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Self-Driving Freight Wagon (SDFW) state of art and use case list

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Introduction

This document presents the conceptual studies conducted on the Self-Driving Freight Wagon (SDFW) as part of the broader research and development efforts within the FP2-R2DATO initiative, specifically under the Technology Element 12 (TE12) “Self-Driving Freight Wagons.

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 also includes the Self Propelled Freight Wagon (SPFW) responsible for the movement of the vehicle.

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.

First a state of art analysis has been carried out where research projects, scientific papers and existing prototypes have been analysed. Then, the main objective is to define a comprehensive set of use cases and an operational concept for the SDFW, including its integration with Terminal Management Systems (TMS) and Yard Management Systems (YMS). This work has been developed in close collaboration with related activities in the fields of automation processes, the Self-Propelled Freight Wagon (SPFW) initiative under Destination 5 [1], and the TMS/YMS developments in Destination 1 [2].

This document shows:

- Introduction: definition of SDFW and content of this document (Section 1).
- State of the Art: A review of existing prototypes and current developments (section 2).
- Operation of Freight Wagon terminal: description of three types of terminals including their processes where the SDFW could be employed (section 3)
- Use Case Definition: A preliminary list of use cases for the SDFW, including potential applications as an inspection vehicle and an updated and validated list of use cases, informed by expert interviews and stakeholder feedback (Section 4).
- Conclusions (Section 5).
- References

State of art

Vehicle technology is changing rapidly due to advancements in digitalization and automation. Fully autonomous vehicles could make road transport much more appealing and safer than it is now. This poses a big challenge for the rail industry, as autonomous road vehicles might replace some of the transport services that are currently rail-based. To address this challenge, the rail industry needs to develop solutions that match or exceed the capabilities of future autonomous road transport. 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.

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.

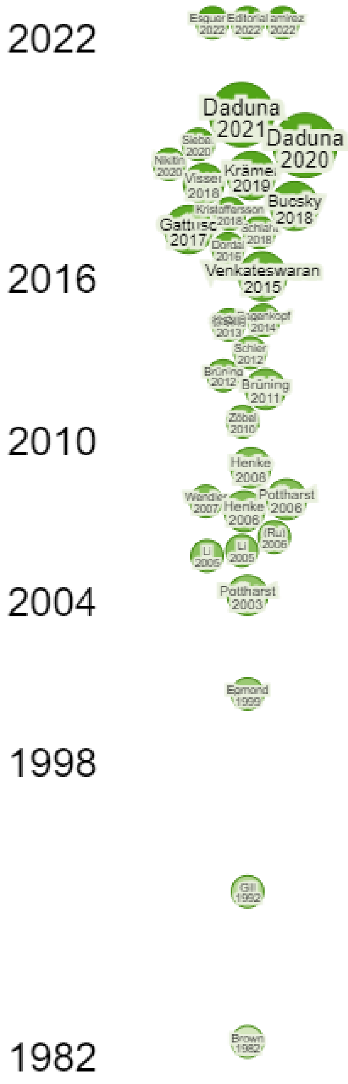

Figure 1: Publications related to SDFW ordered by year

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
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
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
Scenarios for the development of self-driving vehicles in freight transport	2018
Automated rail wagon for new freight transport opportunities	2017
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
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 1: List of publications related to SDFW ordered by year

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 [10], [11], [12], [13], [14] and [15] are not addressed. The three most relevant research projects/articles for the definition of the **SDFW** are:

- **Automated Nano Transport System [3]:** Automatic Nano Transport System (ANTS) (Figure 2): 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. The Drive-Board was planned to be able to carry a 40"-ISO-Container. This is linked to the idea of FP7-PODS4Rail.

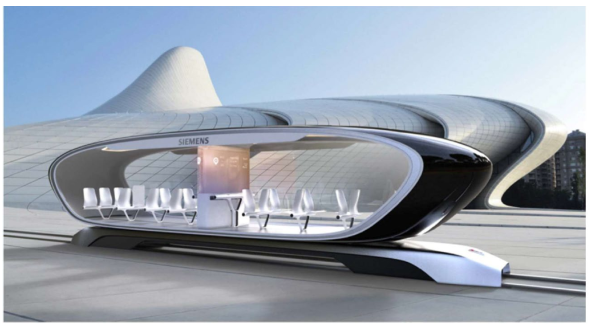

Figure 2: ANTS design study, autonomous micro-vehicle consisting of drive unit and life unit for the individualised transport of passengers (© SIEMENS AG) [3]

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.
- **Energy requirement, power storage mass and drive power:** 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.
- **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.
- **The maximum speed:** limited to 120 km/h

- **Wagon 4.0 [4]:** 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).

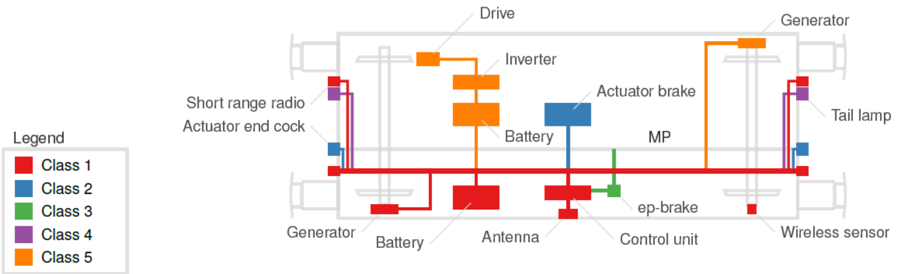

Figure 3: Wagon 4.0 system architecture [16]

Inputs for SDFW: The architecture defined and the list of components is helpful for the definition: Power supply, Data Network, Sensors, Actuators, Algorithms and Operating System

- **Intermodal Competition in Freight Transport - Political Impacts and Technical Developments [5]:** 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.

Inputs for SDFW: Rail automation is progressing through defined Grades of Automation (GoA):

- GoA 3 and GoA 4: Represent driverless and fully unattended operations, respectively.
- Onboard Systems: Automatic Train Operation (ATO-OB) interfaces with trackside systems (ATO-TS) and control centers.
- Communication: Currently based on GSM-R (2G), with future upgrades anticipated.
- Positioning: Primarily odometric, with potential integration of GNSS and sensor fusion.
- Applications: Include autonomous last-mile freight solutions (e.g., CargoMover) and virtual coupling of wagons.
- Operational Trials: Autonomous locomotive control is being piloted in controlled environments such as marshalling yards, with successful implementations in locations like Bremerhaven.

The analysis of the state of the art resulted also in some prototypes already developed and start-up companies. Three of the them are listed as follows:

- **RAGV [6]:** 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.

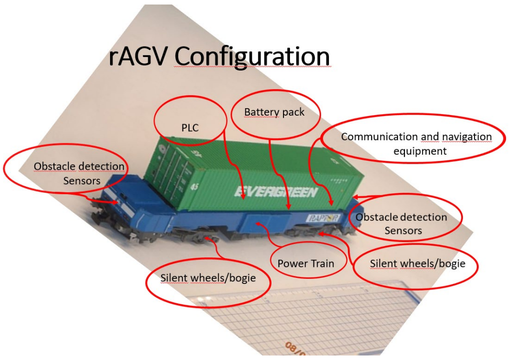

Figure 4: RAGV concept [6]

Inputs for SDFW: architecture and components defined:

- **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.wagon

- **Intramotev [8]:** 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.

Figure 5: Intramotev prototypes [8]

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.

- **Parallel Systems [9]:** was founded in 2020 in California (USA). It developed an autonomous bogie that can be coordinated with a second one to move containers.

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

- **Figure 6: Parallel systems prototype [9]**

- **Inputs for SDFW:** The Parallel Systems technology can be used to transport platoons of 10 to 50 "cars", so it will be a problem if we want bigger 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.

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

Prototype	Advantages	Drawbacks
RAGV [6][7]	• 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 [8]	• 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 [9]	• Reduction in the space needed to store them. • Individual movement and in groups of up to 50.	• Lack of control over the infrastructure.

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.

Operation of Freight Wagon Terminals

This subsection briefly describes three types of freight wagon terminals, namely the terminal yard, flat yard and hump yard. The description includes, the processes carried out in them with the aim of identifying the benefits of the SDFW in these processes.

- 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.

- 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 7: Flat Yard [18]

- 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 8: Hump Yard (Maschen, Germany) [19]

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**.

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.

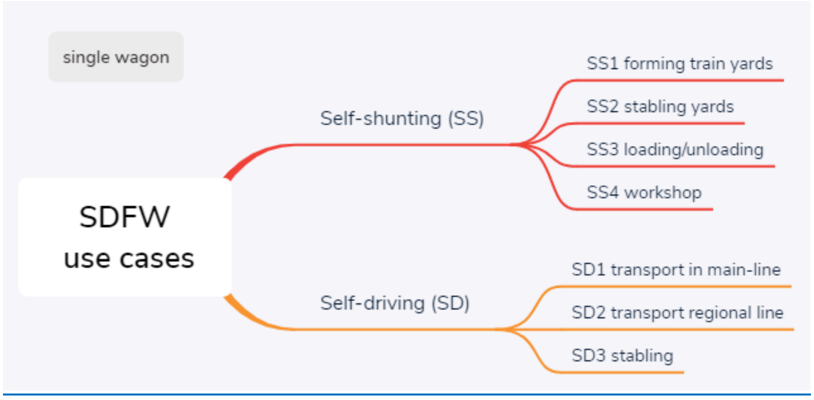

Figure 9: SDFW use cases list

Based on this initial list of use cases, a number of interviews with experts have been carried out. The result of the interviews is the following updated use case list:

Figure 10: SDFW updated use cases list

From the analysis done, the following use cases are selected as reference use cases.

- 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.

Conclusions

This study has outlined the conceptual framework and technical considerations for the Self-Driving Freight Wagon (SDFW). By analyzing current state of art related to the SDFW, three types of terminals, and identifying relevant use cases, the paper provides a foundation for further development and implementation focusing on the two reference use cases defined.

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