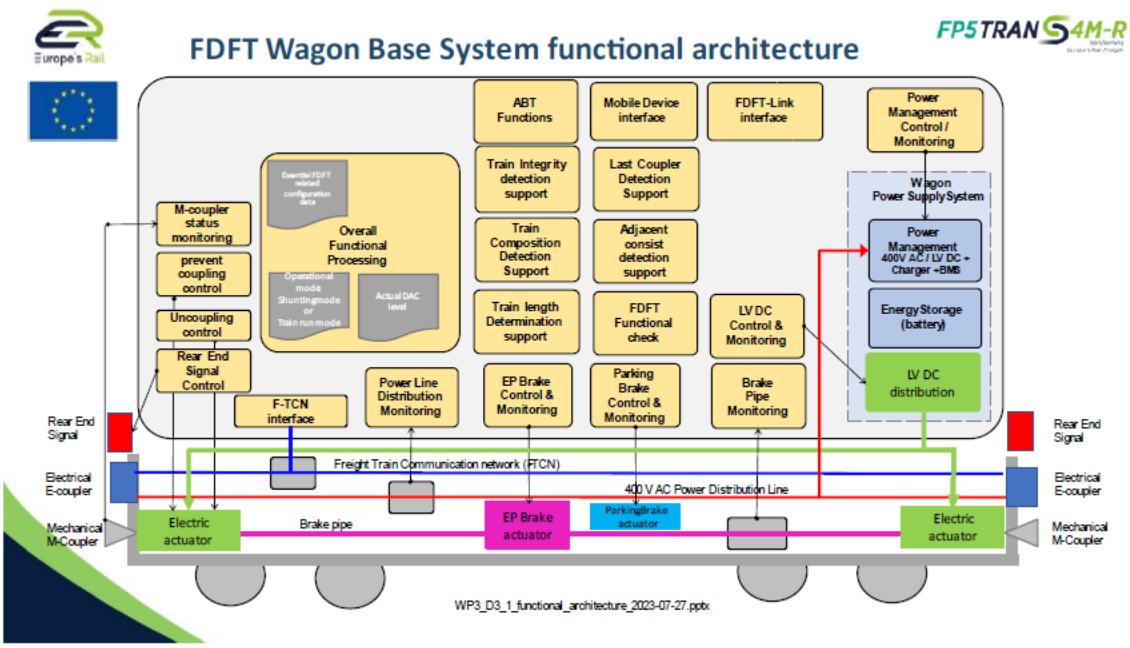


Figure 40: FDFT FP5-TRANS4M-R D3.1 [38]

The next figure and table show the main building blocks of the **SDFW** and the infrastructure elements to which the **SDFW** interacts.

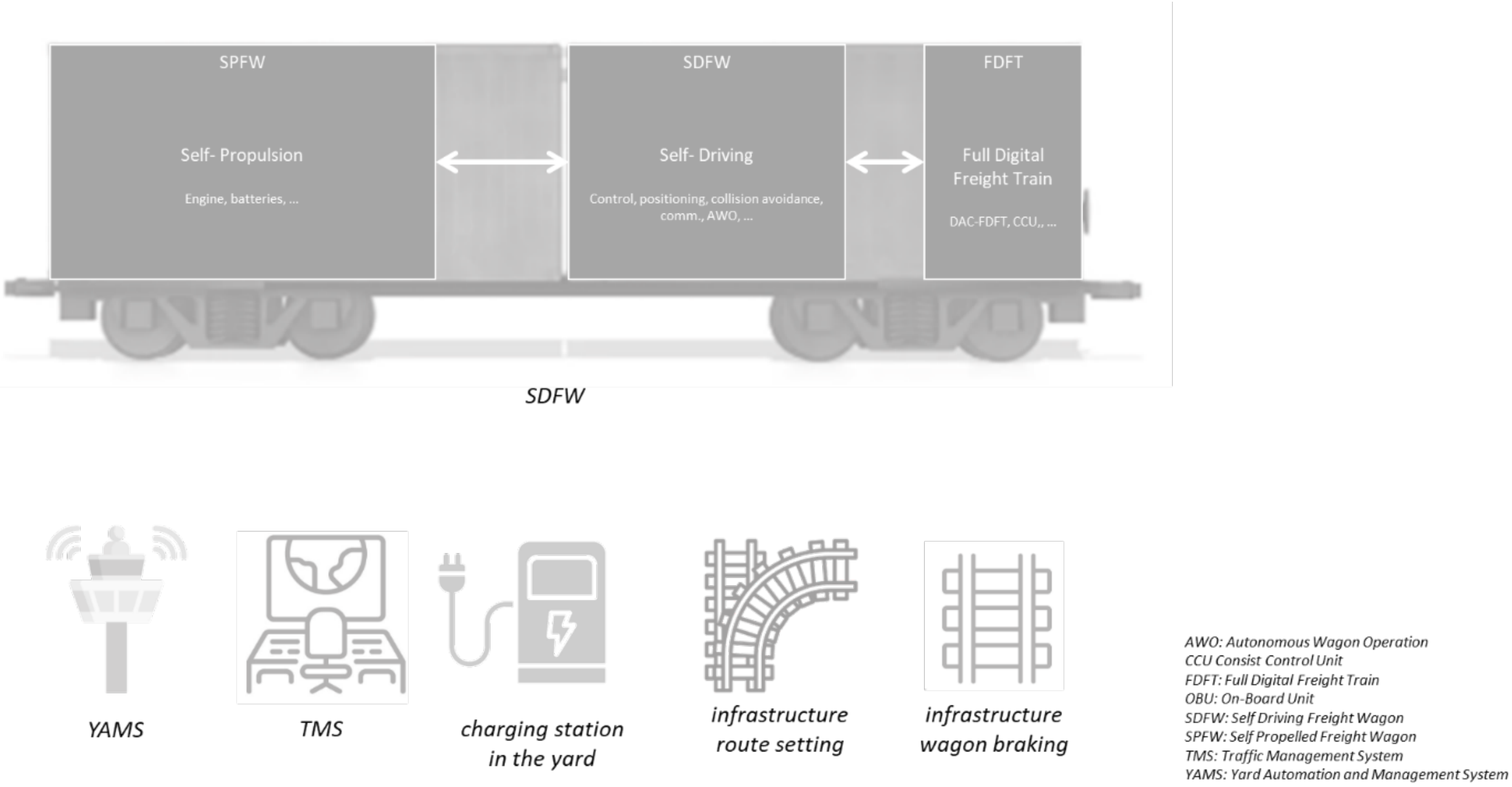


Figure 41: SDFW architecture and infrastructure elements

SDFW main building block	
SPFW	Responsible for the movement of the wagon. It consists of different elements the controller OBU, brake control, traction, battery, battery controller, and/or regenerative braking.
SDFW	Responsible for the decision of the movement of the wagon. Depending on the type it consists of different elements such as the control (AWO), localisation, communication, remote driving, obstacle detection, collision avoidance, VCTS and/or ETCS.
FDFT	Responsible for the integration with the FDFTO. It consists of FDFT CCU and DAC-FDFT.
Infrastructure elements to which the SDFW interacts	
YAMS	Responsible for managing the operations of the **SDFW** on the Yard.
TMS	Responsible for managing the operations of the **SDFW** on operational line.
Infrastructure route setting	Responsible to set the route on the yard, it an operate with and without YAMS.
Infrastructure wagon braking	Responsible to brake the wagon from the infrastructure on the yard, it an operate with and without YAMS.
Charging station in the yard	Responsible for charging the batteries of the **SDFW** on the yard.

Table 17: SDFW elements

Element	Function / Role	Interaction With Other Elements
SPFW (Self-Propelled Freight Wagon)	Provides the physical movement capability of the wagon, including traction, braking, battery, controller, and regenerative braking.	Executes motion commands received from the SDFW module; interacts with the charging station; exchanges data with the SDFW controller; supports braking and traction for autonomous operations.
SDFW (Autonomous Control Layer)	Responsible for movement decision-making, including AWO (autonomous wagon operation), localisation, communication, obstacle detection, collision avoidance, remote driving, and emergency braking.	Receives commands from YAMS (yard area) or TMS (last mile and operational line); sends movement commands to the SPFW; interacts with ETCS or VCTS depending on the SDFW Type; shares localisation, status, and safety data with infrastructure systems.

FDFT (Full Digital Freight Train Components: CCU + DAC-FDFT)	Ensures integration with the Full Digital Freight Train, enabling digital automatic coupling, train data exchange, brake test automation, and unified control logic along the train.	Connects with other wagons and locomotives through the DAC; exchanges train-wide information; supports automatic coupling/uncoupling and brake tests; links the SDFW into wider train operations when operating in a consist.
YAMS (Yard Autonomous Management System)	Supervises and coordinates autonomous operations inside the yard, including routing, track allocation, conflict avoidance, and safety management.	Sends operational commands to the SDFW; receives localisation, obstacle detection, and status information; interacts with yard route setting and wagon braking systems; governs safety for Types 1–3 in yard operations.
TMS (Traffic Management System)	Coordinates operations in the last mile (<50 km) and operational line (>50 km), including routing, scheduling, and integration with European traffic management processes.	Issues movement authority to SDFW during last-mile and mainline operations; receives SDFW status and location; interacts with ETCS for speed, movement authority, and safe separation; governs SDFW operations for Types 3–5.
ETCS (European Train Control System)	Provides Automatic Train Protection (ATP) for mainline operation, ensuring safe speed, braking, and compliance with movement authorities.	Used by SDFW Type 4 for ensuring safety on operational lines; collaborates with TMS for movement authority; integrates with SDFW localisation and braking logic to maintain safe distances.
VCTS	Enables virtual coupling, cooperative train operations, and reduced headways on operational lines through advanced communication and coordination.	Used by SDFW Type 5 for dynamic spacing and coordinated movement; exchanges continuous data between SDFWs and TMS; operates using high-integrity communication systems like SRC and Relative Localisation (RL).
Infrastructure Route Setting	Manages switch positions and defines safe itineraries inside the yard or terminal.	Interacts with YAMS to set conflict-free routes for the SDFW; ensures that SDFW movements follow a predefined safe path; supports Types 1–5 depending on operation area.
Infrastructure Wagon Braking	Provides braking support inside the yard based on fixed yard infrastructure systems.	Works together with YAMS to stop or regulate wagon movement; supports Type 1 operations where safety is assured by the yard rather than by the wagon.
Charging Station	Recharges the SPFW battery system and supplies energy for autonomous operations.	Interacts with the SPFW battery management system; is used during autonomous yard or last-mile operations; required for high-energy SDFW Types (especially 4 and 5).

Table 18: SDFW elements interaction

5.1.2.1 **SDFW** Type 1

In this subsection the **SDFW** Type 1 architecture is shown together with its strengths and weaknesses.

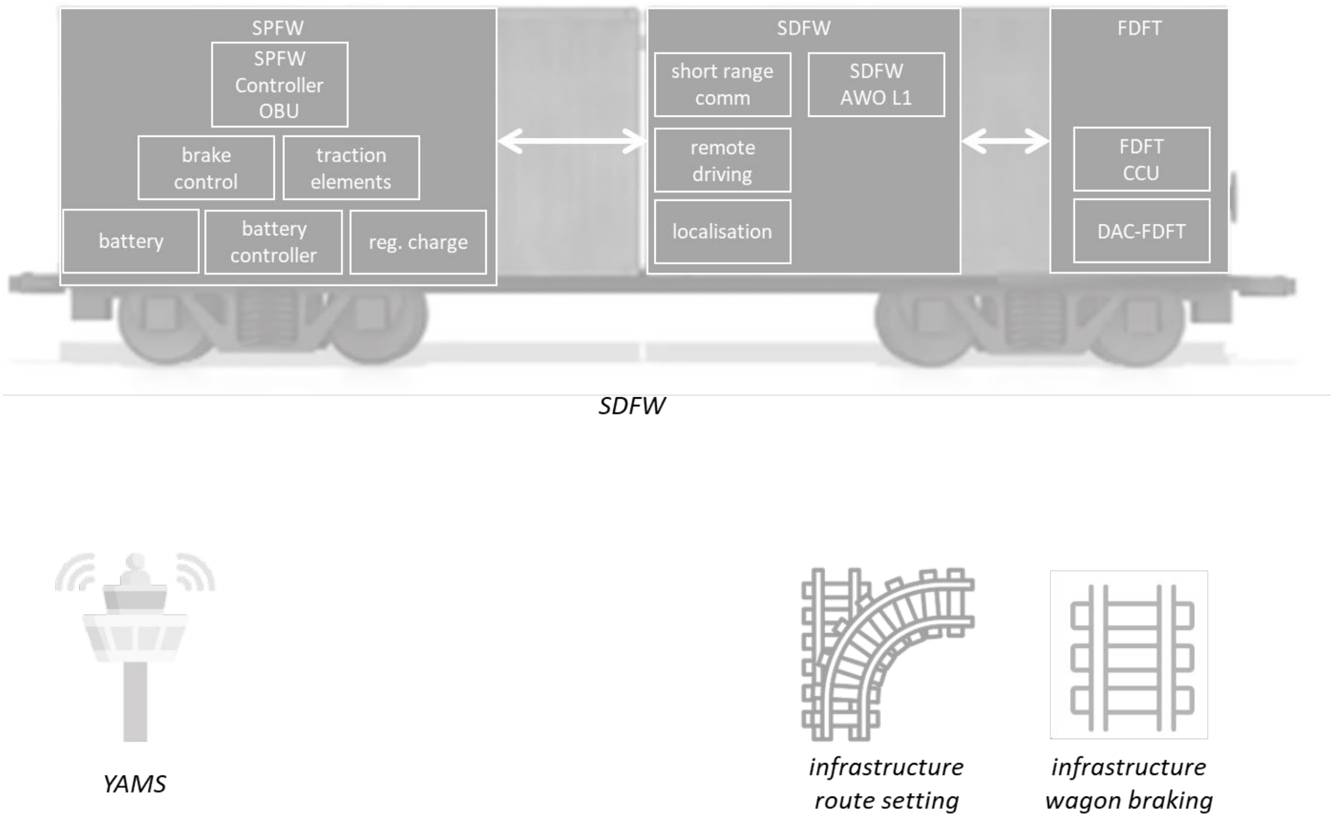


Figure 42: SDFW Type 1 architecture

Strengths	Weaknesses
- It can be integrated in a consist: coexistence with current procedures - It can be recharged thanks to the motion when operating into the train: lower number of charging stations required - Autonomous operations in the shunting yard: safer (less dangerous) because less staff on the ground (ex: shunters) and no need of a shunting locomotive - Faster operations on the yard permitted - Small batteries: higher payload	- Dependent of non-integrated elements (infrastructure wagon braking, YMS…) - It needs a loco in the consist

Table 19: SDFW Type 1 Strengths and Weaknesses

5.1.2.2 **SDFW** Type 2

In this subsection the **SDFW** Type 2 architecture is shown together with its strengths and weaknesses.

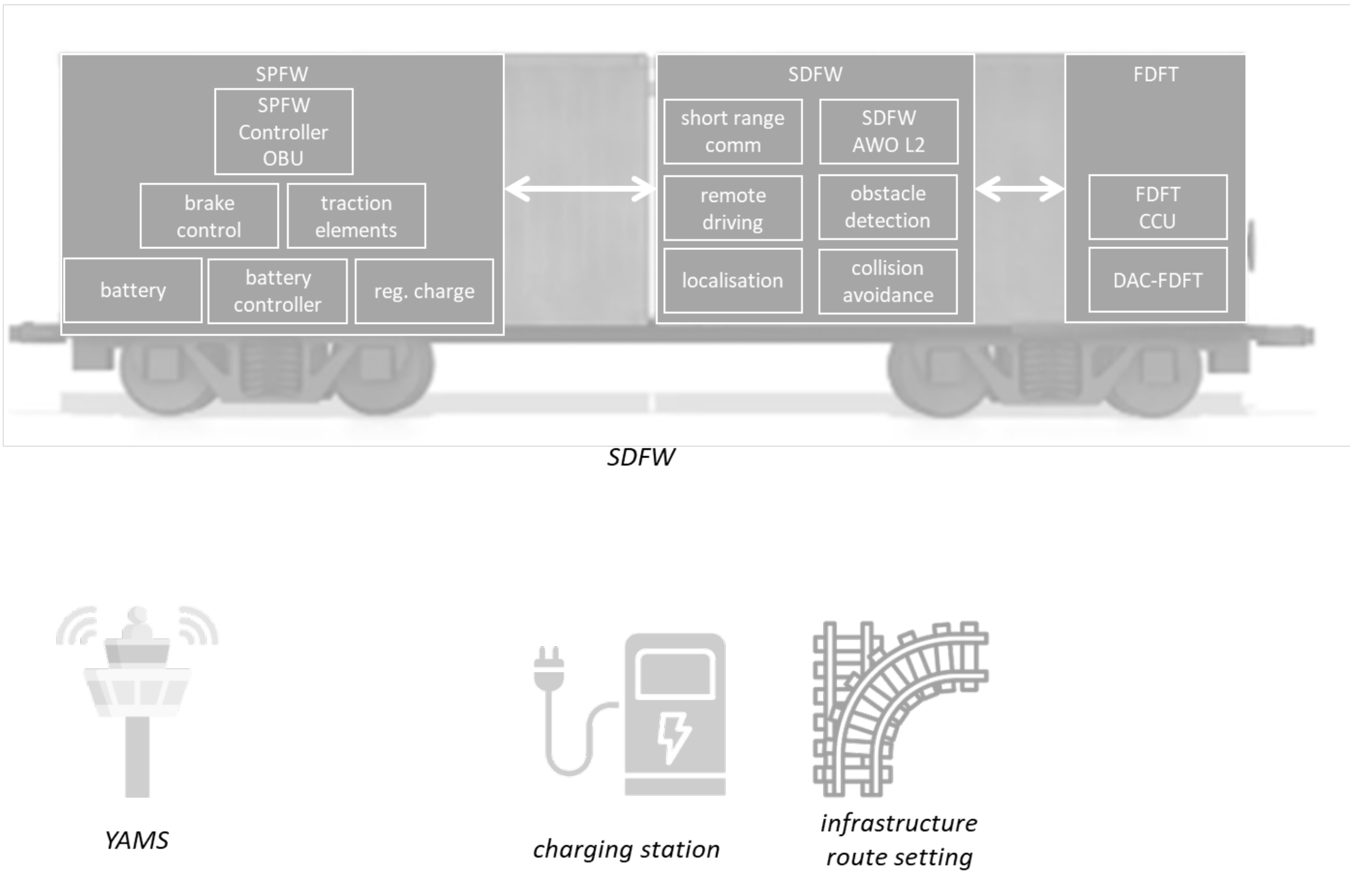


Figure 43: SDFW Type 2 architecture

Strengths	Weaknesses
- It can be integrated in a consist: coexistence with current procedures - It can be recharged via regenerative charging: low number of charging stations required - Autonomous operations in the shunting yard: safer (less dangerous) because less staff on the ground (ex: shunters) and no need of a shunting loco - Small batteries: higher payload	- It needs a loco in the consist

Table 20: SDFW Type 2 Strengths and Weaknesses

5.1.2.3 **SDFW** Type 3

In this subsection the **SDFW** Type 3 architecture is shown together with its strengths and weaknesses.

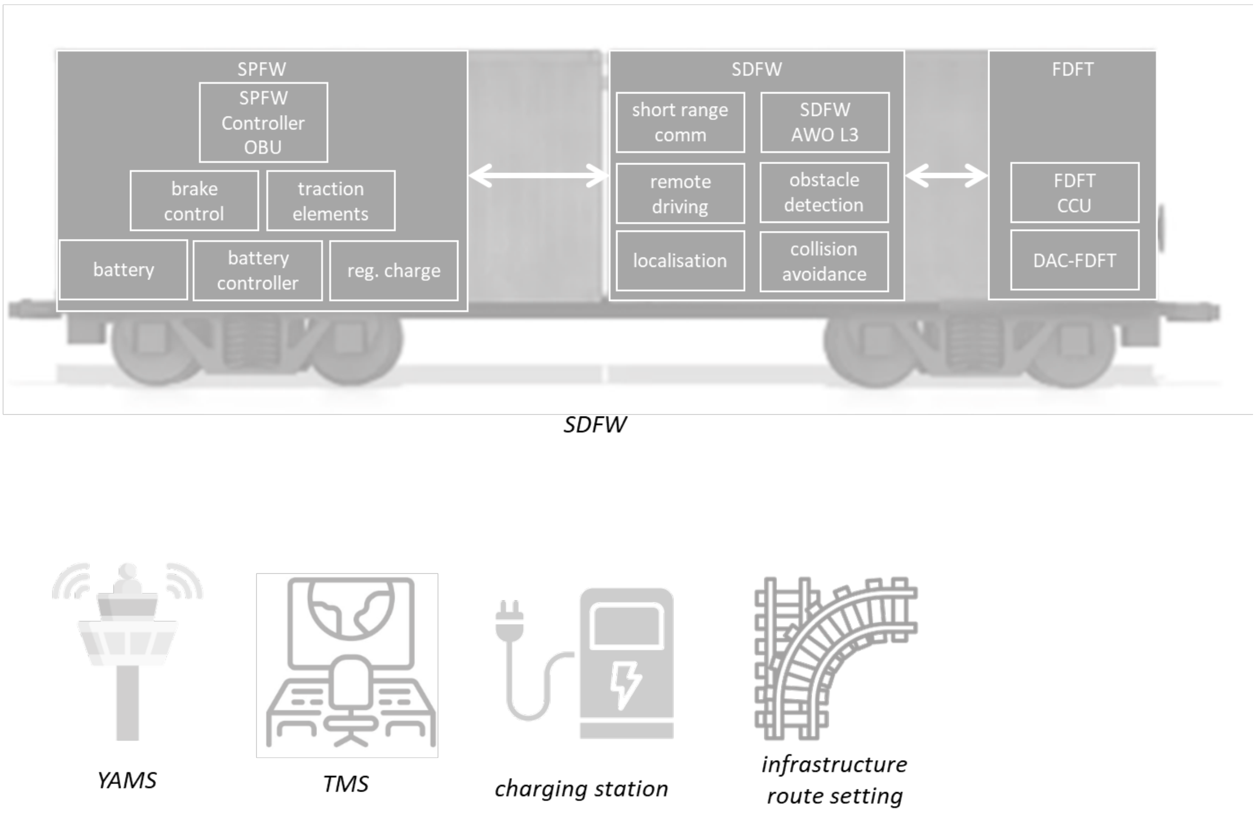


Figure 44: SDFW Type 3 architecture

Strengths	Weaknesses
- It can be integrated in a consist: coexistence with current procedures - It can be recharged via regenerative charging: low number of charging stations required - Autonomous operations in the shunting yard: safer (less dangerous) because less staff on the ground (ex: shunters) and no need of a shunting loco	- It needs a loco in the consist

Table 21: SDFW Type 3 Strengths and Weaknesses

5.1.2.4 **SDFW** Type 4

In this subsection the **SDFW** Type 4 architecture is shown together with its strengths and weaknesses.

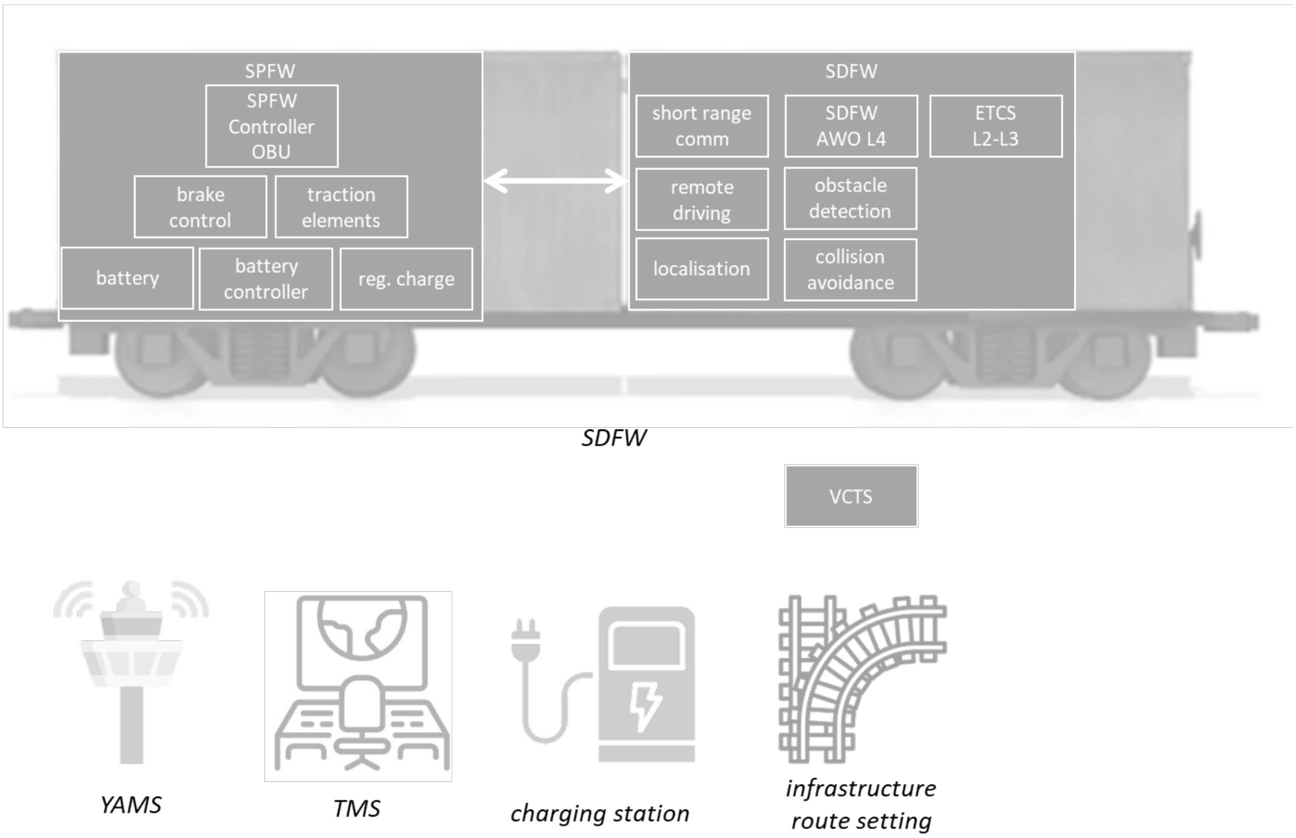


Figure 45: SDFW Type 4 architecture

Strengths	Weaknesses
- Autonomous operations in the shunting yard: safer (less dangerous) because less staff on the ground (ex: shunters) and no need of a shunting loco - Autonomous operations in the operational line: no loco required. - It can be recharged with regenerative braking - Less expenditures: no drivers and no shunters	- Heavy battery (>500 kg): less payload - It cannot be integrated in a consist because no DAC - High cost of ETCS - Charging stations required in the yard and in the operational line

Table 22: SDFW Type 4 Strengths and Weaknesses

5.1.2.5 **SDFW** Type 5

In this subsection the **SDFW** Type 5 architecture is shown together with its strengths and weaknesses.

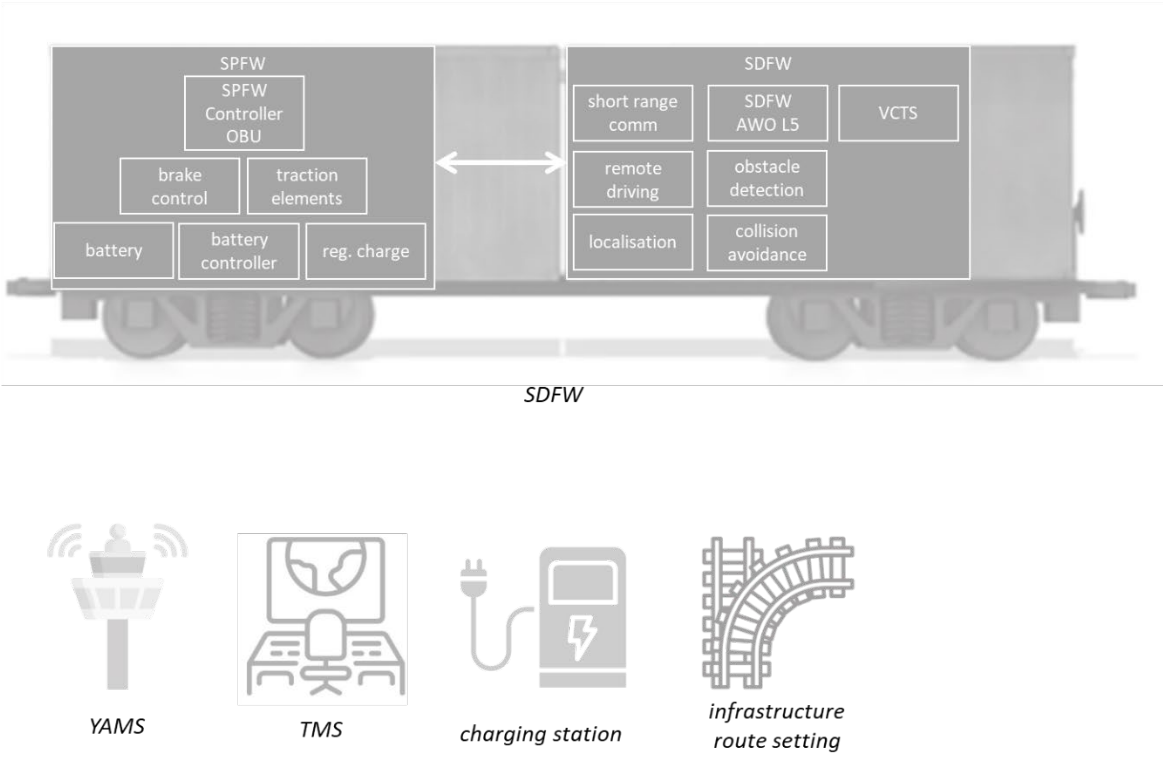


Figure 46: SDFW Type 5 architecture

Strengths	Weaknesses
- Autonomous operations in the shunting yard: safer (less dangerous) because less staff on the ground (ex: shunters) and no need of a shunting loco - Autonomous operations in the operational line: no loco required. - It can be recharged with regenerative braking	- Heavy battery (>500 kg): less payload - It cannot be integrated in a consist because no DAC - Medium cost of VCTS - Charging stations required in the yard and in the operational line

Table 23: SDFW Type 5 Strengths and Weaknesses

5.1.3 Specific cases

The next figure shows how the **SDFW** Type 4 and Type 5 might interact:

- a) refers to the case where **SDFW** Type 5 operates in the ETCS main line directly behind a main line locomotive with ETCS.
- b) refers to the case where **SDFW** Type 5 operates in the ETCS main line behind freight train with a main line locomotive with ETCS. The coverage of VCTS will set the maximum number of wagons that the freight train can take.
- c) refers to the case where **SDFW** Type 5 operates in the ETCS main line behind a **SDFW** Type 4&5.

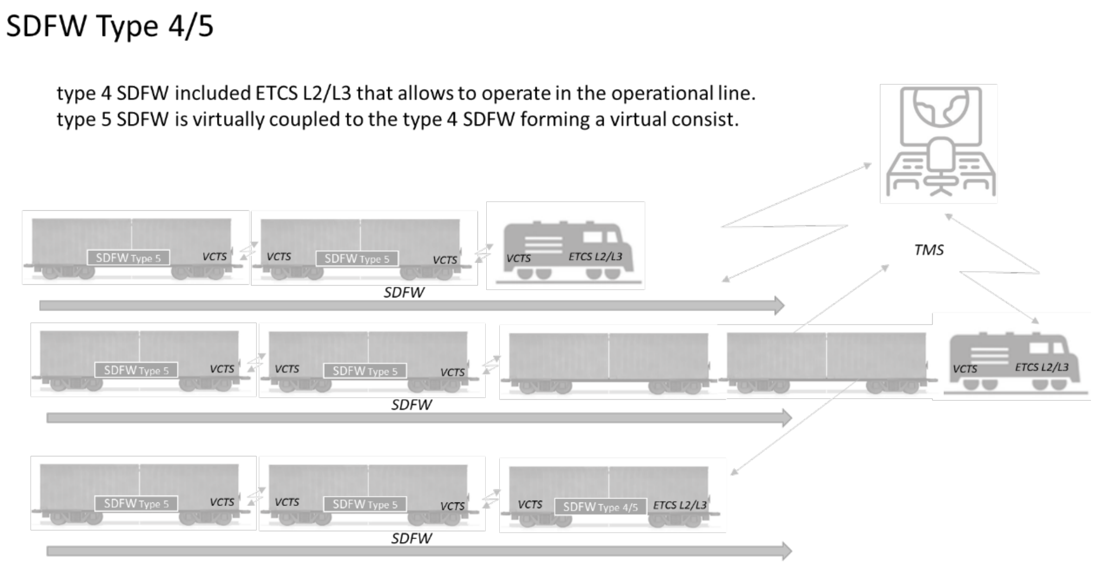


Figure 47: SDFW specific case for Type 4 and Type 5

5.1.4 SWOT analysis

This section includes a SWOT analysis for the SDFW.

Strengths
• Reduces dependence on shunting locomotives and ground staff, increasing safety. • Lowers operational costs. • Supports environmental sustainability goals by cutting emissions. • Flexible operational capability (yard, last-mile, and in some configurations regional lines). • Improved integration with digital rail systems (TMS/YMS) and future fully digital freight operations. • Increases scheduling flexibility and reduces bottlenecks in busy terminals. • Enables more efficient and faster yard operations through autonomous self-shunting.
Weaknesses
• Requires high upfront investment for both new wagons and retrofits. • Additional propulsion, battery, and sensor systems reduce available payload.

• Infrastructure upgrades may be necessary (charging stations, digital yard control, signaling interfaces). • Compatibility challenges with traditional wagons and legacy procedures. • Certification and homologation processes for autonomous rolling stock are complex and lengthy. • Technology maturity gaps, especially for advanced autonomous operation (navigation, obstacle detection). • Workforce training and adaptation required for new procedures and systems.
Opportunities
• Strong potential for deployment in controlled environments such as yards, private terminals, and industrial sites. • New application areas such as snow-removal wagons, construction and maintenance logistics, and military/tunnel operations. • EU-level initiatives aiming for greener, more digital freight transport align perfectly with SDFW deployment. • Standardisation of interfaces, communications, and safety models will accelerate adoption. • Potential to attract freight volumes from road transport due to improved efficiency and lower emissions. • Opportunity to create new automated logistics services and business models.
Threats
• Uncertain return on investment may discourage operators from early adoption. • Infrastructure and operational readiness vary widely across Europe. • Slow regulatory evolution may delay authorization for autonomous yard and line operations. • Coexistence with conventional freight wagons may introduce compatibility issues. • Labour resistance or organisational inertia could hinder implementation. • Cybersecurity risks increase with higher digital dependence. • Competition from autonomous trucks could limit the business case if rail innovation lags

5.2 APPROACH TO BUSINESS CASE

This section includes a first preliminary analysis of the CAPEX and OPEX for the **SDFW** based on the types. This analysis leads to determine which are the most profitable cases for the **SDFW**.

5.2.1 CAPEX

As shown in the previous section, the **SDFW** requires a number of components depending on its Type. In the next table all these elements are listed.

CAPEX			
Wagon			
SPFW	SPFW Controller OBU	SDFW	SDFW AWO
SPFW	Brake Control	SDFW	Short range communication
SPFW	Traction elements	SDFW	Long range communication
SPFW	Battery	SDFW	Remote Driving
SPFW	Battery controller	SDFW	Localisation
SPFW	Regenerative charge	SDFW	Obstacle detection
SPFW	Regenerative braking	SDFW	Collision avoidance
FDFT	FDFT CCU	SDFW	ETCS L2-L3
FDFT	DAC FDFT	SDFW	VCTS

Table 24: SDFW component list

The next table shows a first preliminary analysis of the CAPEX for the **SDFW**.

CAPEX		Baseline Freight wagon	SDFW type				
Wagon			Type 1	Type 2	Type 3	Type 4	Type 5
SPFW	SPFW Controller OBU	-	1	1	1	1	1
	Brake Control	-			1	1	1
	Traction elements	-	2	2	2	3	3
	Battery	-	2	2	3	4	4
	Battery controller	-	1	1	1	1	1
	Regenerative charge	-				-	-
	Regenerative braking	-	-	-	-	1	1
SDFW	SDFW AWO OBU	-	2	2	2	2	2
	Long range communication	-	1	1	1	-	-
	Remote driving	-	2	2	2	2	2
	Localisation	-	1	1	1	1	1
	Obstacle detection (radar, other systems)	-	-	1	2	3	3
	Collision avoidance	-	-	2	2	2	2
	ETCS L2 (includes FRMCS and MB)	-	-	-	-	5	-
	VCTS (includes short and long range communication)	-	-	-	-	-	4
FDFT	FDFT CCU	2	2	2	2	-	-
	DAC FDFT	2	2	2	2	-	-
		4	16	19	22	26	25

-	*does not exist*		1	very low	*<10k€*
2	*low*	*10k€-50k€*	3	*medium*	50k€-75k€
4	*high*	*75k€-100k€*	5	*very high*	*>100k€*

* Drawbacks of the analysis: some elements can be categorized in the lower limit or higher limit of a range. Moreover, some concepts might me gathered together instead of being included twice in the range. This two topics make the analysis less reliable, however from a quantitative point of view the ranking obtained from the analysis is used in the deliverable.

Table 25: SDFW CAPEX[5]

[5] Price difference between GOA1 and GOA3 for new equipment with positioning, obstacle detection, anticollision and comm. is aprox. 250k€.

It should be also taken into account the new shunting yard deployments/building shall be cheaper due to the shift of the complexity from the shunting yard to the wagon.

5.2.2 OPEX

With the aim of analysing the CAPEX, a list of concepts that reduce/increases costs and reduce/increases incomes are listed in the next table

Cost
Cost reduction • Shunting locos usage up to removing it completely. • Main-line loco usage up to removing it completely. • Lower number of wagons required, due to a more efficient use of the FW: shorter time operations in the yard reducing stand-by time. • Less staff required (yards drivers, yard operators) due to the autonomous operations. • Reduced infrastructure (removing hump in hump yards, less tracks for operations) leading to reduce maintenance and operations costs.
Cost increase • **SDFW** equipment maintenance: CPU, sensors, camera, communication unit, location system, battery, propulsion, … • **SDFW** related infrastructure maintenance: battery charging station. • **SDFW** higher risk if unavailability (equipment failure) due to more complex/higher number of technological equipment. • Higher cost for training existing personnel for **SDFW** • Increase the number of train paths and the cost of freight traffic (**SDFW** moving independently). • Reduced payload mainly due to the batteries and traction weight. • Higher unavailability due to charging time for batteries.
Income
Income increase • More efficient operations in the yards – faster. • More efficient operations in the yards - parallel operations. • New market opportunities, i.e. dangerous goods, military case, … • Higher income due to carbon neutral operations (carbon 0 transportation). • better transport quality, gets higher transport fees. • New automation possibilities for inner-company processes is a customer value, which can be paid. • Higher flexibility that enables offering extra services to the customers. • Extending the operation hours of the yard
Income decrease • Unavailability due to charging time.

Table 26: SDFW OPEX concepts

The next table shows a preliminary classification of the financial impact of the different concepts listed in the table. It considers first the economies of the operations for which cost reduction is achieved, secondly it considers the additional costs of operations that the **SDFW** brings and finally the combined value from the previous two items.

OPEX	SDFW Types				
Economies on operations	Type 1	Type 2	Type 3	Type 4	Type 5
Shunting Loco usage up to removing it completely	3	3	3	3	3
Main Line Loco usage up to removing it completely	-	-	-	5	5
Lower number of wagons required for a dedicated traffic (More efficient use of the FW: shorter time operations in the yard)	-	-	3	3	3
Less staff required (in the yards, drivers…)	3	3	3	3	3
Reduced infrastructure (ex : classification yards)	2	3	3	3	3
Total	**8**	**9**	**12**	**17**	**17**
Additional costs on operations	Type 1	Type 2	Type 3	Type 4	Type 5
SDFW equipment maintenance: battery, CPU, sensors, camera, comm. unit, propulsion, …	1	2	2	3	3
SDFW related infrastructure maintenance: battery charging station	2	2	3	3	3
Cost for training existing staff for SDFW or recruiting more qualified staff	2	2	3	4	4
Increased number of train paths	-	-	-	3	3
Reduced payload	1	2	3	3	3
Higher unavailability due to charging time for batteries	1	1	2	3	3
Total	**7**	**9**	**13**	**19**	**19**
	Type 1	Type 2	Type 3	Type 4	Type 5
Combined total (normalized)	**1,3**	**1,2**	**0,4**	0,2	**0,2**

Financial Impact	
Very low	1
Low	2
Medium	3
High	4
Very high	5

Table 27: SDFW OPEX

From the table, it can be extracted that the most of the benefits are brought first by the **SDFW** type 1 and type 2. However, if the economies of operations are considered, type 4 and type 5 are bringing most of the value. Therefore, it can be concluded that the introduction of the **SDFW** shall start with the yard operations with Type 1 or Type 2 **SDFW** and end the full deployment with the Type 4 and/or type 5.

Moreover, other additional beneficial aspects not directly related to cost/income need to be also considered:

- Safer and higher quality jobs are offered dealing to less accidents with personnel.
- More agile and geographically distributed operations due to less complex yard infrastructure.
- More ecological mainly due to the removal of diesel shunting locomotives.

The following topics need also to be taken into account:

- Migration for both Systems coexisting. Transition phase of the technology.
- Maintenance cost of charging stations.
- More qualified personnel Training and qualification for new technologies SDFW will be required. For the new generation of workers, it is assumed to be not as costly as the training for the traditional operations. However, the training for the new technologies of the SDFW is costlier for the existing personnel.
- (Cyber)security costs.
- SDFW will also require new procedures for the Yard, which need to be defined overcome the current traditional procedures.

- Need to be taken into account the location of the batteries and traction system that shall not affect the room for the load.

5.2.3 Summary

From the previous analysis the following summary table can be obtained where the classigficaiton of the CAPEX and OPEX for the different **SDFW** types is shown..

CAPEX-OPEX

	Type 1	Type 2	Type 3	Type 4	Type 5
CAPEX *classification*	1^{st}	1^{st}	2^{nd}	3^{rd}	3^{rd}
OPEX *classification*	1^{st}	1^{st}	2^{nd}	3^{rd}	3^{rd}

Table 28: SDFW CAPEX and OPEX summary

After the analysis it can be stated that the reference use cases SS1 forming train yards: **SDFW** moves to the track where the target train composition in order to couple to corresponding wagon of the train composition with type 1 and 2 **SDFW** and SD1: autonomous operations into the operational line with type 3 **SDFW** shall be the more promising cases.

Use case		SDFW Type	OPEX	CAPEX
SS: autonomous operations into the yard/terminal, it also includes last mile operation	SS1 forming train yards: **SDFW** moves to the track where the target train composition in order to couple to corresponding wagon of the train composition.	1	1^{st}	1^{st}
		2	1^{st}	1^{st}
SD: autonomous operations into the operational line	SD2 transport regional line: **SDFW** travels in the regional line.	3	2^{nd}	2^{nd}

Table 29: SDFW reference use cases, SDFW types, CAPEX and OPEX summary

5.3 Discussion

There are several gaps that need to be addressed for the adoption and integration of the **SDFW** in rail freight operations. A significant challenge lies in integrating the **SDFW** with existing rail infrastructure, which is designed for traditional freight operations, including ensuring compatibility with current signalling systems and track layouts. The transition to self-driving technologies requires substantial capital investment, both for retrofitting existing wagons and developing new autonomous systems, creating a financial barrier that can slow down the adoption process.

Additionally, there is a lack of standardized communication protocols and interoperability standards for autonomous rail operations, which hinders the seamless integration of the **SDFW** across different rail networks and operators. The regulatory framework for autonomous rail operations is still evolving, and ensuring safety and compliance with existing rail regulations poses a significant challenge. Furthermore, current technologies for obstacle detection, navigation, and control systems require further development to ensure reliable and safe autonomous operations in diverse environments in a cost-effective manner.

Despite these challenges, there are significant opportunities for the **SDFW**. The rapid development of digital technologies, such as AI and IoT, presents opportunities for improvements in predictive maintenance and real-time data analytics. There is potential to improve battery efficiency and implement regenerative braking systems, which can extend the operational range of the **SDFW** and reduce energy consumption. SDFWs can significantly improve operational efficiency by reducing the need for manual shunting and enabling more flexible scheduling and routing of freight operations. By reducing reliance on diesel locomotives and optimizing freight operations, the **SDFW** can contribute to lower greenhouse gas emissions and support sustainability goals. Additionally, the development of SDFWs opens up new market opportunities, particularly in regions with dense rail networks and high freight demand, including potential applications in intermodal transport and last-mile delivery. The use cases identified, such as autonomous yard operations and regional line transport, demonstrate the potential for significant cost savings and operational improvements. The business case analysis suggests that while initial capital expenditures are high, the long-term operational savings and environmental benefits can justify the investment. Addressing these gaps and leveraging the opportunities will be crucial for accelerating the adoption of the SDFW, leading to more efficient, sustainable, and competitive freight operations.

Looking ahead, future work should focus on several key areas to facilitate their successful integration into the rail freight sector. Continued research and development are essential to overcome technological limitations, particularly in enhancing obstacle detection, navigation systems, and battery efficiency. Developing standardized communication protocols and interoperability standards will be crucial for ensuring seamless integration across diverse rail networks. Pilot projects should be initiated to validate the operational capabilities and benefits of the **SDFW** in real-world settings, providing valuable insights into technical and logistical challenges. Additionally, collaboration with regulatory bodies is necessary to establish a robust framework that ensures safety and compliance while accommodating the unique aspects of autonomous operations. Exploring innovative business models and financing strategies can help mitigate the high initial investment costs, making the transition to autonomous freight operations more economically viable. By addressing these areas, the rail industry can accelerate the adoption of **SDFW**, paving the way for a more efficient, sustainable, and competitive future in freight transportation.

6 CONCLUSIONS

This deliverable aims to define use cases and an operational concept for the **SDFW**, and connection of the **SDFW** to TMS / YMS in close collaboration with the activities of the work packages related to Automation Processes, the activity of Self-Propelled Freight Wagon in Destination 5 and the TMS/YMS activities in Destination 1. Moreover, it focuses on the conceptualisation of the **SDFW** looking at making use of the SRC and RL technologies. For that, the following topics are considered:

- Study of prototypes already developed. This also includes the study of scientific articles.
- Initial list of use cases for **SDFW** analysing the extension to the use case of an inspection vehicle.
- Update and review of use cases for **SDFW**, based on the initial list and validated e.g. by means of interviews of freight experts on this subject.
- Operational concept description including the link to TMS/YMS defined in destination 1.
- Analysis of the integration with the vehicle concept for the SPFW from Destination 5.
- Estimation of necessary investments.

By means of covering the previous topics, this deliverable contributes to new knowledge in gathering the current state of art, in defining the **SDFW** use cases, the **SDFW** concept definition by means of evolutive types and the **SDFW** architecture linked to FP1-MOTIONAL and FP5-TRANS4M-R; and in estimating preliminarily the **SDFW** of CAPEX and OPEX.

With the aim of having the context for the SDFW concept, and state of the art analysis has been carried out, where more that 700 scientific works for the concepts of self driving (**SDFW**) and self propelled (SPFW) freight wagons in international journal and congresses have been found. From those work, three have been analysis into depth. Moreover, 3 SDFW prototypes have been also included in the study. The analysis of the prototypes, all designed only for freight transport, is summarized in the next table:

Prototype	Advantages	Drawbacks
RAGV [9][10]	• Fully autonomous wagon. • Efficient use of the rail network. • Reduction in emissions. • Transport of both goods and people.	• Lack of control over the infrastructure. • Acceptance of this new model. • Commercialisation of the software.
Intramotev [11]	• Reduction in CO_2 emissions, thanks to the use of batteries. • Reduction in OPEX (between 30% and 80%). • Predictive maintenance thanks to its technology.	• Lack of control over the infrastructure. • Current only deployment in closed areas even though due to the distance it able to travel, it could be used as intercity transport. • Current wagon proposal not compatible with the European wagons.
Parallel System [12]	• Reduction in the space needed to store them. • Individual movement and in groups of up to 50.	• Lack of control over the infrastructure.

Additionally, the concepts from the state of art analysed that can be useful for WP48 (T48.4) can be highlighted. The next table shows the type of communications and positioning employed in each when it applies.

Section	Project/Article/Prototype/Company	Positioning	Communications
2.1.1	Automated Nano Transport System-Ansatz zur Entwicklung autonomer Schienenfahrzeuge [6]	Absolute	Long range
2.1.2	Wagon 4.0 – the smart wagon for improved integration into Industry 4.0 plants and towards inclusion of the freight rail system in the industrial internet of things	Absolute	Long range
2.1.3	Intermodal Competition in Freight Transport - Political Impacts and Technical Developments [8].	-	-
2.2.1	RAGV	Absolute	Long range
2.2.2	Intramotev [11]	Absolute	Long range
2.2.3	Parallel Systems [12]	Absolute	Long range

Table 30: Type of communication and positioning employed in the paper/prototype analysed.

Thanks to the state of the art analysis, it can be stated that the **SDFW** concept is promising, the benefits it will bring to the sector can be assessed by amount of funding received by the on-going companies. Moreover, the **SDFW** will contribute to the objectives of EU white book 50% which aims to reduce the emissions by 2050.

A list of uses cases for the **SDFW** has been also created grouped into yard processes, namely, SS (Self-shunting) and operational lines processes, namely SD (Self Driving). For that, first an initial list of uses cases (7 use cases) has been defined, after that, by means of a questionnaire a number of experts have been consulted and finally with the collected responses the use case list has been enhanced as shone in the next figure.

Figure 48: SDFW updated use cases list

From the analysis done, the following use cases are selected as reference due to the score obtained as a result of the expert consultation:

- SS: autonomous operations into the yard/terminal, it also includes last mile operation
  - SS1 forming train yards: **SDFW** moves to the track where the target train composition in order to couple to corresponding wagon of the train composition.
- SD: autonomous operations into the operational line
  - SD2 transport regional line: **SDFW** travels in the regional line.

The SDFW requires to operate with other elements found in the railway system. Therefore, an analysis of FP1-MOTIONAL [4] for the operation management and FP5-TRANS4M-R [5] for the freight train/wagon related topics have been carried out. From the analysis done the following topics related to **SDFW** have been found.

- **FP1-MOTIONAL:** The management on the line of a **SDFW** by a TMS is considered to be similar to the operation of a train equipped with ATO. However, yard operation on a **SDFW** will vary current procedures. FP1-MOTIONAL also covers Yard operations by introducing the **Yard Control System** (YCS), which is referred (WP10, WP11 and WP12). The YCS relates to the processes of the yard and its management, and shall be linked to the **SDFW**.
- **FP5-TRANS4M-R:** The FDFTO includes elements that are considered in the **SDFW** architecture, on one hand, the Full Digital Freight Train with the DAC and the ASO (WP3, WP5 and WP12) to be integrated in a freight train and operated by the YCS, and on the other the Self-Propelled Freight Wagon elements to enable the movement of the wagon (WP22 and WP23).

The next figure and table show the main building blocks of the **SDFW** and the infrastructure elements to which the **SDFW** interacts.

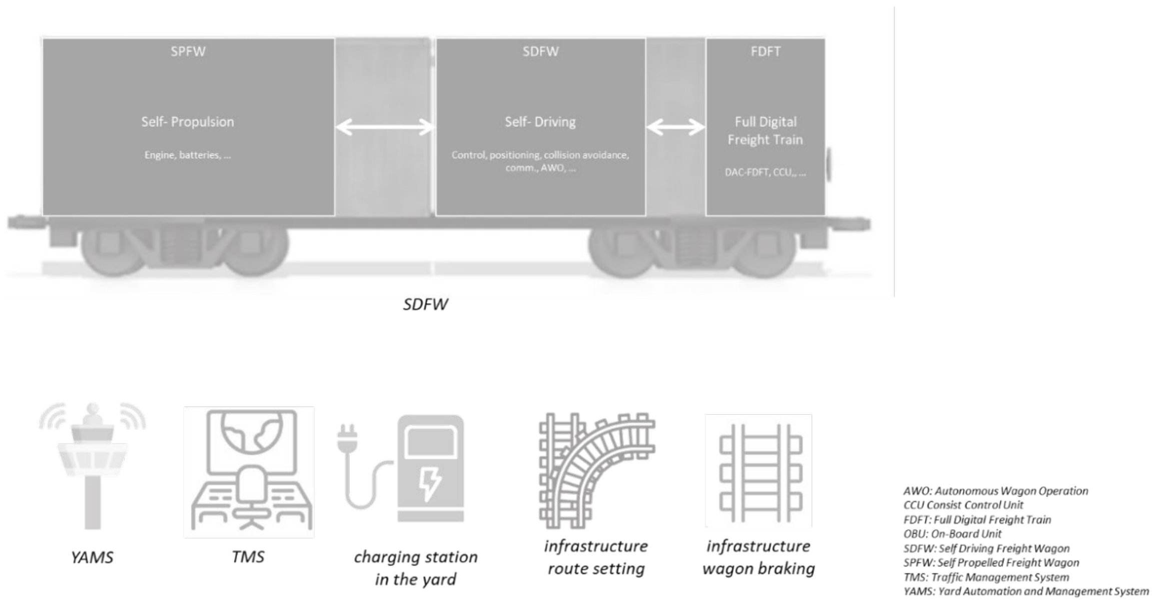


Figure 49: SDFW architecture and infrastructure elements

Five different evolutive types of the **SDFW** have been defined depending on the elements of the architecture and the application on the use cases of the **SDFW**.

- **Type 1:** it allows autonomous operations (movement) only in yards (SS), commanded by the YMS (yard) and within a yard that ensures the safety of the operation (avoids collisions and commands the emergency brake). For the last mile (<50 km) and operational line (>50 km) it operates within a consist.
- **Type 2:** it allows autonomous operations (movement) only in yards (SS), commanded by the YMS (yard) and the own **SDFW** ensures the safety of the operation (avoids collisions and commands the emergency brake). For the last mile (<50 km) and operational line (>50 km) it operates within a consist.
- **Type 3:** it allows autonomous operations (movement) only in yards (SS), and last mile (<50 km), commanded by the YMS (yard) and TMS (last mile), and the own **SDFW** ensures the safety of the operation (avoids collisions and commands the emergency brake). For the operational line (>50 km) it operates within a consist.
- **Type 4:** it allows autonomous operations (movement) in yards (SS), Last Mile (<50 km), and operational line (>50 km), commanded by the YMS (yard) and TMS (last mile and operational line), and the own **SDFW** ensures the safety of the operation (avoids collisions and commands the emergency brake) in the yard and the last mile, and the ETCS (ATP) in the operational line.
- **Type 5:** it allows autonomous operations (movement) in yards (SS), last mile (<50 km), and operational line (>50 km), commanded by the YMS (yard) and TMS (last mile and operational line), and the own **SDFW** ensures the safety of the operation (avoids collisions and commands the emergency brake) in the yard and the last mile, and the VCTS in the operational line.

After the analysis it can be stated that the reference use cases SS1 forming train yards: **SDFW** moves to the track where the target train composition in order to couple to corresponding wagon of the train composition with type 1 and 2 **SDFW** and SD: autonomous operations into the operational line with type 3 **SDFW** shall be the more promising cases.

<table>
<tr><th colspan="2">Use case</th><th>SDFW Type</th><th>OPEX</th><th>CAPEX</th></tr>
<tr><td rowspan="2">SS: autonomous operations into the yard/terminal, it also includes last mile operation</td><td rowspan="2">SS1 forming train yards: SDFW moves to the track where the target train composition in order to couple to corresponding wagon of the train composition.</td><td>1</td><td>1st</td><td>1st</td></tr>
<tr><td>2</td><td>1st</td><td>1st</td></tr>
<tr><td>SD: autonomous operations into the operational line</td><td>SD2 transport regional line: SDFW travels in the regional line.</td><td>3</td><td>2nd</td><td>2nd</td></tr>
</table>

Table 31: SDFW reference use cases, SDFW types, CAPEX and OPEX summary

To sum up, the current state of the art for Self-Driving Freight Wagons (**SDFW**) reveals several gaps that need to be addressed to advance the adoption and integration of autonomous technologies in rail freight operations. A significant challenge lies in integrating the **SDFW** with existing rail infrastructure, which is primarily designed for traditional freight operations, including ensuring compatibility with current signaling systems and track layouts. The transition to self-driving technologies requires substantial capital investment, both for retrofitting existing wagons and developing new autonomous systems, creating a financial barrier that can slow down the adoption process. Additionally, there is a lack of standardized communication protocols and interoperability standards for autonomous rail operations, which hinders the seamless integration of the **SDFW** across different rail networks and operators. The regulatory framework for autonomous rail operations is still evolving, and ensuring safety and compliance with existing rail regulations poses a significant challenge. Furthermore, current technologies for obstacle detection, navigation, and control systems require further development to ensure reliable and safe autonomous operations in diverse environments.

Despite these challenges, there are significant opportunities to enhance the capabilities of the **SDFW**. The rapid development of digital technologies, such as AI and IoT, presents opportunities for improvements in predictive maintenance and real-time data analytics. There is potential to improve battery efficiency and implement regenerative braking systems, which can extend the operational range of the **SDFW** and reduce energy consumption. The **SDFW** can significantly improve operational efficiency by reducing the need for manual shunting and enabling more flexible scheduling and routing of freight operations. By reducing reliance on diesel locomotives and optimizing freight operations, the **SDFW** contributes to lower greenhouse gas emissions and support sustainability goals. Additionally, the development of the **SDFW** opens up new market opportunities, particularly in regions with dense rail networks and high freight demand, including potential applications in intermodal transport and last-mile delivery. The use cases identified, such as autonomous yard operations and regional line transport, demonstrate the potential for significant cost savings and operational improvements. The business case analysis suggests that while initial capital expenditures are high, the long-term operational savings and environmental benefits can justify the investment. Addressing these gaps and leveraging the opportunities will be crucial for accelerating the adoption of the **SDFW**, leading to more efficient, sustainable, and competitive freight operations.

7 FUTURE WORK

The deliverable D48.3 provides a comprehensive conceptual framework for the Self-Driving Freight Wagon (**SDFW**), including use cases, architecture, and a classification of **SDFW** types. For a further evolution, several areas require further development to strengthen the technical and operational foundation of the concept. Looking ahead, future work should focus on several key areas to facilitate their successful integration into the rail freight sector. Continued research and development are essential to overcome technological limitations, particularly in enhancing obstacle detection, navigation systems, and battery efficiency. Developing standardized communication protocols and interoperability standards will be crucial for ensuring seamless integration across diverse rail networks. Pilot projects should be initiated to validate the operational capabilities and benefits of the **SDFW** in real-world settings, providing valuable insights into technical and logistical challenges. Additionally, collaboration with regulatory bodies is necessary to establish a robust framework that ensures safety and compliance while accommodating the unique aspects of autonomous operations. Exploring innovative business models and financing strategies can help mitigate the high initial investment costs, making the transition to autonomous freight operations more economically viable. By addressing these areas, the rail industry can accelerate the adoption of the **SDFW**, paving the way for a more efficient, sustainable, and competitive future in freight transportation.

7.1 Requirements Definition

While high-level requirements are embedded within the use cases and architectural definitions, a deeper analysis is planned for the future and will contribute significantly to the state of the art in autonomous rail freight, thanks to a more detailed and structured analysis of:

- **Functional Requirements**: Specific capabilities the SDFW must support (e.g., autonomous coupling, obstacle detection).
- **Technical Requirements**: Hardware and software specifications, including sensors, communication protocols, and control systems.
- **Operational Requirements**: Integration with yard and traffic management systems, safety protocols, and interoperability.
- **Performance Requirements**: Metrics such as speed, energy consumption, payload capacity, and reliability.

7.2 SRC and RL Technologies

Existing **SDFW** prototypes do not currently utilize SRC and RL. The deliverable should explicitly justify the inclusion of these technologies in future **SDFW** designs. Notably, **SDFW** Type 5 incorporates VCTS, which relies on SRC and RL for safe and efficient autonomous operations. Their integration is essential for enabling advanced coordination and collision avoidance in complex rail environments. The results of T48.4 where SRC and RL is deeply analysed will support the contribution of SRC and RL into the **SDFW**.

7.3 CAPEX and OPEX

The business case analysis presented in Chapter 5 includes preliminary evaluations of **Capital Expenditure (CAPEX)** and **Operational Expenditure (OPEX)**. However, the deliverable should reference the sources from which these values were derived. The current estimations are based on:

- Expert interviews conducted during the use case validation phase.
- Internal experience and domain knowledge from the **T48.3 working group**.

Future iterations should aim to include traceable references, market benchmarks, and cost modelling methodologies to enhance the credibility and reproducibility of the financial analysis.

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