Deliverable D 1.1

Set of KPIs, assessment of emerging technologies and modal share analysis

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1. Executive Summary

This document is Deliverable 1.1 (D1.1) of work package 1 (WP1) within the ESEP4Freight project. The project will support a simple, cost-effective and sustainable modal shift of freight flows to rail and contribute to the European Union's target of reducing greenhouse gas emissions by 55% by 2030 compared to 1990 levels and decarbonizing transport. The overall objective of ESEP4Freight is to contribute to the provision of open, high quality and user-friendly information for all actors in the supply chain and to test innovative new tools to promote modal shift to rail.

The key areas to improve the performance of rail and its share of the transport market are rail automation and digitalization, which include the introduction of advanced innovations. The main innovations researched and developed under the Shift2Rail (S2R) program were digital automatic couplers (DAC) and intelligent video gates (IVG). To assess the impact of the innovations in Deliverable 1.1, the key performance indicators were reviewed and collected. In addition to this set of indicators, this report also summarises indicators that can be used to monitor and evaluate freight flows in the transport networks. With the aim of supporting the functionalities of the web platform, a set of indicators for these purposes has been collected and presented in this report. In this deliverable effects of these innovations on the efficiency of rail freight transport was assessed using analysis and simulation tools. The impact of DAC technology on train processing time of trains in the marshalling yard was evaluated using the total transit time indicator. The results show that significant time savings can be achieved with the implementation of DAC level 4 and DAC level 5. Subsequently, the impact of DAC on total transit time was examined using scenarios for two rail products such as single wagonload and intermodal traffic. Similar to the previous case, a significant improvement can be achieved with DAC. The impact of IVG on efficient operational processes in the marshalling yard was investigated using the AnyLogic simulation tool. Based on the assumption that IVG is used on arrival at the marshalling yard and before hump, it is shown that replacing personnel with IVG can reduce the time required for train processing.

Apart from this, other general emerging innovations that are expected to promote new business models in the rail sector are also considered. It is expected that the introduction of these technologies will have various positive effects on the different performances of the railway, such as the improvement of railway capacity, railway productivity, efficiency of shunting operations, safety levels and the working environment.

With the aim of determining the potential for shifting freight from road to rail, the status of rail freight transport on the European transport market was analysed using a scenario-based methodology based on the cluster method. In addition to the traffic flows, the analysis of current and future market trends was used to identify goods with a higher potential for modal shift to rail. In line with the strategy proposed by European policy to shift goods transported over 300 km by road to rail, the report shows that there is considerable potential for shifting goods to rail. The results are presented by type of NST goods and for specific countries with the highest potential for modal shift to rail.

Keywords: Rail Freight, Indicator, Modal shift, Innovative technologies, Assessment, Transport market

2. Abbreviations and acronyms

Abbreviation / Acronym	Description
AI	Artificial Intelligence
API	Application Programming Interface
B4CM	Blockchain for Conditions Monitoring, Shift2Rail project
BC	Blockchain Technology
CCL	Core Component Library
CFS	Container freight stations
CIM	Contract for Intermodal Carriage of Goods by Rail
CMR	Contract for International Carriage of Goods by Road
CLO	Carglo Load Optimization
CLPO	Cargo Loading Process Optimization
CO2	Carbon dioxide
CONNECTA-2	CONtributing to Shift2Rail's NExt generation of high Capable and safe TCMS. PhAse 2, EU funded project
CSD	Container Security Device
CTS	Container Transfer System
D1.1	Deliverable 1.1
DAC	Digital Automatic Coupling
DACcelerate	Accelerated DAC transformation to full digital rail freight operations in Europe, EU funded project
DLT	Distributed Layer Technology
DT	Digital Twin
EC	European Commission
EDDP	European DAC Delivery Programme
eFTI	Electronic Freight Transport Information
ERA	European Union Agency for Railways
ERRAC	European Rail Research Advisory Council
ESEP4Freight	European Shift Enabler Portal for Freight
ETA	Expected Time of Arrival
EU	European Union
FA	Flagship Area
FINE-1	Future Improvement for Energy and Noise, EU funded project
FLE	Freight Load Efficiency
FR8HUB	Real time information applications and energy efficient solutions for rail freight, EU funded project
FR8RAIL III	Smart data-based assets and efficient rail freight operation, EU funded project
FTL	Full Truck Load

GoA	Grade of Automation
IMPACT-1	Indicator Monitoring for a new railway PAradigm in seamlessly integrated Cross modal Transport chains – Phase 1, EU funded project
IMPACT-2	Indicator Monitoring for a new railway PAradigm in seamlessly integrated Cross modal Transport chains – Phase 2, EU funded project
IMTM	International Forwarding and Transport Message set
IoT	Internet of Things
IVG	Intelligent Video Gate
KPI	Key Performance Indicator
LC	Life Cycle Phase
LDHV	Low Density, High Value
LIE	Linear Interpolated Equation
LSPs	Logistics Service Providers
LU	Loading Unit
MAWP	Multi-Annual Work Programme
MMT RDM	Multi-Modal Transport Reference Data Model
MVP	Minimum Viable Product
NPS	Net Promoter Score
NSW	National Single Window
NUTS	Nomenclature of territorial units for statistics
OCR	Optical Character Recognition
O-D	Origin-Destination
RFC	Rail Freight Corridor
RFID	Radio Frequency Identification
RNE	RailNetEurope, Association For Facilitating Traffic On European Rail Infrastructure
S2R	Shift2Rail, a European rail initiative
SG	Stakeholder Group
SLW	Single Logistics Window
TEN-T	Trans-European Transport Network
TEU	Twenty-foot Equivalent Unit, shipping container
TO	Series of Operative phases
TRS	Trust and Reputation System
TW	Waiting Phases
UIRR	International Union for Road-Rail Combined Transport
UNCTAD	United Nations Conference on Trade and Development
UNECE	United Nations Economic Commission for Europe
UNIFE	The European Rail Supply Industry Association (*Union des Industries Ferroviaires Européennes*)
WP	Work Package

3. Background

One of the political measures that European union has taken in the last two years is to achieve climate neutrality. Reforms are also expected in freight transport. To achieve the Union's target of reducing greenhouse gas emissions by 55% by 2030 compared to 1990 levels and decarbonising transport, rail freight transport should play a key role. This goal can be achieved by promoting the shift from a highly polluting mode of transport to efficient and clean transport solutions.

In order to promote the modal shift to rail, freight customers must have access to comprehensive information that is essential for the development of rail freight supply chains. With the aim of providing customers with comprehensive information, a user oriented online platform is being developed in the ESEP4Freight project.

This document presents Deliverable D 1.1 Set of KPIs, assessment of emerging technologies and modal share analysis in the European Shift Enabler Portal for Freight (ESEP4Freight) project. The project is funded by is the EU-RAIL in the framework of the call HORIZON-ER-JU-2022-02.

4. Objective/Aim

The objective of Deliverable 1.1 is to present the results of the work conducted as part of the Task 1.1, Task 1.2 and Task 1.3. According to the Grant Agreement this includes 1) identification and overview of sets of KPIs in intermodal transport, 2) the description of the most promising innovations and an estimation of their effects on the modal share of rail in freight, and 3) the freight flows and types of goods with higher potential to shift to rail.

WP1 overall objective is to carry out research that will feed later WP2, WP3 and WP4 and will be the basis for the innovations developed in ESEP4Freight.

The specific objectives defined in Grant Agreement for WP1 are the following:

- Compilation of several sets of KPIs to be used and refined in different parts of the project;
- Analysis of the most promising upcoming innovations, identification of their limitations and potential and assessment of innovations deployment on the infrastructure and operational processes;
- Identification of current and future freight market trends and freight flows with high potential for a shift to rail; and
- Collection of infrastructure and operational data for the modules to be developed in WP3 (to be reported in D1.2).

In order to achieve the objectives, four tasks were defined in WP1. In task 1.1, several sets of key performance indicators (KPIs) were defined. The KPIs were categorised for use and refinement in the subsequent tasks to assess upcoming innovations, to identify freight flows that could be shifted to rail and to facilitate visualisation on a web platform. The result of task 1.1 is presented in chapter 5. Certain KPIs were selected from the set of defined KPIs in order to achieve the objectives of other tasks. To achieve the second objective, for example, a mixture of KPIs was used in task 1.2. KPIs from the infrastructure and operations clusters were used to assess the impact of DAC and IVG on train handling time and operations in the marshalling yard. The opportunities and limitations of upcoming innovations in the rail freight transport sector were identified in Task 1.2 and presented in Chapter 6. In Task 1.2, Digital Automatic Couplers (DAC) and Intelligent Video Gates (IVG) were selected for evaluation, while other general emerging innovations that are expected to boost new business models were also considered. These include the Internet of Things (IoT), digital twins, the use of artificial intelligence and machine learning, and digital innovations in smart contracts and digital transport agreements. In this task, a description of the processes for at least: i) train preparation, ii) shunting, iii) train operation, iv) wagon monitoring (telematics), v) goods monitoring, vi) loading, & unloading and maintenance vii) analysis of administrative processes was presented. A similar process was carried out for the operational processes for the marshalling yard, freight terminals and cross-border operations. Task 1.3 analysed the status of rail freight transport in the European transport market in order to identify the rail freight demand and supply at nodes and links, and to investigate and estimate the potential for freight modal shift from trucks to rail. This task is related to the 3rd objective mentioned above. In order to achieve the defined objective, certain methods were applied, which primarily include KPIs of clusters such as transport market, accessibility and connectivity. As part of the same task infrastructure improvements and other measures that could improve rail operations in Europe were analysed. Defined KPIs were used to carry out these activities in order to achieve the 3rd objective of WP1. The results of this task are included in Chapter 7 of this report. The last defined objective in WP1 is the part of the deliverable 1.2. This objective was mainly achieved with the help of the KPIs defined in this deliverable. From the defined clusters, the KPIs were selected according to the requirements of the web platform for data collection. Based on the requirements for the development of the web platform, mainly infrastructural and operational KPIs were used for data collection.

The output of this deliverable is link to the Multi-Annual Work Programme (MAWP) from Europe's Rail JU in several ways. ESEP4Freight is a project belonging to the Exploratory Research field (HORIZON-ER-JU-2022-ExplR-03) and, as part of the Exploratory Research, ESEP4Freight contributes in D1.1 to the research on emerging technologies and assess the impact of innovations on operations in rail freight transport.

In addition, D1.1 as first step in the development of the Web Platform, is expected to primarily contribute, at a high-level, to the second cluster of the Flagship Area 5 (FA5), "Seamless rail freight". The Web Platform is developing an online portal providing relevant information on the European rail freight system. The goal is to position the Web Platform as the reference tool for stakeholders in the logistics chain seeking high-quality information on the possibilities of modal shift to rail. Information about rail schedules, potential transport flows between regions, and information about the available infrastructure are expected to play a centra role in targeting the appropriate audience. The Web Platform would serve in this manner as gateway to promote and facilitate the use of advanced tools developed in the "Seamless rail freight" cluster from FA5, such as multimodal journey planner with dynamic information or booking features.

5. Overview of KPIs in rail freight transport

Key Performance Indicators (KPIs) are defined as quantitative or qualitative measurable values used to report how an entity progresses towards the delivery of factors identified as critical to the success of a transportation organization's goals and objectives. The review and collection of KPIs in this project is the foundation of the ESEP4Freight project on which other tasks are built. The main idea in creating the KPI catalogue as part of D1.1 was to create a comprehensive set of indicators that can be used to assess the impact of innovations (T1.2), to monitor freight flows (T1.3) and for the development of the Web Platform (WP3) as well as, if needed, in other WPs.

In the ESEP4Freight project KPIs have been reviewed and collected from different sources such as projects, reports, databases, scientific articles and conference papers. Then, using the same search string scientific articles and conference papers were found in the scientific databases Scopus and ScienceDirect. However, not many studies on KPIs for intermodal transport were found. Due to the lack of KPIs for certain modes of transport, some studies have been initiated. For example, KPIs for measuring port performance in the intermodal supply chain were discussed in (Monteiro, 2007). Some KPIs for freight transport were analysed in (Bruzzone et al. 2023), from which the most important KPIs were identified. In the study (Zis et al. 2023), a comprehensive set of KPIs for autonomous shipping was defined and three specific use cases in Europe are analysed and evaluated against these KPIs.

Pierro et al. (2017) evaluated intermodal transport systems using a developed methodology in which some KPIs were defined and evaluated. The results showed that the most important KPIs for all stakeholders are average waiting time and average vehicle speed. In the work presented by Ricci et al. (2016) to evaluate the impact that innovations in intermodal freight terminals can have, appropriate KPIs (e.g. total/partial transit times) were used for evaluation. KPIs for intermodal transport were highlighted using the components and elements of intermodal transport in the chapter presented by Gronalt et al. (2019), which is based on the findings of Posset, Gronalt and Häuslmayer in "COCKPIIT—clear, operable and comparable key performance indicators for intermodal transportation". To assess the wider impact of intermodal transport infrastructure development, Dimitriou and Sarzetaki (2020) introduced a set of KPIs to review the performance of project development in each economic system.

In relation to rail freight transport, some research studies have also looked at KPIs. In (Pace and Ricci, 2018), possible methods for evaluating the performance of rail freight terminals and the safety of intermodal interfaces within an integrated transport network are described using KPIs. However, there is a lack of universal KPIs for rail freight transport and especially for intermodal transport. Therefore, a universal and comprehensive set of KPIs was overviewed in this deliverable.

The first and initial group of projects and reports relevant for KPIs were suggested by project partners who worked on them. Additional relevant projects and reports were found through Google search using the search string "Key Performance Indicators" AND "Intermodal transport".

The Intergreen-Nodes project (Interreg Central Europe, 2024) and Modus project (*Modelling and assessing the role of air transport in an integrated, intermodal transport system*, https://modus-project.eu/) provided detailed indicators which characterise the intermodal transport, seamless traffic flows, characteristics of terminals regarding travel time, accessibility, connection with other modes and characteristics of railway infrastructure. Some indicators from an intermodal perspective were found in the AGORA project (intermodal-terminals.eu). Since the purpose of the ESEP4Freight project is to promote modal shift most rail-related KPIs are identified in Shift2Rail projects such as CONNECTA-2 (Europe's Rail, 2024a), FINE 1 (Europe's Rail, 2024b), IMPACT-1 (Europe's Rail, 2024c) and IMPACT-2 (Europe's Rail, 2024d). In addition to these projects, the Eurostat database (https://ec.europa.eu/eurostat/data/database) was used for collecting KPIs for different modes of transport and RailNetEurope (https://rne.eu) was scanned for specific KPIs for rail. KPIs selection was complemented by freight KPIs from associations, such as Ferrmed (2024), and maps such as OpenRailwayMap (https://openrailwaymap.org) and TEN-T Map (TENtec, 2024), Routescanner (https://www.routescanner.com), and emission calculator EcoTransit (https://www.ecotransit.org).

5.1 Categorisation of KPIs

KPIs were collected from the literature above and presented in Table 2. To improve the readability and usefulness of the table, the KPIs have been grouped in clusters and subclusters. The clusters chosen are the following ones:

- Infrastructure
- Operational information
- Accessibility and connectivity
- Quality
- Externalities
- Costs
- Transport market

The KPIs have been used as a first overview of possible parameters to be used in the work in T1.2 and T1.3. Those used in these tasks have been marked with a cross. During the work carried out in T1.2 and T1.3 other KPIs have been identified for specific sections. More information on this can be found in the following chapters.

In addition to the KPIs for T1.2 and T1.3, a first assessment of KPIs for T3.2 (third column in Table 2), related to the Web Platform, has been carried out. For this, a colour code as shown in Table 1 below has been applied to evaluate if the KPIs could be of interest and suitable for the Web Platform (e.g. KPIs with a high degree of granularity or highly dynamic are not considered suitable). The availability of the data has been also considered as a relevant factor to assess the KPIs.

Table 1. Colour code for KPIs assessment

Colour	Probability of being used/represented
(green)	Likely
(orange)	Unclear
(red)	Unlikely

The colour code chosen represents three different levels of probability of being used or represented in the Web Platform. Green represents a high probability, orange represents that the KPI could be of interest but must be further assessed and red represents a low probability of being used or represented. The assessment of the KPIs has being made in a sequential form in three stages. Firstly, the availability of the data has been assessed. From the remaining group, highly dynamic data have been discarded. The final selection has been reduced to those data consider useful for the future user of the platform. It is important to highlight that this assessment is the first step in the process of identifying relevant inputs to be represented in the Web Platform. The second stage will take place in T1.4 where the KPI list will be refined and cross-checked with the available information online. The last step will take place in the T3.2, where it will be decided which KPIs and information will be included in the Web Platform.

The same logic has been applied to the fourth column in Table 2, where the potential usefulness of the KPIs has been assessed for other tasks. It has been detected that a few of them could be of interest for the T4.2. Those KPIs of interest for T4.2 have been provisionally marked as orange ("unclear" according to Table 1) as further analysis must be performed in T4.2 when WP4 starts its work by the beginning of September 2024.

Below the KPIs table with the clusters and subcluster classification as well as the assessment of the KPIs can be found.

Table 2. KPIs assessment table

Cluster	Subcluster	Name of indicator	T1.2	T1.3	T3.2	Other tasks?
Infrastructure	Basic information of terminals	Working time				
		Terminal name				
		Terminal operator				
		Coordinates, address and website of terminal				
		Available mode of transport				
	Terminal characteristics	Total terminal area				
		Capacity of terminal				
		Capacity of storages				
		Capability of terminal				
		Available services				
		Facilities type				
		No. of truck posts				
	Network characteristics	Number of tracks	X	X		
		Length of tracks	X	X		
		Length of electrified line and type of current				
		Type of signalling system				
		Maximum allowable speed	X	X		
		Maximum train length	X	X		
		Maximum axle load				
		Track gradient				
		Track gauge				
Operational information	Travel and throughput time and operational efficiency (Network)	Average time necessary for a replacement service to be available to replace a cancelled one				
		Actual time of travel/ best possible journey time	X	X		
		Average of time spent per transition	X			
		Average waiting time of transport unit	X			
		Average throughput of the system	X	X		
		Turnaround time	X			
		Train punctuality		X		
		Average delay of a train				
		Delays on the rail network (number of slots affected)				
		Percentage of empty wagon / container runs				
		Fastest average travel time				
		Total Travel Time	X	X		
		Ratio Waiting Time / Total Travel Time				
		Event documentation time generation	X			
	Lead time and operational	Idle time between arising an event and getting informed				

Cluster	Subcluster	Name of indicator	T1.2	T1.3	T3.2	Other tasks?
	efficiency (Terminals)	Visibility of the alternate or diverted route				
		Data exchange standards supported by the Information and Communications Technology (ICT) systems				
		Average time necessary to load/unload a train in a terminal or in an end point				T4.2
		Average delay of the loading/unloading process in terminal				T4.2
		Average time necessary to get wagons coupled to form a train	X			T4.2
		Average idle time (waiting in terminal, waiting for departure, for handling in port)				T4.2
		Waiting for equipment (time to wait for assigning equipment or resources, e.g. engine, driver)				
		Waiting for another train to assume the wagons/cargo)				
		Handover time between the partners				
		Various other services (technical inspections, customs, commercial inspections, etc.)				
		Percentage of empty wagon / container runs				
		Fastest average travel time				
		Total Travel Time	X	X		
		Ratio Waiting Time / Total Travel Time				
		Ratio Access or transfer time / Total Travel Time				
		Congestion at the road gates of the terminal (added time to both terminal users and passer-by)				
	Traffic information (Terminals and network)	Rail transport volume				
		Road transport volume				
		IWW transport volume				
		Total transport volume				
		Payload				
		IN/OUT transhipment				
		No. of containers (TEU) moved				
		No. of swap bodies moved				
		No. of trailers moved (piggyback)				
		No. of cars moved				
		No. of trains an wagons moved				
		No. of trucks moved				
		No. of vessels moved				
		No. of barges moved				
	Terminal productivity	Intermodal terminal throughput				
		Equipment utilization				T4.2
		Labour utilization rate				
		Storage area utilization				T4.2
		Rail track utilization				T4.2
		Berth utilization				T4.2
		Productivity of terminal facilities				
		Saturation degree of the terminal				T4.2

Cluster	Subcluster	Name of indicator	T1.2	T1.3	T3.2	Other tasks?
		Total length of tracks/Total usable length				
		Marshalling yard capability				
		Utilization rate of the marshalling yard				
		Number of trains on rail line				
		Operational unavailability				
		Number of trucks				T4.2
		Number of vessels				T4.2
		Number of barges				T4.2
		Loading unit acceptance				
		Cargo type transshipment / handling				
		Availability of an additional service in case of special needs (e.g., additional train load)				
		Additional capacity available on the existing train services				
		Frequency of the first mile (last mile) service				T4.2
		Number of departures per day and per destination				
Accessibility and connectivity	Freight services	Number of phases required to complete a journey				
		Number of connections				
		Dwell times (mins) during stops				
		Station of departure or arrival		X		
	Terminals	Number and type of destinations which can be reached from an origin				
		Number of phases required to complete a journey	X	X		
		Number of connections and dwell times (mins) during stops	X	X		
		Mode of transport				
		Access time				
		Number of connections				
		Time of connections				
		Distance of connections				
		Destinations served by the terminal or by the whole network				
		Connection with main rail lines (name/bounds)				
		Connection with waterways (name)				
		Connection with main motorways (name)				
		Number of options to make a trip				
		Number of legs required to complete a journey				
		Number of modes used to complete a journey				
		Number and type of destinations which can be reached from an origin (connectivity)				
		Rail access/ (private) access line (if applicable)				
		Access to rail services in terminal / SF infrastructure				
Quality	Quality assessment	Percentage of consignments received as contracted				
		Percentage of loading units received as contracted				
		Physical accounting correspondence				
	Reliability	Trustiness of the information	X			
		Trustiness in generated documentation	X			

Cluster	Subcluster	Name of indicator	T1.2	T1.3	T3.2	Other tasks?
		Cancelled services				
		Number of cancellations of train service				
		On-time service				
		Departing / arriving on-time or within defined tolerance		X		
		Train path availability (% of successful satisfaction vs. rejections)				
		Frequency level				
		Delay rate				
		Cancellation rate				
	Flexibility	Ability to rebook or change transport (its destination or parameters)				
		Time necessary to rebook or change	X			
		Time necessary to book a slot on a train				
		Coupling incompatibility				
	Information availability	Cargo for which the information in transit is available	X			
		Mileage on which the information in transit is available	X			
		Availability of precise tracking and tracing	X			
		Availability of information in case of disruptions	X			
		Volume of data exchange (no of different messages / processes / communication dialogs covered by data exchange)				
Externalities	Air pollution	Average CO2 emissions				
		kg CO2e/TEU				
		CO2 emissions				
	Noise	Percentage of people exposed to noise class				
Costs	Terminal costs	Equipment cost				T4.2
		Engineering cost				
		Manufacturing cost				
		Certification & commissioning costs	X			T4.2
		Maintenance costs				T4.2
	Travel costs	Documentation costs	X			
		Sum of costs to complete a journey	X			T4.2
		Total transit costs (terminal to terminal, door to door)	X			T4.2
		Total origin-destination transport cost	X			T4.2
	Energy	Average fuel consumption				T4.2
		Average diesel consumption				
		Energy usage per Train-Kilometer				
		Energy usage per Tonne-Kilometer				
		Energy consumption per TEU				T4.2
		Utilization of engine power				
Transport market	Share in transport market	Unitisation in the different modes of transport - tonne-kilometre for gross weight of goods				
		Unitisation in road freight transport - tonne-kilometre for gross weight of goods				

Cluster	Subcluster	Name of indicator	T1.2	T1.3	T3.2	Other tasks?
		Unitisation in rail freight transport- tonne-kilometre for gross-gross weight of goods				
		Unitisation in inland waterways freight transport - tonne-kilometre for gross-gross weight of goods				
		Unitisation in maritime freight transport - tonnes for gross weight of goods				
		Modal shift potential of long-distance road freight in containers - tonne-kilometre				
		Modal shift potential of long-distance road freight in containers - tonne				

5.2 Discussion and validation of KPIs

With the aim of validating the KPIs represented in the tables above, a simplified version of Table 2 was presented to the stakeholders during the physical Stakeholder Group (SG) meeting in Verona in February 2024. The SG meeting was attended by fourteen different stakeholders from all over Europe. The main reason for consulting the stakeholders was to draw attention to the KPIs and for them to share their preferences for the KPIs used in the Web Platform and to collect inputs about their information needs. Although most stakeholders were satisfied with the indicators listed, a few of them had suggestions for improvement. The main concern was related to the high number of KPIs and their integration into the Web Platform. One stakeholder found the set of KPIs understandable and well-structured, but extensive and rather "hardware-oriented". Instead, the stakeholder would primarily ask users about their Net Promoter Score (NPS) (customer satisfaction) to evaluate the Web Platform based on the following grid:

- Overall customer satisfaction;
- Satisfaction with the registration process;
- Satisfaction with the time taken to search;
- Satisfaction with the granularity of the solution;
- Satisfaction with the completeness of results;
- Satisfaction with the robustness of the information provided;
- Ease of access to the solution;
- Ease of integration of the solution with other supply chain solutions.

This list of proposed criteria will be considered for the evaluation of the Web Platform in WP4 together with the KPIs of interest identified in Table 2. However, as a Web Platform is being developed as part of the ESEP4Freight project, NPS would be better suited as part of the future function. Once implemented, the platform will be available to users, who will be able to take into account functionalities, expectations and satisfaction levels.

Another stakeholder agreed that customer satisfaction is a suitable criterion for the Web Platform to measure performance. However, it was considered to be quite complicated to collect this information. It was suggested to check the Rail Freight Corridor (RFC) website, part of RNE, where a few user satisfaction data should be available. In addition, this stakeholder suggested that for the visualization of scenarios, the selection of KPIs should be revised to separate general information from the indicators that directly measure performance and productivity. Examples of less relevant aspects related to KPIs are: terminal name, terminal operator, terminal area, and total terminal area (e.g. TEU throughput per ha as criteria for productivity instead).

One stakeholder shared the main priorities from the shippers' perspective and which exemplary KPIs are needed. They believe that KPIs are needed for the available infrastructure and routing options (like any navigation tool), i.e. transit time, frequency, CO_2 emissions, and average cost (these last two KPIs to compare rail to road transport). Relevance of KPIs for capacity and utilization were mentioned, i.e. available capacity at the terminal (for supply network design) and rail utilization (including reverse flow). In addition, KPIs for partners and customer satisfaction can also be useful, e.g. for rail company service, and customer satisfaction (on-time delivery/arrival).

As already identified by the consortium, the main problem is the quality and availability of data for the KPIs. Therefore, it would be very useful to have a KPI categorization for defining a Minimum Viable Product (MVP) to distinguish between general information, in-process measures and evaluation measures and to understand the source and exact definition of the indicators.

The feedback of the SG on the KPIs and indicators to be displayed in the Web Platform and for its subsequent evaluation will be taken into account in the future refinement of KPIs and indicators in T1.4, T3.2 and T4.2.

6. Assessment of emerging technologies in rail freight

In order to improve the railways' share of the transport market, the introduction of new technologies was recognized as a possible solution. With the aim of clarifying the potential of new technologies and the challenges in rail freight transport, some of them have been evaluated in this chapter. The evaluation of these technologies was carried out with analytical equations and a simulation tool, using the KPIs listed in Table 2 in Chapter 5.1 as the basis and input for the equations and tool. Internet of Things (IoT), Digital Automatic Coupling (DAC), Intelligent Video Gate (IVG), Digital Twin (DT) solutions, smart container and contract, AI as well as multimodal technologies have shown potential positive impact in transportation in general and are therefore assessed in this report.

6.1 Emerging technologies influence on processes in marshalling yard

The marshalling yards can be divided into three categories: flat-shunted yards, gravity yards and hump yards. The flat-shunted yards are constructed on level ground or on a slope that is too gentle to permit the movement of the cars without the use of locomotives. In this instance, freight cars are transported to their intended destination with the assistance of a locomotive (Kneafsey, 1975). In contrast to the flat-shunted yard, the gravity yard allows freight cars to be moved by gravity. Nevertheless, this type of yard was never widely employed due to the continued necessity of shunting engines in many instances, particularly in relation to meteorological conditions (Berti, 1959). The final type of marshalling yard is the hump yard. It is recognised as the most efficient type of marshalling yard and, as a result, the most widespread type of marshalling yard. In contrast to gravity yards, hump yards operate in a manner analogous to gravity yards, with the exception that the descent occurs primarily at a specific section designated as the hump. The hump serves as the central hub of the yard, comprising a lead track situated on a minor elevation where an engine pushes the cars. At or slightly before reaching the apex of the hump, individual cars or groups of coupled cars are detached and allowed to roll by gravity onto their respective tracks within the classification yard, which is the area of the yard designated for sorting cars (ABC's of Railroading: Terms of the Trade, 1991). As the marshalling yard that is the subject of this study is a hump yard, a more detailed description will be provided.

A hump yard can be represented as depicted in Figure 1. The train arrives and stops in the arrival yard. Subsequently, the locomotive is detached, as are the freight cars, or a group of freight cars if some of them are to remain together. Subsequently, a shunting engine arrives and pushes the cars over the hump. Thereafter, the gravity automatically makes the cars roll to the classification yard, where they are sorted based on their final destination. The final assembly of the train occurs in the classification yard or classification bowl, where the freight cars are coupled once more. Additionally, the brakes are filled with air and tested in the classification yard for safety reasons. Once all the requisite tests have been completed, another shunting engine is coupled with the cars. Following a further series of tests, the train is then conveyed to the departure yard. Upon arrival in the departure yard, the shunting locomotive is decoupled and departs. Finally, the line locomotive arrives and is coupled to the train. Once the final brake tests have been completed, the train is prepared to depart (Antognoli, 2020).

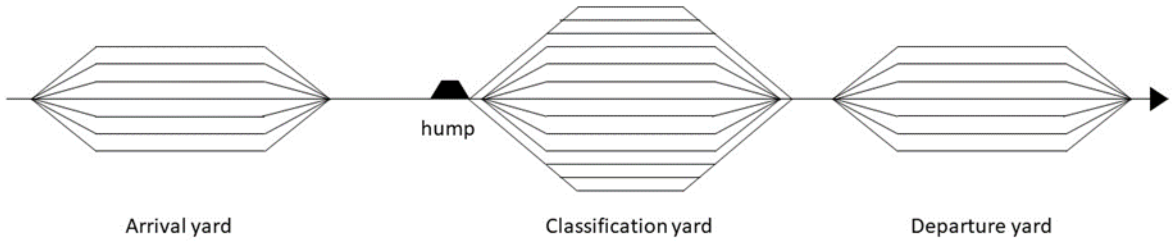

Figure 1. Description of a Hump yard

In this deliverable the main part of this work will examine the impact of emerging innovative technologies and their effects on train routing and scheduling. To date in Europe's Rail projects, marshalling yards, terminals and their applications have been employed as case studies for these technologies.

To better present the processes for at least: i) train preparation, ii) shunting, iii) train running, iv) wagon monitoring (telematics), v) goods monitoring, vi) loading, & unloading and maintenance vii) analysis of the administrative processes Hallsberg marshalling yard has been selected as a case study. The main reason for selecting Hallsberg is the volume of trains handled, which makes it the largest yard in Sweden (Antognoli, 2020). The Hallsberg marshalling yard, the various operations that take place within it, and the latest technological improvements designed to enhance its efficiency were the subject of the Shift2Rail (S2R) and Europe's Rail projects.

In Hallsberg yard the arrival yard consists of 8 tracks with different lengths from 590 to 690 m, connected to the classification yard via a double hump, though the humps are never in simultaneous operation due to safety constraints. The classification yard has 32 tracks with different lengths from 374 to 760 m, and the departure yard consists of 12 tracks with lengths from 562 to 886 m. When a train arrives, it should be prepared for rolling over the hump. The preparation process takes about 28 min for a set of 32 wagons for traditional manual coupling and decoupling and it includes several tasks described in section 6.2.1.

6.1.1 Potential effects of emerging technologies in intermodal terminals

Intermodal terminals allow transshipment of loading units between different means of transport (ships, trucks, and trains) and play an important role in intermodal freight transport. Effectiveness and efficiency of this terminals depends on the quality of terminal services and the efficiency of terminal processes that directly influence on the quality and cost of the entire transport chain (Gronalt et al., 2019).

Intermodal freight terminals connect the different modes of transport (rail, road, and inland waterways) of intermodal transport chains. Nevertheless, handling processes can be seen as unattractive because they are time-consuming and cost-intensive. The performance of an intermodal freight terminal is determined by several factors, influenced by different actors within the intermodal chain. The most important terminal performance indicator is throughput, the number of loading units per time. Regarding physical factors, the main influences are the geographical position of the terminal within the transport network (connection to rail, road, and inland waterways), the size and shape, the length of the track facilities, and the number and capacity of the handling equipment (gantry cranes and reach stackers). The layout of most modern intermodal freight terminals are based on a modular design (see Figure 2).

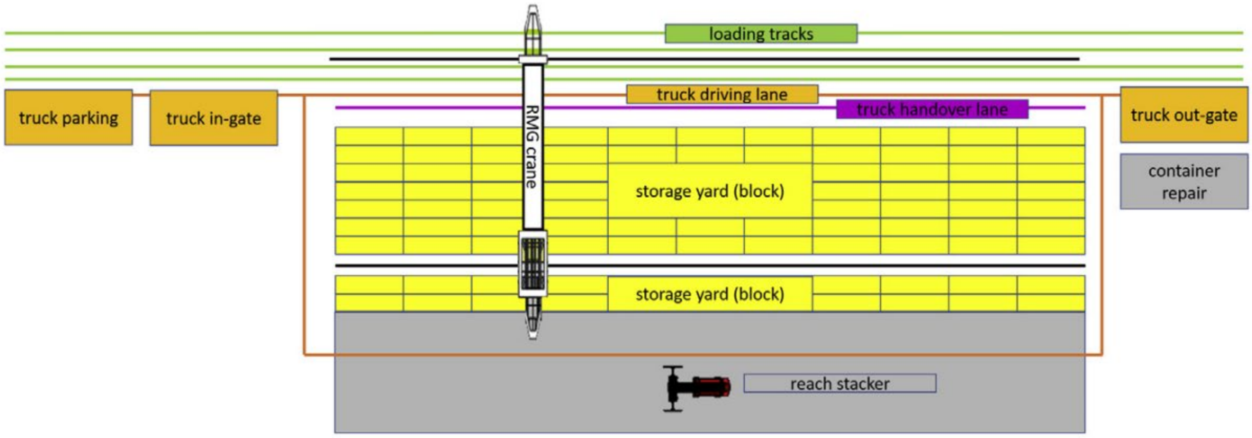

Figure 2. Intermodal terminal layout

The processes in intermodal chain and handling loading unit (LU) can be considered through several stages. 1) the intermodal LU is transported by truck from the consignor to a transshipment node. 2) the LU is transhipped within the transshipment node to another mode of transport such as rail or inland waterways. 3) the main run begins on rail or inland waterways linking the dispatching and the receiving transshipment nodes. At the receiving transshipment node (destination terminal), the LU is transhipped from rail or inland waterways to the truck and transported to the receiver. In the ESEP4Freight project effect of emerging technologies in intermodal terminals such as IVG and DAC were analysed with a focus on the processes related to transhipped LU to another mode i.e rail and transport of LU by rail. Regarding the IVG implementation in intermodal terminal and utilisation of it is similar to the marshalling yard. In case of IVG, it will have the same rule as in marshalling yard and will facilitate the processes of investigation and damage detection on LU and transport unit what will have positive effects related to time consuming and waiting of LU and transport unit in terminal.

It is important to point out that intermodal rail transport differs from traditional rail in four areas (Bontekoning et al., 2004). In intermodal rail transport, trains with fixed schedules travel between terminal locations with minimal or no handling between the source and the destination terminal. Due to the separation of the LU and the transport unit, fleet management challenges in intermodal transport are more complex. Location decisions for intermodal transshipment are much more complex for further traffic, due to the need to connect at least two modes of transport. Therefore, there are various known rail production systems, but not all of them are used today (see Figure 3).

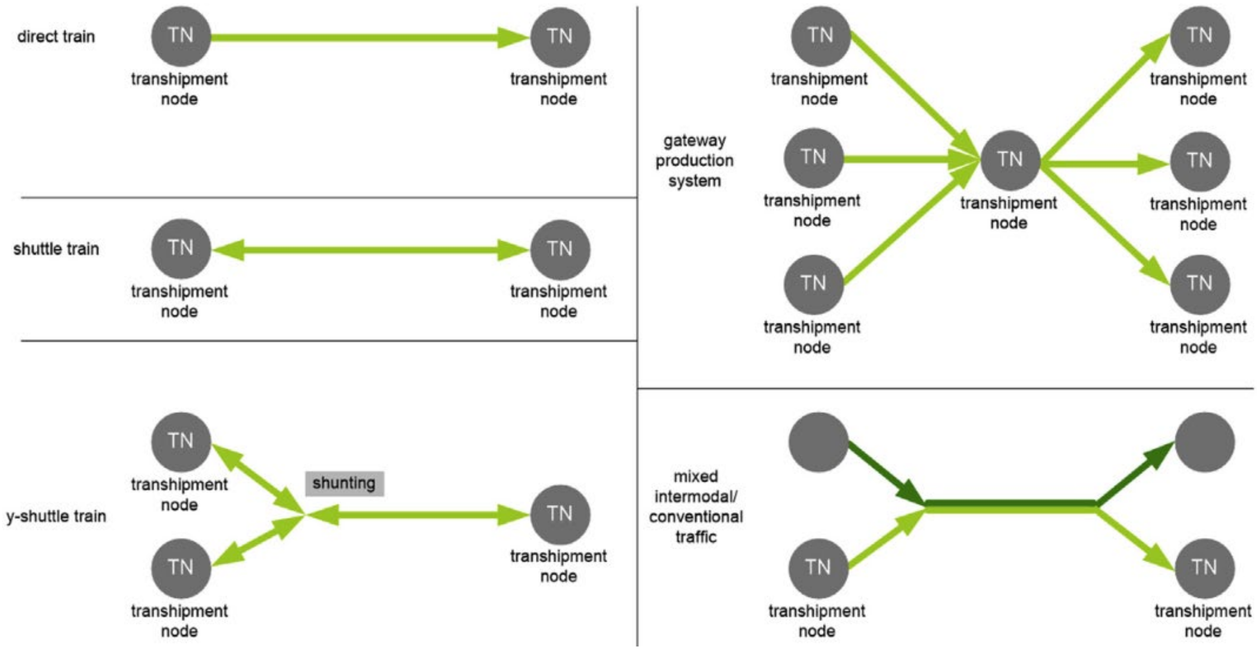

Figure 3. Rail product systems

On the next tables, we can observe a summary on which processes can the new upcoming innovations help by optimizing them.

Table 3. Summary of emerging technologies for Marshalling Yards and Intermodal Terminals

Process	IVG	DAC	DT	Smart Container	AI	Smart Contracts
Train preparation		X	X			
Shunting		X	X			
Train Running		X	X			
Wagon monitoring	X	X	X	X		X
Goods monitoring	X			X		
Loading&Unloading			X			
Maintenance			X		X	
Administrative process	X		X		X	X

Table 4. Summary of emerging technologies for seamless train scheduling

Process	IVG	DAC	DT	Smart Container	AI	Smart Contracts
Train preparation		X	X			
Shunting			X			
Train Running	X	X	X			
Wagon monitoring		X	X	X		X
Goods monitoring				X		
Loading&Unloading		X	X			
Conflict resolution			X		X	
Maintenance			X		X	
Administrative process	X		X		X	X

6.1.2 Barriers for rail freight cross-border transport and potential improvements by emerging technologies

Cross-border transport plays an important role in improving accessibility and cohesion for a short and long-distance transport and in achieving the ambitious goals of modal shift in Europe. In order to develop a Europe-wide rail network, a well-connected cross-border rail network is the backbone of European transnational mobility and the key to the European TEN-T policy. To facilitate rail freight transport in the European union (EU), rail freight corridors (RFCs) were created and supported by Regulation 913/2010 (Bacian, 2021). The main objective of Regulation 913/2010 was to improve the conditions for international rail freight transport through better cooperation at all levels, in particular between the infrastructure managers (IMs) and between the RFCs, with the dual aim of: developing the RFCs in terms of infrastructure capacity and performance to meet market demand and to providing good high quality freight services that meet customers' expectations (Pastori et al., 2020). Consequently, eleven RFCs are in operation and connect Europe i.e RFC1, RFC2, RFC3, RFC4, RFC5, RFC6, RFC7, RFC8, RFC9, RFC10 and RFC11. Although the interoperability of the European railway system has been improved, progress so far has been slow and uneven in different areas. Significant improvements have been made in infrastructure connectivity, but at many cross-border points reflected by different national systems, there are still certain functional, i.e. technical and operational, problems that prevent the railway from realising its potential. Nevertheless, some progress has been made in harmonising regulations and procedures, while improvements in rolling stock and infrastructure have been slow, partly due to the longevity of rolling stock. In addition to rolling stock and infrastructure, the adoption of technical standards to support the availability of information and data exchange in the EU has also been delayed. This incomplete harmonisation and unfinished interoperability influence the improvement of the status of rail freight transport in the transport market and the increase in the share of the mode of transport in recent decades, which is even the most sustainable mode of transport (ERA, 2022).

The main problem of interoperability is related to the fact that each country has its own infrastructure, train protection systems, operating rules, signalling and safety regulations. In order to enable seamless train traffic across borders, trains must therefore comply with the operating regulations of the country they are travelling through. For example, a train must be formed in accordance with the country-specific regulations, i.e. the waggon sequence as well as the train length and weight must meet the respective requirements. In addition, each locomotive should be authorised for a specific route network and equipped with the respective national train protection systems. Otherwise, a change of locomotive is required at the borders if there are no multi-system locomotives to overcome these infrastructure interfaces. A change of train drivers is also required if they do not hold the national licences or speak the respective operating language. (ERA, 2022).

To overcome interoperability issue 15 main technical and operational barriers in rail freight have been identified in (Panteia Consortium for DG MOVE, 2022). In the report barriers mainly related to the processes at borders such as braking sheets and braking performance; technical checks at border stations; train composition (harmonisation of wagon list, real-time communication and harmonisation of train composition message, working handbrake last wagon, no push 6 axles wagons, buffer wagons); taillights versus plates; new train number; cabin crew; equipment of border stations with commutable electric power supply and operational implementation of the traffic in ERTMS were pointed out based on the analysis of over 70 cross border points within TEN-T network. The positive examples the freight railway operations are between Germany, Denmark and Sweden (e.g. between Padborg in Denmark and Flensburg in Germany along RF3), despite the remaining different train braking rules; it reported, instead, significant time losses on RFC7 at the cross-border stations Curtici (Romenia) and Ruse (Bulgaria). In (ERA, 2022), the two most important case studies, i.e. the Innsbruck (Austria) - Brennero (Italy) link, along RFC3 and Giurgiu Nord (Romania) - Ruse Razpredel (Bulgaria), along RFC7 were analysed for the most important obstacles. The results, which were measured on the basis of the annual number of trains, show that, for example for the cross-border section Giurgiu Nord - Ruse Razpredel there is a high loss of time per train for technical checks at the border stations (384 min), real-time communication (222 min), new train number (118 min), non-electrified cross-border section (120 min), train length restrictions (75 min), no push 6 axles wagons (75 min), working handbrake in the last wagon (45 min), and train braking rules and documents (20 min).

The highest losses were recorded, for example, at the technical checks at the border stations. At this border, technical checks are carried out both after arrival and before departure at border stations, in accordance with Regulation No. 250 (Regulation No. 250), when trains have a waiting time of 6 to 8 hours at the station. Regulation n. 250 imposes technical checks both after arrival and prior to departure at border stations whenever trains experience a waiting time of 6 to 8 hours at the station. The simulation of time consumption in the case of the IVG implementation shows that IVG can save time. Based on these results, it can be assumed that the time required for technical checks can be significantly reduced by introducing IVG at the border.

For no push 6 axles wagons 75 minutes are required, as legal or internal company rules prohibit 6-axle wagons, even if the manufacturer's specifications state otherwise. These 75 minutes are divided into 60 minutes for the train to be split and 15 minutes for the shunting service. It has also been estimated that in the event of a working handbrake in the last wagon, 50% of the trains are affected by this problem and each train loses a total of 45 minutes. These 45 minutes result from 30 minutes for the reordering of the wagon (assuming a 600 m long train, wagon from the middle to the end, the approach of the shunting locomotive and coupling) and another 15 minutes for waiting for the shunting service.

Based on the new technologies analysed in WP1, a potential to reduce these losses at the borders was identified. In both cases, these are manipulations with the train that require coupling and uncoupling. As shown in sections 6.2.1.1 and 6.2.1.2 the implementation of DAC Level 4 and Level 5 can contribute to significant time savings in both cases.

Djordjevic et al. (2024) found that DAC can have a positive impact on the dwell time at the borders, e.g., on the process of changing locomotives, which includes the task of (un)coupling. In paper they used DEA model (Appendix 2) for the calculation of efficiency of corridors with DAC and IVG implementation.

To investigate the effect of "*dwell time of changing locomotive*" on the efficiency of RFCs, this process was included as an input indicator in the main model. Figure 4 shows the results of the efficiency of the RFCs by adding the dwell time of locomotive change to the model as a blue line. To test the effect of the dwell time of the locomotive change on the not inefficient RFCs, the values of the inputs were varied by 5% and reduced. In Figure 4 it can be seen blue and orange lines. The blue line represent results without reduction, while orange line represents results with the 5% reduction of input data. From the figure it can be seen that the locomotive change has an impact on the efficiency as all the inefficient RFCs became efficient on blue line, while RFC4-20 and RFC4-21 became inefficient.

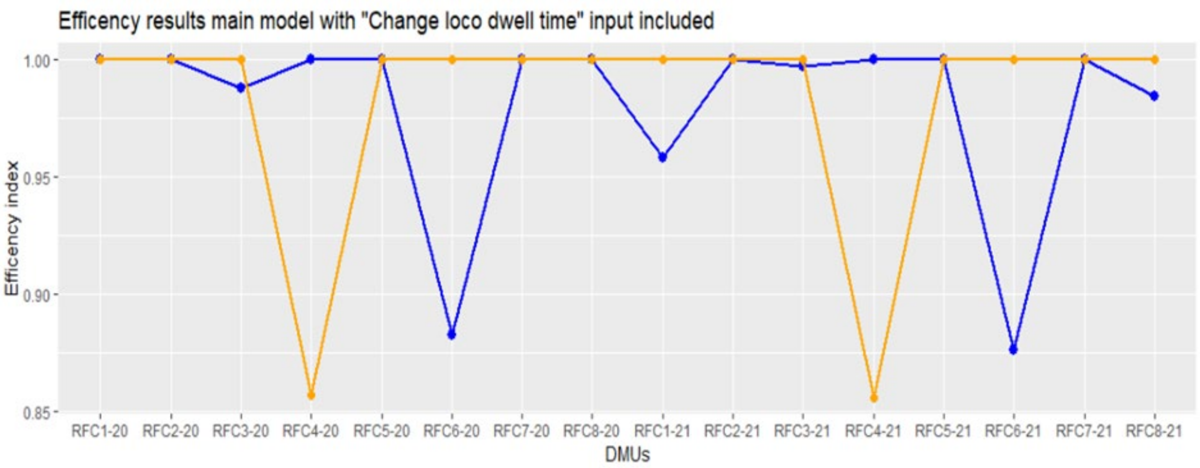

Figure 4. Efficiency results with added input "Change loco dwell time" to the main model. Orange line represents results with the 5% reduction of input data

In addition, Djordjevic et al. (2024) pointed out with the results that the introduction of new technologies, such as intelligent video gates (IVGs), can have a positive impact, especially on reducing train handling times in terms of technical and administrative tasks in freight stations and intermodal terminals (Kordnejad et al., 2020), (FR8HUB project, 2018). The tasks related to the clearance of trains at RFCs in freight stations, terminals and borders are related to technical and administrative control of freight trains. The technical control and administrative tasks are particularly represented in the formation of new freight trains before their departure and can be realized with IVGs. Therefore, these two tasks are included in the calculation of the efficiency model as input indicators as *dwell time of technical check* and *dwell time of administration*.

The impact of these indicators on efficiency after inclusion in a model was evaluated and represented by the blue line in Figure 5 and Figure 6. To identify potential efficiency improvements in RFCs, inputs were reduced by 5% for all non-efficient RFCs. The efficiency results of the reduced input values are shown as orange lines in the figures. As can be seen in Figure 5 and Figure 6, the efficiency of all non-efficient RFCs was improved.

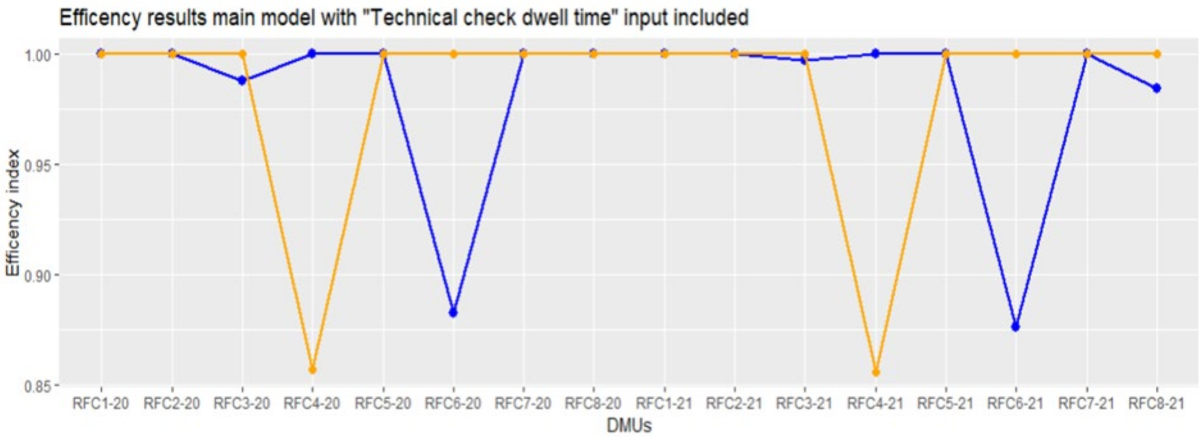

Figure 5. Efficiency results with added input “Technical check dwell time” to the main model.

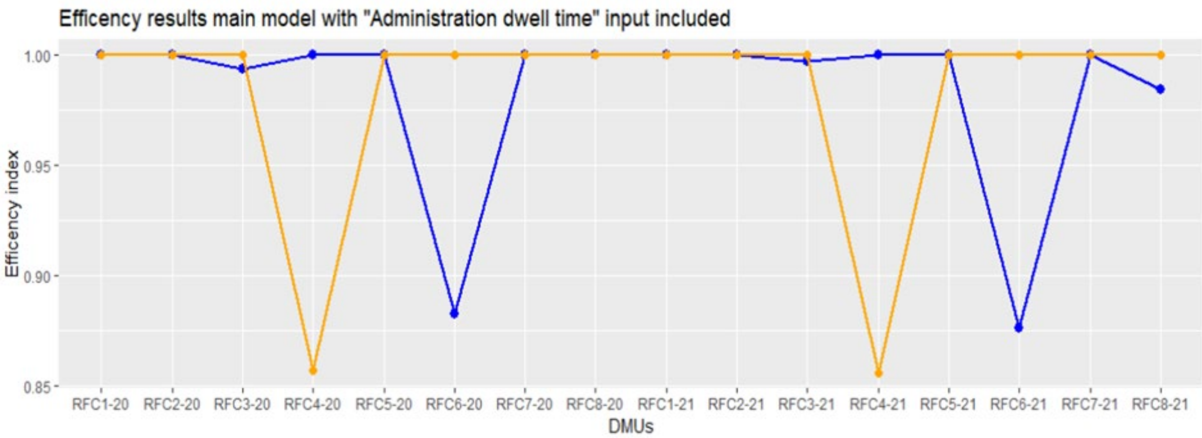

Figure 6. Efficiency results with added input “Administration dwell time” to the main model

In Table 5, we can observe a summary on which processes can the new upcoming innovations help by optimizing them.

Table 5. Summary of emerging technologies for cross-border operation

Process	IVG	DAC	DT	Smart Container	AI	Smart Contracts
Train preparation		X	X			
Shunting						
Train Running	X	X	X		X	
Wagon monitoring	X	X	X	X		X
Goods monitoring				X		
Loading&Unloading		X	X			
Maintenance			X		X	
Technical checks	X	X	X		X	X
Braking Performance		X	X			
Infrastructure adoption						
Administrative process	X		X		X	X

6.1.3 Implementation of emerging technologies: feasibility, costs and efficiency

To contribute to the European Green Deal, an increase in rail freight with 100% by 2050 is required, as set out in the EU Strategy for Sustainable and Smart Mobility. The main question, however, is how additional traffic can be accommodated within the unchanged infrastructure capacity. Building new infrastructure is complex and presents many challenges, the most important of which is related to cost. Therefore, a significant part of the future volume must be transported on the existing infrastructure. Nevertheless, operational characteristics such as train length, load factor, speed and network utilisation must be improved. In addition, operating times in stations and marshalling yards must be significantly reduced. To overcome capacity problems, the industry has proposed a new technical solution for wagons and locomotives: the "Digital Automatic Coupling" or DAC. Many see DAC as the technology of choice to enable the automation of rail freight transport and offer customers more attractive services, increase the quality of rail freight transport and reduce operating costs. However, apart from the benefits of DAC pointed out in previous projects such as DACcelerate there are also direct costs of DAC such as the cost of the couplers and the cost of mounting the couplers, the cost of the additional components required to deliver all the targeted functionalities. These additional components are bundled into technical packages in order to present a range of potential impacts for DAC, the infrastructure and IT costs, one-off costs associated with DAC deployment and recurring costs after DAC deployment (INECO, 2023). The cost benefit characteristics of DAC as a potential technology for rail freight improvement will be aligned with the work within TRANS4M project within the WP19.

Due to the overall significant benefits listed in (INECO, 2023) and costs which are not negligible, feasibility of DAC is considered through the migration strategy and migration scenarios. In Deliverable 4.2 of DACcelerate project the migration strategy and its evaluation presented in this report has been developed and aligned with a multitude of stakeholders of the sector. Migration to the Scharfenberg DAC is feasible despite its non-compatibility with the prevalent screw coupler. The sector will need to further intensify its efforts to solve the challenges head-on. (DACcelerate, Deliverable 4.2, 2022).

The costs of IVG for the constituent components are in many cases very difficult to pinpoint and monetize, depending on local cost structures and the design of the concept regarding e.g. single or double track construction and the number of cameras. The implementation costs of an IVG are mainly focused on the initial costs for the gate's physical construction and the IT-system needed. Nevertheless, the costs of IVG installation involves the administrative preparation, the equipment, the building of the gate, electric installation and connection to IT systems. Purchasing of new software and hardware, support during the installation and preparations of the local terminal management systems, in order to be able to communicate with the IVG,

Expected changes in fixed costs are mainly related to the fact that IT systems are expected to increase due to licenses and fees for using a common information-exchange platform. Other fixed costs are not expected to change such as the costs for transshipment equipment at terminals or shunting equipment at yards, land area, fence, lighting poles, rail track(s), office/buildings, rail connection to the network and realisation costs (total infrastructure and pavement).

Variable costs expected to change include costs related to administration, employees, energy, insurances, maintenance, and support for IT-systems and management/manager(s).

There are no expected changes in variable costs regarding security, interest rate, network fee for rail access and terminal licenses or other taxes (Mitrovic et al., 2018).

The functional feasibility of the implementation of IVG has been tested in the project FR8HUB, WP4 Intelligent Videogate, in laboratory environment and full-scale demonstrations were carried out in Sweden and Germany within the framework of the sub-sequent Shift2Rail project "FR8RAIL III WP3 Demogate". The image processing functionalities developed were also tested with real images obtained on-site with two different cameras, which also provided successful results in the detection and identification of LU and UIC codes, as well as different dangerous cargo signs. The concept is currently being further developed in EU-Rail FP5 TRANS4M-R project within WP29 "Standardised European Checkpoints", where the concept is being rolled out also in other European countries, now also including Netherlands, Spain and Austria. Moreover, another operational stop apart from intermodal terminals and yards is considered, namely borders. This in order to facilitate seamless cross border traffic. Additional functionalities are also investigated, mainly regarding developing algorithms for damage inspections as well as improved the algorithms for detection of codes and dangerous goods.

Establishing IVG at intermodal terminals and freight yards can have several positive effects. From the perspective of the terminal operator (TO), the IVG concept would imply an improvement in operational efficiency, mainly due to (Kordnejad et al., 2019):

- Faster arrival process. Handling deviation and identification of wagons and cargo carriers with higher degree of automation during arrival processes, e.g. check-in (document handling) / damage claims / handling of dangerous goods.
- Faster departure process. Higher degree of automation at departure e.g. departure control, improved safety and handling of dangerous goods.
- Improved and faster operational management when sequence of wagons and loading units (LU) (and any deviations from pre-arranged sequence) are known in advance, which enables optimized transshipment plans and a more seamless interface toward road transporters.

Obviously improved services at terminals imply an improved and more attractive range of services, which in the long perspective should lead to a higher degree of customer satisfaction. Improved monitoring capabilities is also beneficial for infrastructure managers, enabling an improved efficiency in network management, in particular for cross border traffic.

6.2 Internet of Things

As stated in UNECE´s project White Paper on IoT Standards for Trade Facilitation (UNECE, 2023) we can observe the definition for Internet of Things comprehended in it to define what technologies can be stated as IoT:

IoT is a network that connects uniquely identifiable "things" or devices to the Internet. These devices have sensing capabilities and can, potentially, be programmed. Through the exploitation of their unique identification and sensing capabilities, information about these devices can be collected and the state of these devices can be changed. •

Some of the key features of an IoT ecosystem include:

- Possibilities for interconnections with and between devices
- Sensing capability
- Embedded intelligence
- Communication capability
- Programmability

IoT ecosystems have the potential to make novel applications possible that facilitate cross border paperless trade through the use of connected devices that sense, collect, process, share and act on data. Data such as temperature, humidity, location can be collected from IoT devices and can be used to power a number of applications ranging from the ability to ensure freshness of produce across a supply chain, to asset location tracking, to detect equipment failure in logistics and transportation.

IoT devices also have the ability to capture and record data in real time and in a continuous manner and to associate this data with unique IDs. Therefore, they can be used to trace the origin of data from basic sensor readings even as this data is used by software applications to create complex derived information. This real time data can be fed into decision systems that are part of an international supply chain for further action and automation as documented by the UN/CEFACT Smart container project.

IoT creates interesting opportunities for trade facilitation by providing the ability to create and exchange cross border electronic information without human interference, and thus in a more secure, effective, and economical manner. IoT systems can also be designed to ensure the integrity of data about the physical condition of things such as packaging, vehicles, and containers. In combination with other emerging technologies such as Blockchain, 5G, API's and Cloud platforms, IoT could have a huge impact the drive toward significant automation of international supply chains and the facilitation of cross border paperless trade. Given the huge interest in IoT technology, there are already many projects around the global trying to revolutionize supply chains with operational efficiencies created by IoT through better asset tracking, inventory management and the predictive maintenance of equipment. An interesting example of this is documented in the Smart Containers project of UN/CEFACT which looks at how smart containers that are standardized seagoing containers fitted with sensors are enabling door-to-door trackings and monitoring. Smart Containers have the potential to drive end-to-end visibility and transparency throughout the entire supply chain.

Given the widespread use of IoT within a wide range of varying systems with different properties and support for communication channels, this paper seeks to highlight the role of standards and how UN/CEFACT can play a role in terms of developing or extending existing technical specifications to maximize this technology's value to UN/CEFACT's constituency.

This paper therefore focuses on the role UN/CEFACT standards can play in defining data and process flow between IoT devices operated by various parties as part of an international supply chain and how this data can be integrated into existing supply chain automation processes in an interoperable manner.

This can give the idea that IoT is a wide ranged technology in which common traditional "things" such as sensors or containers or any device connect with others to give information/data.

Within this definition, we can state that DAC and IVG can be considered IoT innovations. Smart containers is also an IoT innovations while Digital Twins use this kind of technology as well which will be addressed in the following sections. In the following sections DAC technology with its effects on train time processing in the yard and train travel time, as well as railway capacity will be presented. In addition, the main and other potential benefits of DAC were pointed out and an assessment of them according to three railway product systems has been done, as well as consideration of DAC benefits for new rail market segments has been conducted. For IVG effect of train processing in terminals and challenges and benefits will be presented. For those two technologies, feasibility analysis has been presented.

6.2.1 Digital Automatic Coupler

In rail freight transport, a distinction is traditionally made between three degrees of automation for couplings: manual, semi-automatic and fully automatic. In Europe, couplings are still predominantly coupled manually with screw couplings. This traditional way of coupling freight waggons is inefficient, physically demanding, time-consuming and labour-intensive. According to the Technical Innovation Circle for Rail Freight Transport (Hect et al., 2020), automatic coupling is categorised and defined in five automation levels. Type 1 involves the automatic coupling of the mechanical connection, i.e., it is similar to semi-automatic coupling. Type 2 also couples the main brake pipe automatically. A Type 3 automatic coupling also automatically couples the power lines, while Type 4 also couples the data lines. Type 4 and higher automatic couplings can be referred to as DACs, as only these types offer automatic connection of the power and data lines. A DAC level 5 offers fully automatic coupling and uncoupling (Hect et al., 2020; Cantone et al., 2022).

The digital automatic coupler (DAC level 4 and DAC level 5) is an important building block for modern and digital European rail freight transport. It will not only increase efficiency through automation processes, but also ensure a sufficient energy supply for telematics applications and secure data communication throughout the train (Shift2Rail, 2021; RailCargo, 2021).

Taking production systems with the intermediate manipulation of transport units on the way from origin to destination within transhipment node in this section (6.2.1) different scenarios were developed to estimate effect of DAC on the travel time of freight trains, as the next stage in intermodal chain. For each scenario different technological processes were presented in tables from Table 10 to Table 14. Based on the results, can be seen that DAC technology in intermodal terminal can have positive effects in terms of time reduction. In comparison with marshalling yard in intermodal terminal with DAC train will be faster prepared in composition of numerous transport units to take over LU. In case of direct and shuttle trains that drive directly to the destination station without intermediate station all processes are same in origin node and destination node for (un)building trains as those described processes of marshalling yard with the difference whether shunting activities exist or not.

6.2.1.1 Effect of DAC on time saving in terminal

To evaluate and quantify the effectiveness of DAC for time-consuming in terminal that is related to train processing time, a specific performance indicator for total transit time is presented by Sladkowski (2020).

Total transit time is an important parameter which gives an indication about the efficiency of its management. It is the period of time from the arrival of the wagon at the gate of marshalling yard from an external transport infrastructure to the departure of the wagon from the marshalling yard towards another transport infrastructure.

In general, this indicator depends on various parameters, i.e. external parameters such as line capacity, operational planning of external services and internal parameters such as operational planning of the marshalling yard (e.g. technical equipment), dimensions of the marshalling yard and operational constraints (rules, procedures).This indicator, as can be seen in equation (1), total transit time or TTR in (1) is the sum of a successive operating phase (TO) and the preceding waiting phase (TW) of wagon *i* in terminal.

$$TTR = \sum_{i=1}^{n} TW_i + \sum_{i=1}^{n} TO_i \quad (1)$$

6.2.1.1.1 Case study

Data on time during conventional train processing and staff coupling and uncoupling were obtained from the Hallsberg marshalling yard. To verify the potential reduction, the overall train processing tasks are divided into three phases: Preparation for shunting, operation phase, and departure phase. The total time required for preparing train for shunting, operation phase and departure phase are given in Table 6.

Table 6. Total time of preparation, operation and departure phases

Phases	Conventional	DAC level 4	DAC level 5
Preparation phase	47.94 minutes	31.71 minutes	25.19 minutes
Operation phase	43.83 minutes	34.96 minutes	32.96 minutes
Departure phase	13.17 minutes	12.9 minutes	12.6 minutes

For each phase, experiments were conducted for the 32 wagons using three approaches. The first approach was conventional/staff coupling and decoupling, while the second approach is DAC4, where decoupling functions are partially applied. The last approach represents the introduction of DAC5, where the duration of the coupling and decoupling functions are significantly reduced. The times for all tasks are assumed in the experiment for all developed scenarios and are listed in tables.

Phase 1: Preparation for shunting

When a train arrives, it should be prepared for rolling over the hump. The preparation processing manual coupling and decoupling takes about 48 minutes for a group of 32 wagons and includes several tasks described in table. Under DAC4, the time for the group of 32 wagons is reduced, and under DAC5 it is reduced even further. The tasks and/or their duration marked with a star (*) in the tables indicate a reduction in the time for the task.

Table 7. Approximate time in minutes to prepare a train for shunting with DAC level 4 and level 5

Tasks	**Time (min)**		
	Conventional	DAC 4	DAC 5
Reserve time (based on braking before the signal)	0.23	0.23	0.23
Driving	2.63	2.63	2.63
Securing cars and uncoupling them from locomotive	0.50	0.3*	0.2*
Checking and preparation (0,5 min per car)	32	16*	9.6*
Coupling to the shunting locomotive	0.08	0.05*	0.03*
Towing, releasing brakes, waiting for signals	1	1	1
Pushing ears over to the hump (230 + 40 m with 1.2 m/s)	3.75	3.75	3.75
Rolling over hump	7.7.5	7.75	7.75
Total time	47.94	31.71	25.19

* *Reduction of time for the task*

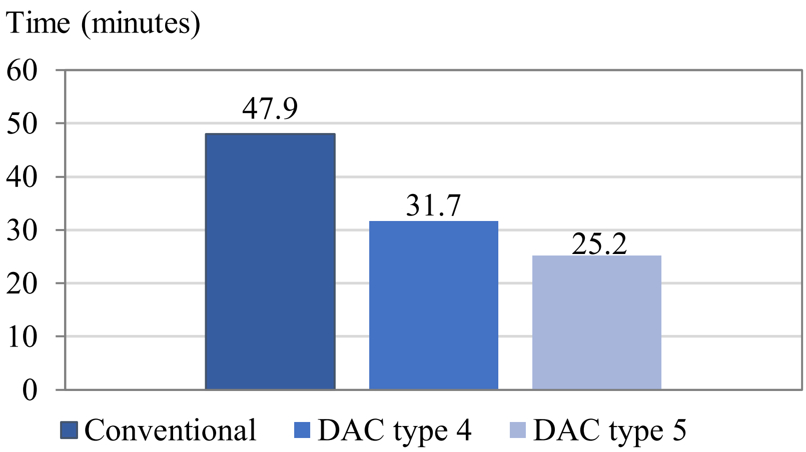

Figure 7. Approximate time to prepare a train for shunting: Conventional and DACs

Phase 2: Operational phase

Details of the tasks and their duration in the operational phase when DAC level 4 and level 5 are introduced can be found in Table 8.

Table 8. Dedicated time in minutes to different detailed operational task with DAC level 4 and level 5

Tasks	Time (min)		
	Conventional	DAC 4	DAC 5
Coupling cars and brakes (100 m/min + 10 s/car)	12.50	6.2*	6.2*
Time for filling the brake system with air	15	15	15
Testing the brake system	1	1	1
Refilling the brake systems after the test	0.33	0.33	0.33
Brake test, hitting the brakes, controlling each car	3	2*	1.5*
Releasing brakes	2	2	2
Controlling that all brakes have been released	3	1.5*	0*
Release buffer stops	0.25	0.25	0.25
Activate brakes	0.08	0.08	0.08
Time for driving the locomotive to the cars and coupling it	0.17	0.1*	0.1*
Releasing brakes	2	2	2
Simple brake test	1	1	1
Time for departure including path reservation	2.5	2.5	2.5
Time for activating buffer stops, relays, reaction time	1	1	1
Total time	43.83	34.96	32.96

** Reduction of time for the task*

The sum of the time within the operational phase with manual coupling and decoupling and the time with DAC level 4 and level 5 can be seen in Figure 8Figure 8. From Figure 8, it can be seen that the time for conventional coupling and decoupling processes can be reduced with DAC level 4 and DAC level 5.

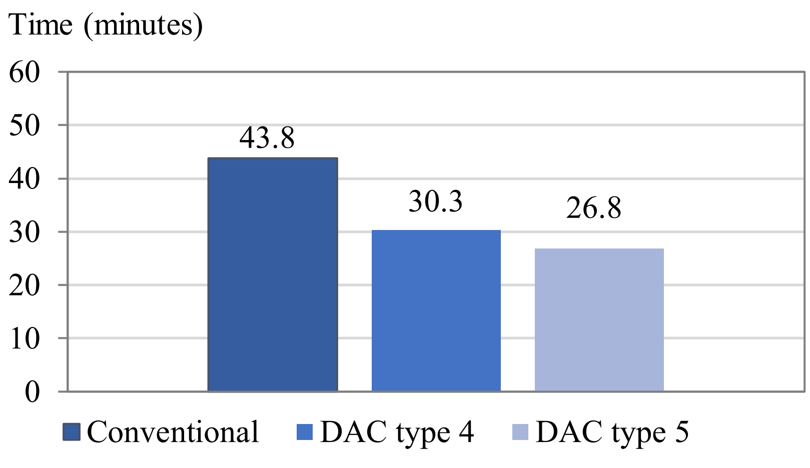

Figure 8. Dedicated time to operational phase: Conventional and DACs

Phase 3: Departure phase

In the departure phase, only the tasks related to the shunting and line locomotive are associated with coupling and uncoupling. In Table 9 the tasks required for preparation of the train before departure are indicated with their durations.

Table 9. Dedicated time in minutes to different required tasks with DAC level 4 and level 5 before the train departures

Tasks	**Time (min)**		
	Conventional	DAC 4	DAC 5
Driving	1.6	1.6	1.6
Uncoupling from the shunting locomotive	1	0.8*	0.5*
Driving the shunting locomotive away	0.2	0.2	0.2
Driving the line locomotive to cars	0.2	0.2	0.2
Coupling to the line locomotive	0.17	0.1*	0.1*
Charging the brake pressure	5	5	5
Simple brake tests	1	1	1
Waiting for the signal	2	2	2
Departing	2	2	2
Total time	13.7	12.9	12.6

** Reduction of time for the task*

As within the previous phases, introduction of DAC level 4 and level 5 can reduce time for preparing the train for departing (see Figure 9).

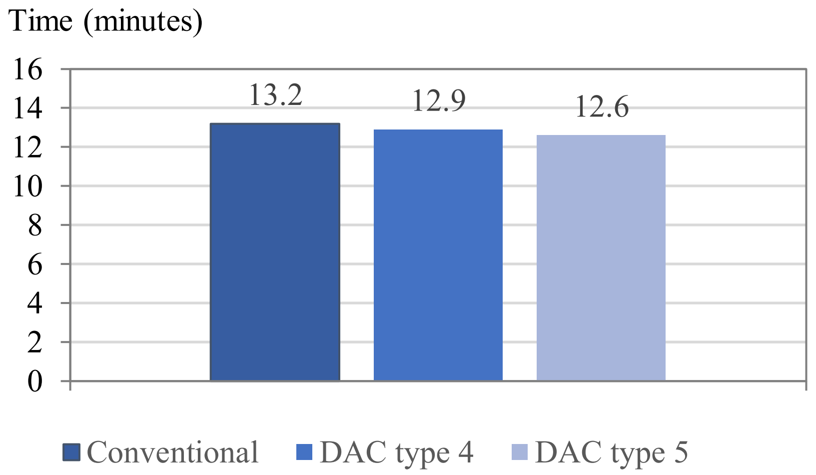

Figure 9. Dedicated time to departure phase: Conventional and DACs

6.2.1.2 Effect of DAC on freight train travel time for different railway products

This chapter examines the effects of conventional coupling and decoupling, DAC level 4, and level 5 on train travel time during handling of wagons at station on their route to the final destination.

6.2.1.2.1 Formulation of travel time

According to (Sladkowski, 2020), the generalized travel time for passenger railway transport can be estimated as the sum of the pure travel time PT, plus a pure transfer travel time penalty (PTP) for each transfer n as presented in equation (2).

$$GTT = PT + n \cdot PTP \quad (2)$$

In (Sladkowski, 2020), the formulation of the total transit time of the wagon through the marshalling yards was introduced. Considering this and the generalized time for passenger transport, we defined the total travel time of a freight train as following:

$$TTT_i = \sum_{i=1}^{N} PT_{i,j}^{j-1} + n \sum_{j=1}^{N} TM_j \quad (3)$$

TTT_i- travel time of freight train *i*

$PT_{i,j}^{j-1}$ – pure travel time of train *i* between previous station (j-1) and first station where train composition is changed

n - number of station where wagons are added or removed from freight train

TM_j – total time on handling of wagons at station *j*

In the case of Stockholm-Malmö railway line, the maximum allowed speed is higher than 121km/h. This means that the travel time of a train for the 318.7 km route is 2.63 hours or 157.8 minutes. However, the most important part of this report is the impact of DAC on removing and adding wagons to the train on its route. Therefore, the following scenarios are developed to show the potential reduction in waiting time of trains in intermediate stations.

Developed scenarios for single wagonload and intermodal rail products

To estimate the impact of the introduction of partial and full DAC on the travel time of freight trains, two rail products (single wagonload traffic and intermodal traffic) were considered with the 32 wagons in composition in the developed scenarios. The data and times for manual coupling and uncoupling are taken from operation in the Halsberg marshalling yard, while for DAC Type 4 and DAC Type 5 it was assumed that the time for operation will be reduced with the introduction of these technologies.

In addition to the basic scenario, two scenarios were developed for intermodal rail products in order to analyse the effects of DAC. Similar to single wagonload transport, in base scenario it was assumed that coupling and uncoupling is done manually, while in scenario 1 it was assumed that the train stops at a terminal to leave 32 wagons and is equipped with DAC level 4 in the first case and DAC level 5 in the second case. In the second scenario, it was assumed that the train picks up 32 wagons from the terminal and that the wagons are equipped with DAC level 4 in the first case and DAC level 5 in the second case.

Base scenario: In the base scenario, it was assumed that all tasks, on train with 32 wagons, related to the handling of waggons are carried out in the traditional way, i.e. that the waggons are manually coupled and/or uncoupled.

Scenario 1: In the first scenario, it was assumed that a train with 32 wagons stops at a station in the middle of the line in order to leave last 5 wagons at the end of the train.

Scenario 2: In the second scenario a train with 32 wagons stops at a station in the middle of the line to leave first 5 wagons behind locomotive.

Scenario 3: Scenario three was developed under the assumption that the train with the 32 wagons stops in the middle of the line and leaves 5 waggons, which are placed in the centre of the train.

In the developed scenarios, it was assumed that during the movement of trains from the origin to the destination, various handling of wagons take place. it was assumed that in the basic scenario, screw couplers couple and uncouple the wagons, while in three scenarios, DAC level 4 is fitted to the wagons in the first case and DAC level 5 in the second.

Results of wagonload traffic

Table 10 shows technological procedure of the group of handling of wagons in the first scenario. The table also shows the time differences of the individual tasks with DAC level 4 and level 5. The sum of the time duration for the whole process in scenario 1 with manual and automatic coupling and uncoupling is shown in Figure 10.

Table 10. Technological procedure and duration of handling of wagons under Base and Scenario 1

Tasks	**Time (min)**		
	Conventional	DAC 4	DAC 5
Uncoupling 5th wagon and securing cars from train	1	1	0.05*
Driving the shunting locomotive	0.2	0.2	0.2
Coupling to the shunting locomotive	0.08	0.05*	0.03*
Waiting for a signal	2	2	2
Driving the group away	0.2	0.2	0.2

** Reduction of time for the task*

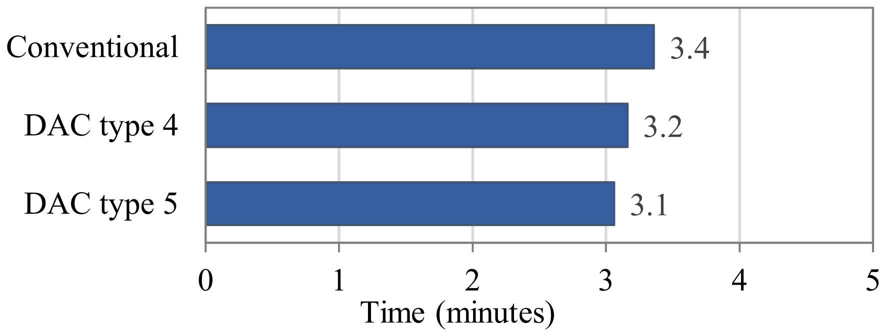

Figure 10. Reduction of time with DAC under Scenario 1

The procedure for removing 5 wagons from the front of the train/behind locomotive in the station is shown in Table 11. The time duration for each task and the possible reduction with DAC level 4 and level 5 is also given. From Figure 11 can be seen that the total time of the conventional procedures would be significantly reduced with DAC level 5.

Table 11. Technological procedure and duration of handling of wagons under Base and Scenario 2

Tasks	Time (min)		
	Conventional	DAC 4	DAC 5
Uncoupling composition from locomotive and securing wagons	1	1	0.5
Uncoupling group (5 cars) from other	1	0.8*	0.5*
Driving the shunting locomotive	0.2	0.2	0.2
Coupling to the shunting locomotive	0.08	0.05*	0.03*
Waiting for a signal	2	2	2
Driving the group away	0.2	0.2	0.2
Driving the line locomotive to cars	0.2	0.2	0.2
Coupling to the line locomotive	0.17	0.1*	0.07*
Charging the brake pressure	5	5	5
Simple brake tests	1	1	1
Waiting for the signal	2	2	2
Departing	2	2	2

** Reduction of time for the task*

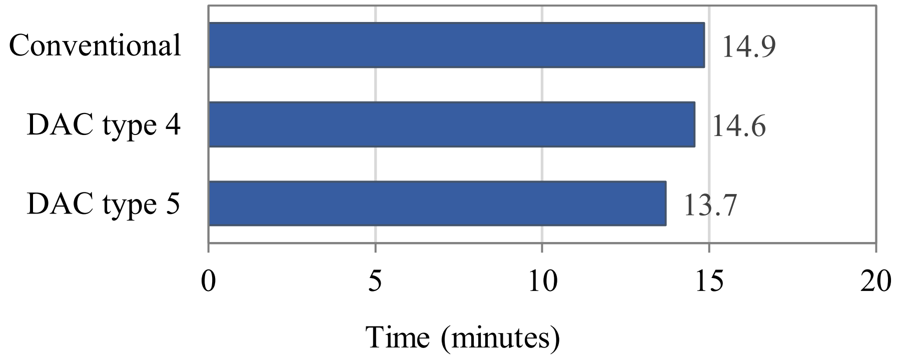

Figure 11. Reduction of time with DAC under Scenario 2

In Scenario 3 five wagons are left from the middle of the train and this wagonload traffic is described using the various tasks in Table 12. As can be seen, the duration of numerous tasks can be reduced by introducing DAC level 4 and level 5. Figure 12 shows that the duration of the conventional procedure in this scenario can be reduced by about 13 minutes with DAC level 5.

Table 12. Technological procedure and duration of handling of wagons under Base and Scenario 3

Tasks	Time (min)		
	Conventional	DAC 4	DAC 5
Uncoupling group of 5 wagons from front side	1*	0.8*	0.5*
Uncoupling group of 5 wagons from back side	1*	0.8*	0.5*
Driving the shunting locomotive	0.2	0.2	0.2
Coupling 1st group to the shunting locomotive	0.08*	0.05*	0.03*
Waiting for a signal	2	2	2
Driving the group away	0.2	0.2	0.2
Uncoupling and securing 1st group from the shunting locomotive	1*	0.8*	0.5*
Driving the shunting locomotive	0.2	0.2	0.2
Coupling to the shunting locomotive to 5 wagons	0.08*	0.05*	0.03*
Waiting for a signal	2	2	2
Driving the group away	0.2	0.2	0.2
Uncoupling 5 wagons from shunting locomotive and securing wagons	1*	0.8*	0.5*
Driving the shunting locomotive	0.2	0.2	0.2
Coupling to the shunting locomotive to 1st group	1*	0.8*	0.5*
Driving the group	0.2	0.2	0.2
Coupling the 1st group to composition	1*	0.8*	0.5*
Charging the brake pressure	5	5	5
Simple brake tests	1	1	1
Waiting for the signal	2	2	2
Departing	2	2	2

** Reduction of time for the task*

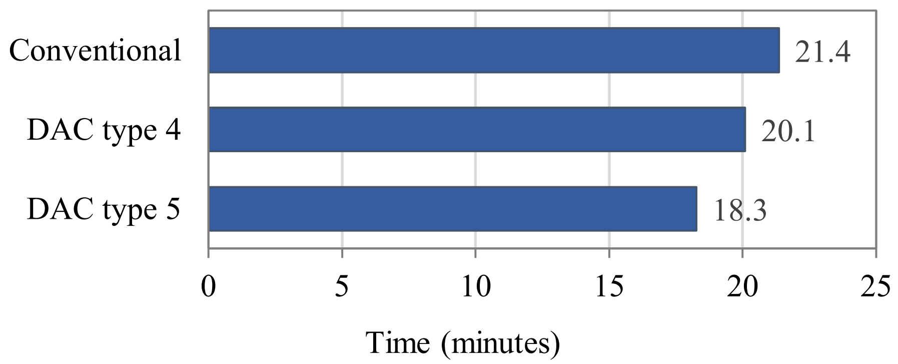

Figure 12. Reduction of time with DAC under Scenario 3

Results of intermodal traffic

The difference in task duration between conventional coupling and decoupling and DAC level 4 as well as level 5 for scenario 1 of intermodal transport is shown in Table 13. In this scenario, no significant reduction can be achieved with DAC level 5 since only uncoupling composition from locomotive is involved (see Figure 13).

Table 13. Technological procedure and duration of handling of wagons for intermodal traffic under Base and Scenario 1

Tasks	**Time (min)**		
	Conventional	DAC 4	DAC 5
Reserve time (based on braking before the signal)	0.23	0.23	0.23
Driving	2.63	2.63	2.63
Uncoupling cars from locomotive and securing them	0.50	0.3*	0.2*

** Reduction of time for the task*

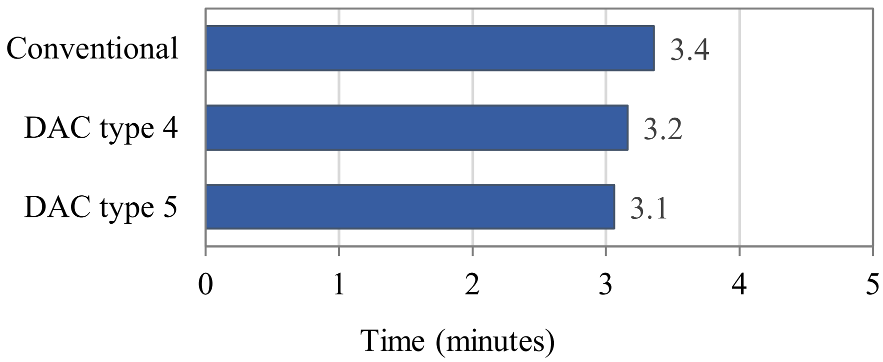

Figure 13. Reduction of time with DAC under Scenario 1

Compared to the previous scenario, scenario 2 includes many more tasks. The duration of these tasks and the possible reduction with DAC level 4 and level 5 are shown in

Table 14. In this scenario, the time reduction for certain tasks with DAC level 4 and level 5 is summarized in Figure 14. From the figure, it can be seen that the duration of the conventional procedure is reduced by 11 minutes with DAC level 5.

Table 14. Technological procedure and duration of handling of wagons under Base and Scenario 2

Tasks	**Time (min)**		
	Conventional	DAC 4	DAC 5
Driving the shunting locomotive	0.20	0.20	0.20
Coupling cars and brakes (100 m/min + 10 s/car)	12.50	6.25*	3.00*
Coupling to the shunting locomotive	0.17	0.1*	0.1*
Waiting for a signal	2.00	2.00	2.00
Driving the shunting locomotive away	0.20	0.20	0.20
Charging the brake pressure	5	5	5
Simple brake tests	1	1	1
Waiting for the signal	2	2	2
Departing	2	2	2

** Reduction of time for the task*

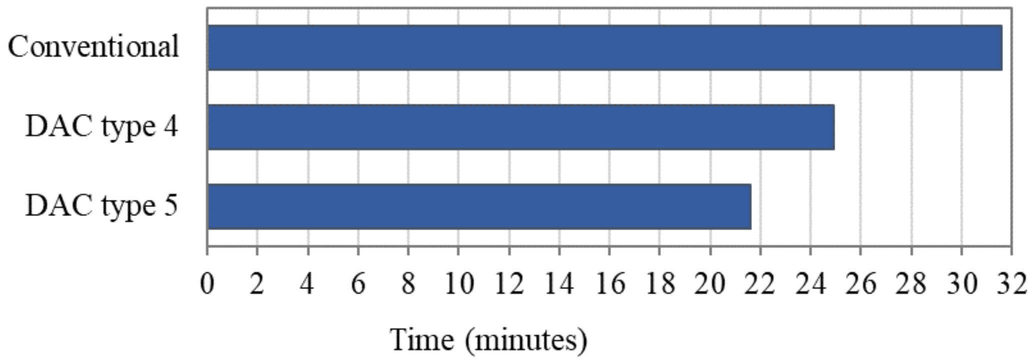

Figure 14. Reduction of time with DAC under Scenario 2

6.2.1.3 Effect of DAC on Railway Capacity

In the previous section, the Stockholm-Malmö rail line was used as a case study to analyse the impact of DAC on freight train travel time under different scenarios. Here, the Stockholm-Gothenburg line is used for the analysis of capacity improvement by DAC and the cost calculation of capacity utilisation. Capacity is calculated for the baseline scenario and two scenarios representing DAC level 4 and level 5, respectively. In addition, possible capacity improvement measures and constraints are examined and discussed.

6.2.1.3.1 Method

The cities of Stockholm and Gothenburg are connected by a double-track line. Here, capacity is calculated for one track only, assuming a single-track line. Additionally, it is assumed that the capacity doubles for double-tracked rails. The capacity of this line can be estimated using a simple equation (4):

$$K = 60/[2(\frac{D}{S} + T) \quad (4)$$

where K is the capacity (in trains per hour), D is the distance (in km), S is the speed (in km/min), T is the length of layover/Turn-round time (in minutes) (Preston, 1992). Based on the equation calculates the theoretical line capacity without considering any infrastructure constrains.

6.2.1.3.2 Scenarios of Capacity calculation

Base scenario

In the base scenario, capacity on the Stockholm-Gothenburg line is calculated on the basis of real data collected. The maximum allowed speed on the Stockholm- Gothenburg rail line is more than 121 km/h. For the capacity estimation, the value of the speed on this route is assumed to be 120 km/h. The Hallsberg marshalling yard is located on the Stockholm-Gothenburg line. We can assume in the base scenario that the train with 32 wagons from section 4 passes the Hallsberg marshalling yard without stopping.

Scenario 1

In this scenario, we assume that a train with 32 wagons enters Hallsberg marshalling yard and is coupled/uncoupled manually.

Scenario 2

In this scenario, it is assumed that the train enters Hallsberg marshalling yard on the Stockholm-Gothenburg line and has been processed. Then it is assumed that the train leaves the marshalling yard with the same number of wagons. In scenario 2, it is assumed that DAC level 4 is introduced.

Scenario 3

In this scenario, the same train is used as in the previous two scenarios. However, in Scenario 3, it is assumed that DAC level 5 is introduced. Consequently, the turnaround time of the same train in the baseline scenario is further reduced.

6.2.1.3.3 Results of Capacity calculation

This section shows the results of the rail capacity calculation. Capacity is calculated for a baseline scenario that does not include a yard stop and coupling and uncoupling operations. Based on the speed on this route of 120 km/h this means that the travel time of a train for the 396 km route is 3.3 hours or 198 minutes in base scenario, see Table 15. In this case, based on the ideal travel time from origin to destination, we can use 4.55 trains per hour on the Stockholm-Gothenburg rail line. In scenario 1, it was assumed that the train stops at Hallsberg marshalling yard and all coupling and uncoupling operations are performed manually. It can be summarised that it takes the train 104.9 minutes or about 1.75 hours to pass through all the marshalling yards. The turnaround time in this scenario is increased by the manual coupling/uncoupling process. This means that the turnaround time of the train increases by 1.75 hours, resulting in a total travel time of 5.5 hours. Therefore, the number of trains on this line is reduced compared to the capacity determined for the base scenario. Table 15 shows that the turnaround time is reduced under the assumption that the coupling/uncoupling operation is performed at the Hallsberg marshalling yard as DAC level 4. In this scenario, a capacity increase can be seen compared to scenario 1. In scenario 2 the turnaround time of the same train from Scenario 1 is reduced. This means that the turnaround time of the train increases by 1.25, resulting in a total travel time of 4.55 hours. As with the previous scenarios, it can be summarized that the train takes 64.5 minutes or about 1.07 hours to complete all procedures through all yards in scenario 3. This means that the turnaround time of the train increases by 1.07, resulting in a total travel time of 4.38 hours.

The highest capacity increase on the Stockholm-Gothenburg line, when the train passes through the Hallsberg marshalling yard and is coupled/uncoupled in the station, is achieved with DAC level 5.

Table 15. Inputs for capacity calculation

Inputs	K – capacity	D – distance	S – speed	T – turn-round time
Base scenario	4,55 trains per hour	396 km	120 km/h	3,3 h
Scenario 1	3,41 trains per hour	396 km	120 km/h	5,5 h
Scenario 2	3,82 trains per hour	396 km	120 km/h	4,55 h
Scenario 3	3,90 trains per hour	396 km	120 km/h	4,38 h

6.2.1.4 Challenges and benefits of Digital Automatic Coupler

The introduction of DAC in rail freight will bring numerous benefits. In (Troche, 2019), the following benefits related to the coupling and uncoupling processes can be expected from the use of automatic couplers: reduced staff need/increased labour productivity, improved working comfort and safety, faster coupling and uncoupling, reduced infrastructure utilisation/increased throughput, increased vehicle utilisation due to reduced shunting dwell times, and shorter transportation times. However, all these benefits, which certainly bring economic savings, are achievable in rail freight under certain operating conditions, with a high deployment rate and other technical innovations. In addition to the reduction in indirect and direct costs associated with the benefits listed, the direct costs associated with workforce reductions are obvious and are presented in (Troche, 2019). However, there is a question about the costs associated with increasing rail capacity with DAC.

Rail infrastructure development has not kept pace with freight demand growth in recent years, leaving many railways around the world facing the "capacity challenge." In the European Union, many railways have experienced significant growth in passenger kilometres and freight tonne kilometres since 1995. According to forecasts, rail traffic in Sweden will increase by 28% by 2030. As far as the share of each mode is concerned, rail transport will remain constant at 25% for long-distance transport > 100k.

6.2.1.5 Other Digital Automatic Coupler benefits

Benefits related to productivity gains identified concerns (see: (Troche, 2019) D5.5 – CBA for Automatic Couplers):

- Reduced wear on the track
- Reduced risk for derailment
- The possibility to operate heavier trains and longer trains
- Simplified and lighter design of the wagon frame is possible in the future, thus an enabler to instead increase the effective payload. With the DAC as an enabler, important functions for increased productivity are:
- EP-brake.
- Use of moving block.
- Connectivity to the network management system. The DAC is a starter for the intelligent wagon and automation in a system perspective.
- Train integrity check. Apart from enabling moving block function, this function removes the need for line-side equipment such as track circuits or axle-counters if implemented in full scale.
- Monitoring of running gear components. Reduce risk of derailment apart from enabling predictive maintenance.

All the benefits listed above contribute to some extent to higher average speed, higher rolling stock utilization and reduction of transport time, consequently leading to a higher productivity. The benefits actually or potentially arising from the use of Automatic Couplers can be assigned to three groups:

1. Benefits relating to the transmission of tractive and compressive forces in the train consist
2. Benefits relating to the coupling and de-coupling process
3. Benefits relating to the enabler-/facilitator-role of Automatic Coupler for other innovative solutions

It is mainly the first group which enables the operation of longer and heavier trains as elaborated in the following section.

6.2.1.5.1 Benefits relating to the transmission of tractive and compressive forces

When it comes to the first group of benefits, relating to the transmission of tractive and compressive forces, these can arise from the capability of Automatic Couplers to transfer higher longitudinal forces than screw couplers, at least when it comes to tractive forces.

It would be in principle possible to design even screw couplers with similar capabilities, however, the limiting factor here is the need to keep the weight of movable parts of the screw coupler, which have to be lifted manually, on a reasonable level. Therefore the dimensions of these parts cannot be increased beyond a certain limit. A general trend to tighten work safety and work comfort rules might in the future even have an effect in the opposite direction, i.e. reducing the possibility to design screw couplers for high longitudinal forces.

The ability to allow higher tractive and compressive forces with Automatic Couplers in the longitudinal central axis of the wagon / train, can generate a number of benefits:

1. Possibility to operate heavier trains (this often means also longer trains)
2. Higher running safety, in particular reduced risk for derailments
3. Possibility to raise train speeds by allowing higher brake forces
4. Simpler and lighter design of the wagon frame, since both tractive and compressive forces are transferred in the center of a wagon (today compressive forces are taken up on the sides of a wagon)

While all these benefits certainly arise in theory, their practical relevance in European rail freight is nonetheless somewhat more limited:

Train weights and train lengths in Europe are – with exception of very few isolated traffic operations - usually not such, that the use of screw couplers would constitute a limitation for the train weight.

Europe trains with up to ca. 4000 gross tons have already been in the past operated with screw couplers. Even with a general trend towards higher axle-loads and longer trains it is rather unlikely that a significant number of traffic operations would reach this weight. To give an example: An intermodal train in Europe has a typical meter-weight of ca. 2.2 – 2.5 t/meter. Even with a train length of 1000 meters and head traction only the train would not reach a weight where longitudinal forces would reach a level, which could not be transferred by screw couplers. For unit trains with bulk commodities meter-weights are certainly higher and there might be some few traffic operations where train weights will reach levels which cannot be transferred safely with screw couplers. However, often these are isolated traffic operations, where Automatic Couplers could be introduced without requiring a European- and fleet-wide migration to Automatic Couplers.

The higher running safety (reduced risk for derailments) is partly stemming from the fact that with Automatic Couplers both the compressive and tractive forces are transferred along the longitudal central axis of the wagon/train. A further improvement can arise from the possibility to easier introduce ep-braking in freight trains with the use of Automatic Couplers (from type 4). In this latter case this benefit sorts rather under group ‘3’, since it also requires introduction of further innovations (ep-brake for freight). It is difficult to assess today the practical relevance of this improvement, since rail transport is relatively safe and only few derailments occur. It would require a deeper analysis of freight train derailments in order to assess this benefit properly.

Regarding the possibility to run trains at higher speeds due to the possibility to allow higher longitudinal forces with Automatic Couplers the practical benefits will vary in Europe, due to the fact that braking rules till vary quite considerably in different countries. This means that at least in some countries major improvements of freight train speeds could also be achieved still with the current screw coupler system, by amending braking rules to a more “ambitious” (but still safe) practice in Europe.

Concerning the advantage stemming from the possibility to make use of simpler and lighter designs for the wagon frame of freight wagons, this advantage naturally only is relevant for new-built wagons, not for wagons subject to retrofitting. For new-built single-frame container bogie wagons the weight net advantage could be in the magnitude of 0.5-1.2 tons, in combination with other improvements of the wagon design even higher. However, it should also be noted that the weight benefit depends on the type of wagon; for certain wagon types there may even be no advantage or a very low one, e.g. for intermodal pocket wagons, where longitudinal forces are taken up by side beams. In this case it is therefore no advantage to transfer compressive forces at the ends of the wagon centrally.

Further advantages of Automatic Couplers relating to the transmission of tractive and compressive forces are:

5. Reduced wear on wheels and rails through reduced lateral forces at the rail/wheel interact
6. Elimination of buffer wear and need for buffer lubrication

Regarding the reduced wear on wheels and rails there have been indeed reported substantial reductions in specific traffic operations where Automatic Couplers todays are used in isolated operations. For the “lignite shuttle” reductions of up to 30% have been reported. However, these results are strongly due to the very specific infrastructure and operational conditions in this specific traffic, such as:

- Relatively high actual train weights and axle-loads
- Very small radii on some rail sections
- Train is pushed over certain sections with tight curves

Thus, the results from these operations cannot be generalized. For the majority of the rail network and for the majority of traffic operations the reduction of wheel and rail wear through Automatic Couplers is likely to be very low and probably almost neglectable. Significant effects can be expected, if at all, on sections and in networks with frequent tight curves in combination with heavy trains (high axle-loads). However, to assess the potential effect more precisely further research would be needed.

Buffer wear and the need for buffer lubrication is for natural reasons eliminated with Automatic Couplers, since buffers are not part of the system any longer. At the same time certain wear and need for component service is also connected to Automatic Couplers. However, the design of the draft gear (taking over the role of the buffers in a system with Automatic Couplers) will likely lead to a lower wear, especially since lateral glide movements are largely reduced.

6.2.1.6 Assessment of Digital Automatic Coupler benefits

Consequently, important direct benefits of introducing automatic couplers in different production systems are related to “Rationalisation of the coupling process” and “Transmission of higher longitudinal forces” but also to indirect benefits such as synergy effects in combination with other innovations (see Table 16).

An assessment of the magnitude of the benefits show that the largest benefits are found for wagonload traffic and related to “Increase of labour productivity”, “Improved working comforts and safety” “Automated brake test” and “Generation of train composition list”, as illustrated by Troche (2019).

For trainload systems the benefits with highest impact relates to “Possibility to run heavier trains” and “On-board train integrity control” and for intermodal trains the main direct benefit is “Possibility to run faster trains through increased use of brake regime ‘P’” and indirect benefits such as; “Electric on-board power supply”, “On-board train integrity control” and “Real-time monitoring of wagon condition”.

Table 16. General assessment of importance of benefits of Automatic Couplers in different production systems

	Trainload	Wagonload	Intermodal
Transmission of higher longitudinal forces			
Higher safety / reduced risk for derailment	Low	Low	Low
Possibility to run heavier trains	High	Medium	Medium
Possibility to run faster trains through increased use of brake regime 'P'	Low-Medium	Medium	High
Reducing wear on wheels and rails	Medium	Low	Low
Rationalisation of coupling process			
Increased labour productivity	Medium	Very high	Medium
Increased rolling stock utilization	Medium	Medium	Medium
Reduced infrastructure occupation / yard dwell time	Low	High	Low-Medium
Reduced transport times	Low	Medium	Low
Improved working comforts and safety	Medium	Very high	Medium
Indirect benefits (synergy effects in combination with other innovations)			
Electric on-board power supply	Medium	Medium	High
Automated brake test	Medium-High	Very high	Medium-High
Generation of train composition list	Medium-High	Very high	Medium
On-board train integrity control	High	High	High
Real-time monitoring of wagon condition	Medium-High	High	High

6.2.1.6.1 Critical Measures and Boundary Conditions

The following parameters constitute identified critical measures and conditions and thus the basis for recommendations on measures given in this study:

- Current brake rules and break tables for longer trains
- Lengths of siding tracks (on lines and yards)
- Vertical gradients of tracks
- Signalling
- Axle-counters

6.2.1.7 Assessment of potential of Digital Automatic Coupler to allow rail entering into new market segments

The introduction of DAC – together with further innovations, which DAC is an enabler/facilitator for – can be used to extend and launch new service features for rail freight. In particular two aspects should be mentioned:

- The speeding up of operational processes as can be seen in sections 6.2.1.1 and 6.2.1.3 in connection with the train formation (in case of DAC 5 even train splitting), train preparation and the ability to run at higher speeds due to improved braking performance paves the way for reducing transport times. This can be used to enter (respectively re-enter) to a larger extent than today into the market for time-sensitive shipments.
- The possibility of electric power supply on the wagons can be used to provide energy to wagon-mounted equipment of new, innovative trans-shipment technologies. This could in particular be interesting for solutions for horizontal trans-shipment of intermodal loading units, for which the absence of onboard power supply today often constitutes a drawback. New innovative trans-shipment technologies have the potential to re-shape the service features of intermodal transport, e.g. by setting up of new small-scale low-cost terminals and by introducing liner-train concepts with trains making intermediate stops instead of serving only point-to-point relations. This can enable rail to enter into regional transport markets targeting even more scattered transport flows and transport over shorter distances.

It must be noted that the market for time-sensitive shipments (point 1 above) is characterized by often low specific density (kg/m3) and a high specific value (EUR/kg). Therefore, the goods transported in this market is even called LDHV (= low density, high value). Typical demarcation values used to define the market segment are a maximum of 250-300 kg/m3 and a minimum trade value of 0,50 EUR/kg (SPECTRUM, 2012). A study from 2012 quantified the total LDHV-market in EU27+CH being ca. 12% of total road freight, however, including even perishable goods with a higher density and lower value (SPECTRUM, 2012).

When it comes to the potential role of DAC in connection with new production concepts there is an important potential to catch a larger share of the market for transports over shorter distances i.e time-sensitive shipments. The (road) transport volume tends to increase the shorter the distance is. Also, feeder transports by road in long-distance transport chains can be reduced. A pre-condition for both is to increase the geographical density of the intermodal terminal network. New trans-shipment technologies can contribute to achieve this. With the possibility to provide electric power on wagons DAC can become a facilitator for such new technologies.

While the above considerations indicate interesting market potentials for rail, which DAC can help to exploit, it must be made clear, that the introduction of DAC alone will certainly not directly lead to rail entering into these market segments. In order to make more substantial inroads into these segments often further measures must be taken, concerning i.a.:

- infrastructure (e.g. setting up of new terminals/access points)
- technology development (e.g. transshipment technologies)
- timetabling and capacity management (e.g. provision of train paths for “fast” freight trains).

Taking into account the above, it appears not reasonably possible to quantify any market volume of new market segments, which rail would enter into as a direct consequence of the introduction of DAC.

While there is a potential of DAC to help rail to enter into new market segments, exploiting this potential is dependent on many other developments and measures to be taken. In many cases the introduction of DAC is only removing one – of many – barriers for rail to exploit this potential. It is therefore most likely that entering into new market segments will not be a short-term impact of DAC, but rather a medium-to-long term perspective.

Nonetheless, taking into account that DAC has been identified as an important enabler and facilitator of a broader automation and digitalization of rail freight, and that automation and digitalization in general will be an important factor for allowing rail to meet the often demanding and specific logistical requirements of new market segments, the strategic role of DAC for allowing rail to enter into new markets should not be underestimated.

6.2.2 Intelligent Video Gate

6.2.2.1 Effect of Intelligent Video Gates on train processing in terminal

In order to enable a higher level of automation in terminals and to reduce the lead-time needed for the identification/verification process of train-sets, a concept named Intelligent Video Gates (IVG) is introduced within the project FR8HUB III WP3. The IVGs capture data through optical character recognition and radio-frequency identification from wagons and intermodal loading units. In the framework of the project, full-scale demonstration gates have been installed in Sweden and Germany. To assess and analyse the impact of IVG on train handling in a freight terminal, the AnyLogic simulation was used for model and scenarious development, while the Hallsberg marshalling yard served as a case study.

6.2.2.1.1 Scenario 1: Operations with current automation and digitalization

In order to be more accurate when simulating the yard operational procedures, Table 17 was followed. In these scenarios, time was the only factor considered in the simulation.

Table 17. Time to prepare a train of 32 wagons for shunting

Steps	**Time (s)**	**Time (min)**
Train arrival		
Reserve time (based on braking prior to the signal)	14	0,23
Driving	157	2,62
Securing wagons and uncoupling them from locomotive	30	0,5
Arrival inspection (1 min per wagon)	1920	32
Coupling to the shunting locomotive	5	0,08
Towing, releasing brakes, waiting for signal	60	1
Pushing wagons towards the hump (230+40 m with 1.2 m/s)	225	3,75
Pushing over the hump	465	7,75
Sum (train arrival)	*2876*	*47,93*

The simulated model of Hallsberg marshalling yard is shown in Figure 15. The place of interest was mainly the receiving yard and the hump. However, part of the classification bowl was drawn to show a more detailed model.

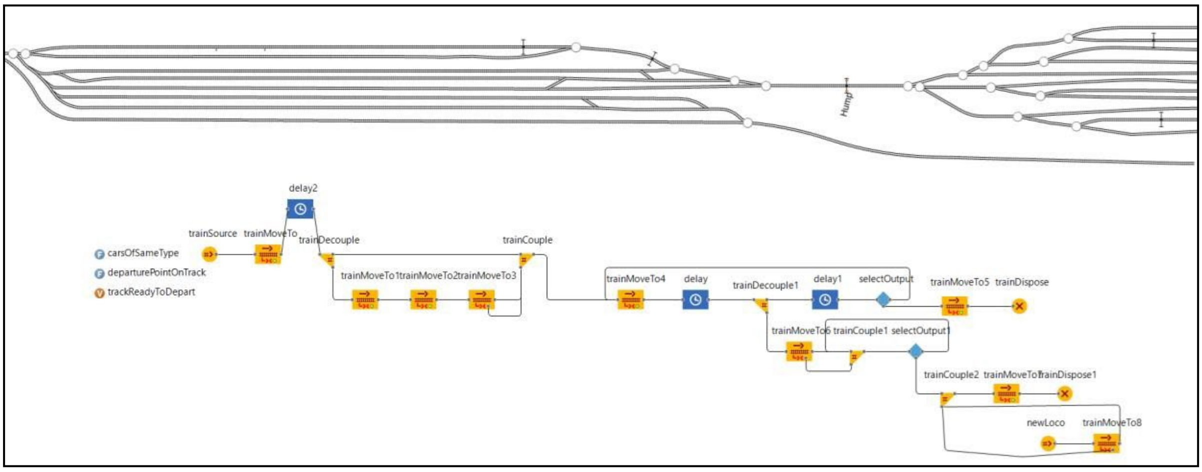

Figure 15. Hallsberg arrival yard with part of the classification bowl

When the train arrives at Hallsberg receiving yard, it stops for change of locomotive and inspection. According to Table 17 the time of inspection is approximately 1 minute per wagon. Figure 16 shows a simulated freight train that has just arrived at Hallsberg and is stationary forinspection and preparing marshalling procedures.

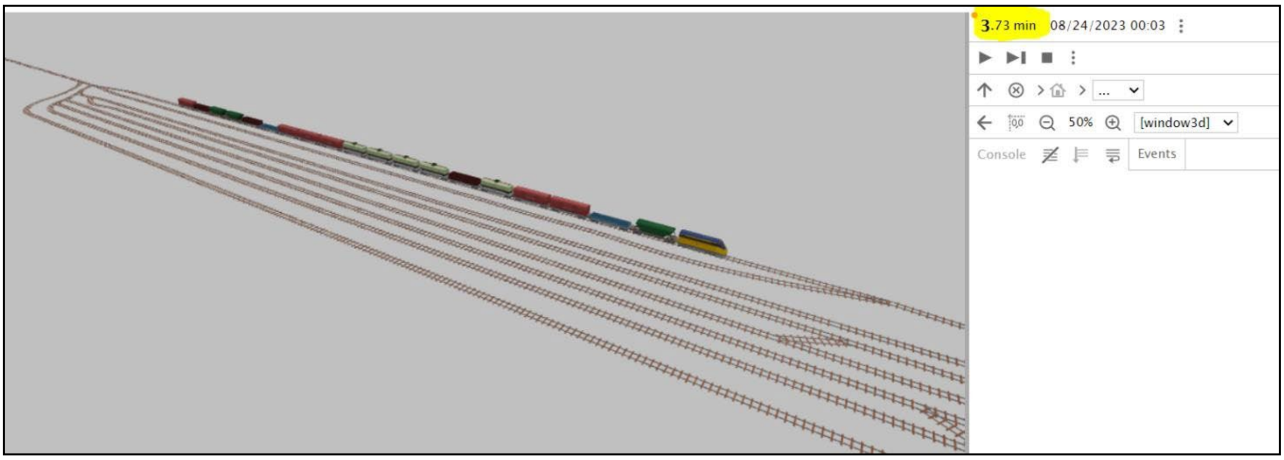

Figure 16. Train arriving at Hallsberg and stopping for inspection

The locomotive coupled to the train from behind after inspection and decoupling of wagons. In thismodel Figure 17, the same locomotive was chosen as a shunting locomotive to push the wagons through hump for simplicity.

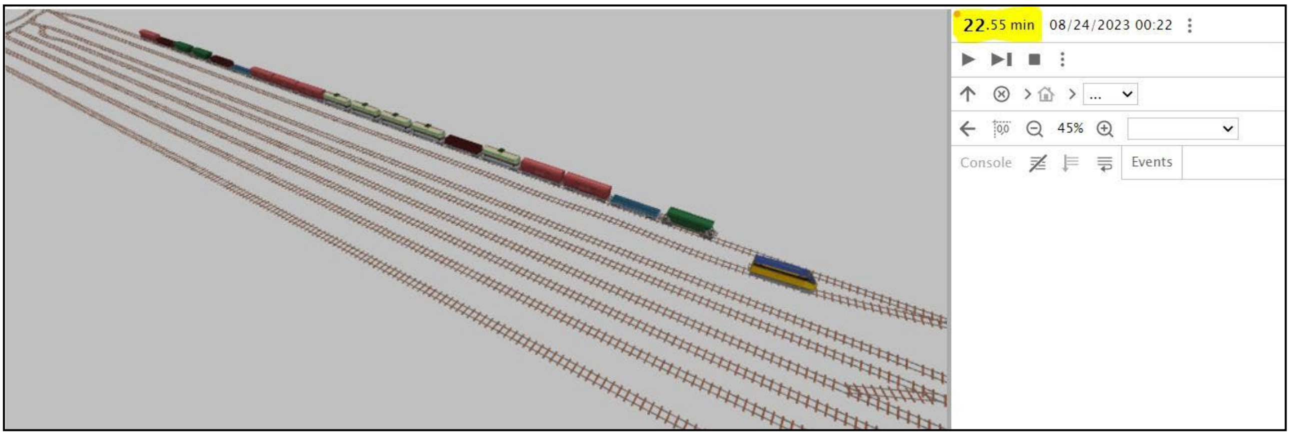

Figure 17. Locomotive decoupling after inspection to push wagons through the hump

The wagons are then classified according to their final destination and stopped in the classification bowl (see Figure 18).

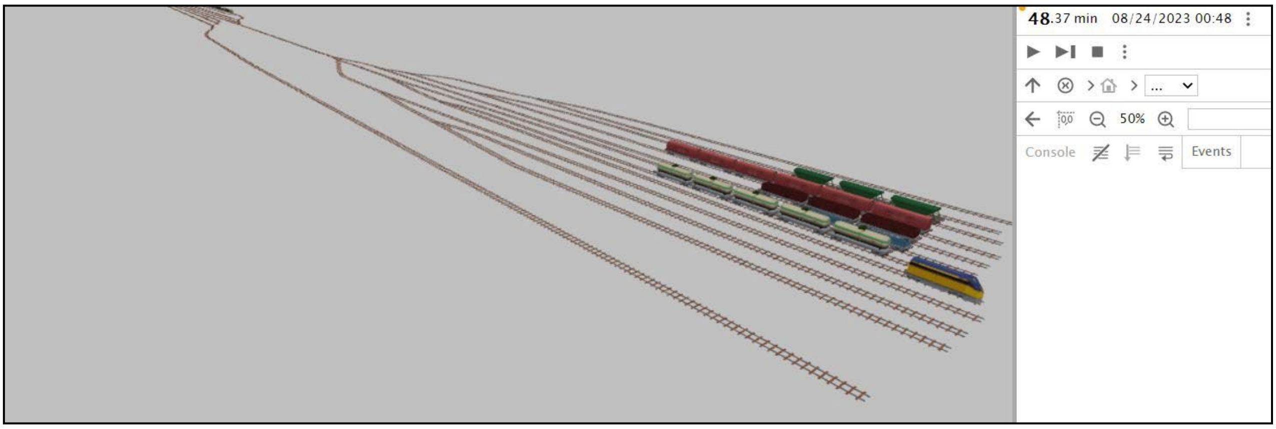

Figure 18. Classification bowl with the total time without IVG

6.2.2.1.2 Scenario 2: Operations with more advanced automation anddigitalization (IVG)

In this scenario the IVG was chosen to be installed at the entry track of the receiving yard (see Figure 19) in the purpose of helping with among other things, inspection and control of wagons. The technology has resulted in a significant 20-minute time savings when compared to the current operational methods as seen in Figure 20.

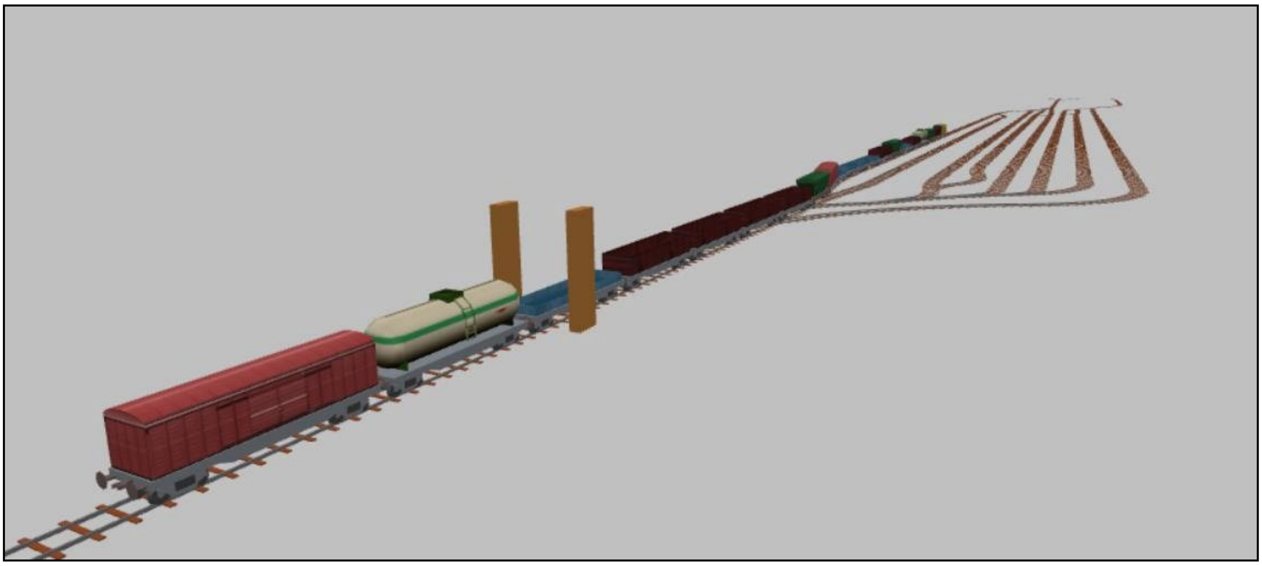

Figure 19. IVG installed at the entry track of the receiving yard

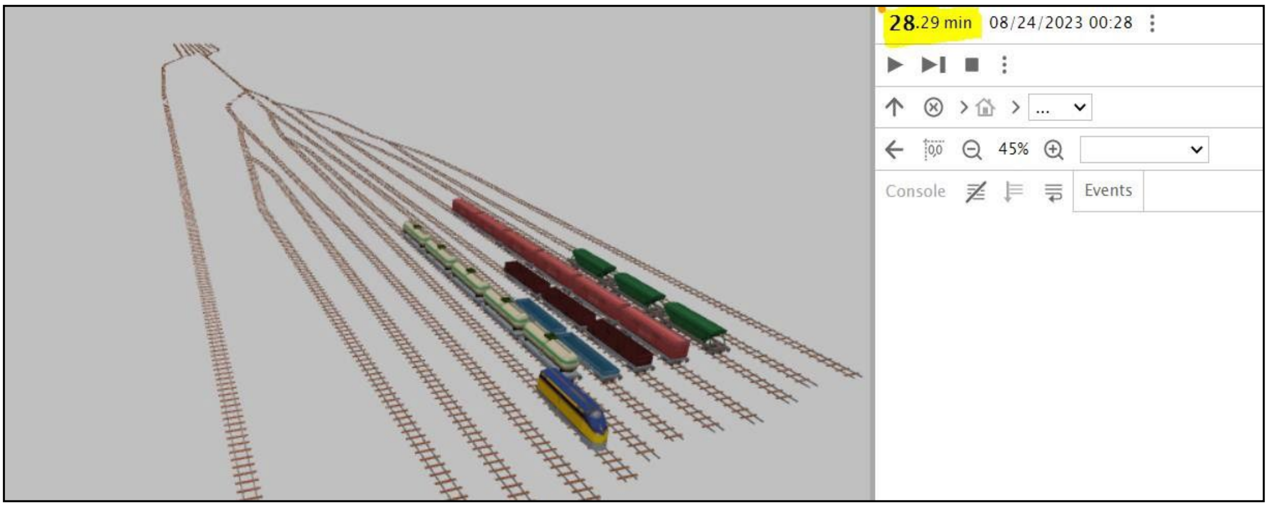

Figure 20. Position in the classification bowl with the total time with IVG installed at the entry track

After completing all procedures at the receiving yard, the freight train is then shunted to the hump. There are two steps identified at this stage and they are mentioned in Table 18. The time taken for *arrival inspection* which was 1 minute/wagon is now assumed to behalved if the IVG was to be installed at the hump. The simulated track is flat and no consideration to the yard height difference was taken.

Table 18. Hump operations of a freight train without IVG

Steps	**Time (s)**	**Time (min)**
Hump operations		
Pushing wagons towards the hump (230+40 m with 1.2 m/s)	225	3,75
Pushing over the hump (32 wagons - 18 meters long and 1,2 m/s)	465	7,75
Sum per train	*690*	*11,5*

In this scenario, the IVG is placed at the hump as seen in Figure 21 where it mainly is used to detect damages to the wagons.

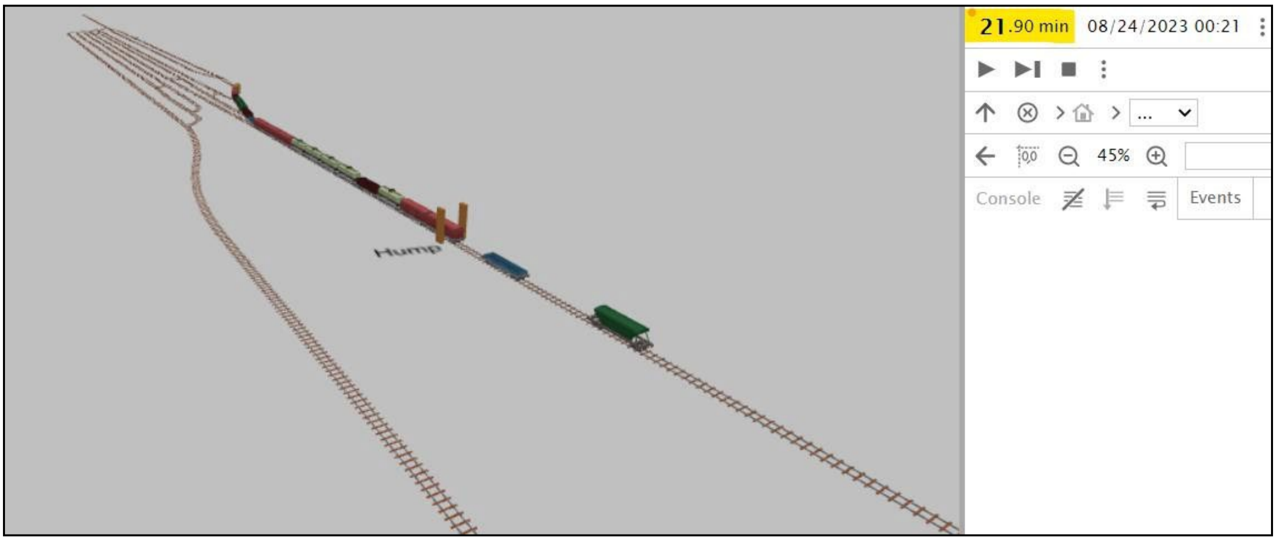

Figure 21. Train passing through with IVG installed at the hump.

In Figure 22, the wagons are classified in the bowl after passing the IVG at the hump. The total time taken to reach the classification bowl is approximately 38 minutes.

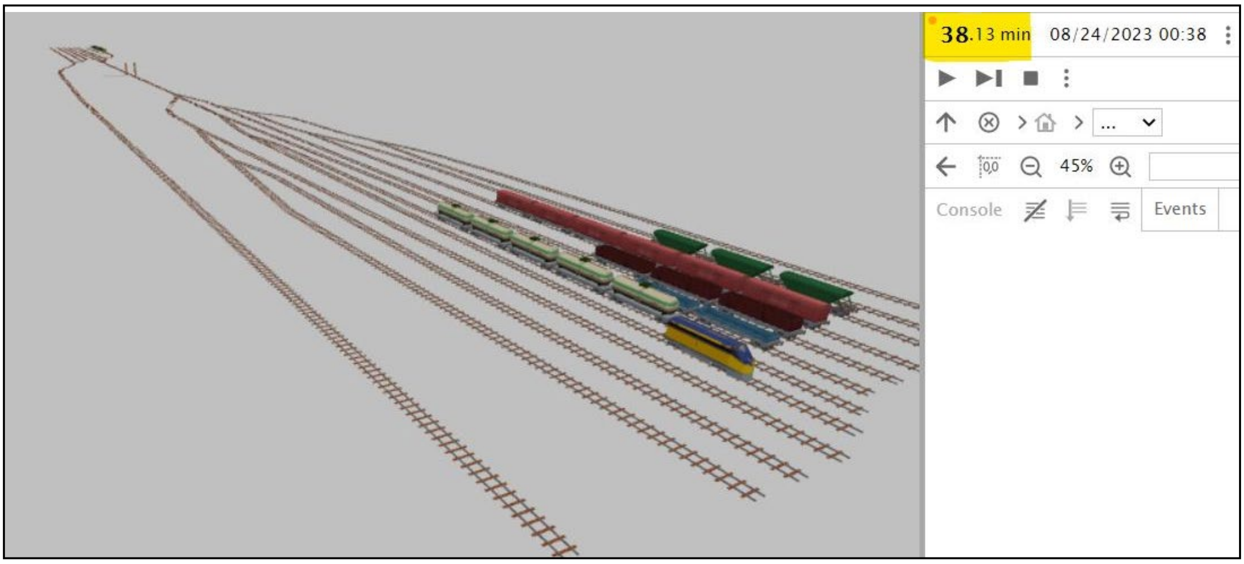

Figure 22. Position in the classification bowl with the total time with IVG installed at the hump

6.2.2.1.3 Comparison between different scenarios

Traditionally, gate operations relied on manual inspections, which resulted in lengthy processes and the possibility of human mistakes. However, using IVG in the simulated case eliminated some of themanual processes.

In the simulation, there were several variables that could be controlled and were chosen to be constant through the scenarios, for instance:

- Train speeds, acceleration and deceleration
- Same track position was used so that the distance travelled at the yard was the same.
- The shunting locomotive was the same locomotive in the train.
- The number of wagons was 32 in all scenarios.
- The wagons have automatic coupling and uncoupling system.

This resulted in a noticeable difference in marshalling time as seen in the second scenario with IVG installed at the arrival yard Figure 20 with a total time of 28 minutes compared to the first scenario Figure 18 where the total time was around 48 minutes. However, in the simulation, there was a 10- minute time difference when installing IVG at the hump compared to the first scenario.

It is also worth mentioning that the time difference resulted from installing IVG is under the conditionthat it works with 100% efficiency.

6.2.2.2 Challenges and benefits of Intelligent Video Gates

Intelligent Video Gates (IVGs) provides essential benefits such as automatic wagon identification, damage detection, and security monitoring, they also have limits relating to cost, infrastructure needs, environmental considerations, data processing, and privacy challenges. These restrictions may be efficiently addressed by using measures such as cost minimization, technical developments, strong data management, and regulatory compliance. Furthermore, considering the restrictions in installing and maintaining intelligent video gates, such as infrastructure compatibility and maintenance needs, may assure the system's long-term operation and stability.

Installing intelligent video gates requires large upfront investments for obtaining cameras, creating software, and building the appropriate infrastructure. Retrofitting existing infrastructure or implementing the technology across a large train network can be costly. To address thisconstraint, through cost-benefit analysis, staggered deployment tactics, and researching financing options might be considered. Conducting rigorous cost-benefit analysis to determine the financial viability of implementing intelligent video gates.

A variety of IVGs functionalities were discussed, including enhanced security, fasteridentification, and processing, reduced operational costs, data collection and analytics, improved traffic flow, integration with other systems, environmental friendliness, dynamic updates and scalability, reduced human errors, operational transparency, safety, time management, and enhanced planning. IVGs are more than simply surveillance; they are about utilizing the power of technology to make stop point operations more secure, efficient, and adaptable to future demands. IVGs have enormous potential for altering the way stop points work, and their integration might redefine freight transportation norms.

Intelligent video gates are located at the intersection of image processing and sensor technologies. These devices are particularly installed at stop points and are a game changer for the rail freight industry. On the other hand, intelligent video gates can interpret massive amounts of visual input at unprecedented speeds. This feature provides quick container identification, lowering stop times and, as a result, increasing goods flow. Rail stop security is critical. Intelligent video gates, with their advanced algorithms, can detect unwanted access and keep goods safe. Furthermore, given the stringent compliance standards of international rail freight, these gates ensure that all freight corresponds to specified criteria, preventing costly regulatory violations. Intelligent video gates, in addition to real- time surveillance, provide predicted insights via continuous data collecting. This information can be important in anticipating possible challenges, whether they are infrastructure-related or connected to the freight itself, ensuring early responses.

As it is imagined the rail freight scene of the future, it is clear that technology, particularly data image processing, sensors, and intelligent video gates, will be at the forefront.

As intelligent video gates become increasingly common, the benefits they provide, ranging from security to efficiency, will propel the industry to unprecedented growth and reliability. These technologies make cargo identification easier, verify operational preparedness, and guarantee that items are on the proper track, both literally and metaphorically. Furthermore, automation based on powerful machine learning algorithms has speed upfreight train procedures.

6.2.3 Implementation of emerging technologies: feasibility, costs and efficiency

To contribute to the European Green Deal, an increase in rail freight with 100% by 2050 is required, as set out in the EU Strategy for Sustainable and Smart Mobility. The main question, however, is how additional traffic can be accommodated within the unchanged infrastructure capacity. Building new infrastructure is complex and presents many challenges, the most important of which is related to cost. Therefore, a significant part of the future volume must be transported on the existing infrastructure. Nevertheless, operational characteristics such as train length, load factor, speed and network utilisation must be improved. In addition, operating times in stations and marshalling yards must be significantly reduced. To overcome capacity problems, the industry has proposed a new technical solution for wagons and locomotives: the "Digital Automatic Coupling" or DAC. Many see DAC as the technology of choice to enable the automation of rail freight transport and offer customers more attractive services, increase the quality of rail freight transport and reduce operating costs. However, apart from the benefits of DAC pointed out in previous projects such as DACcelerate there are also direct costs of DAC such as the cost of the couplers and the cost of mounting the couplers, the cost of the additional components required to deliver all the targeted functionalities. These additional components are bundled into technical packages in order to present a range of potential impacts for DAC, the infrastructure and IT costs, one-off costs associated with DAC deployment and recurring costs after DAC deployment (INECO, 2023). The cost benefit characteristics of DAC as a potential technology for rail freight improvement will be aligned witht the work within TRANS4M project within the WP19.

Due to the overall significant benefits listed in (INECO, 2023) and costs which are not negligible, feasibility of DAC is considered through the migration strategy and migration scenarios. In Deliverable 4.2 of DACcelerate project the migration strategy and its evaluation presented in this report has been developed and aligned with a multitude of stakeholders of the sector. Migration to the Scharfenberg DAC is feasible despite its non-compatibility with the prevalent screw coupler. The sector will need to further intensify its efforts to solve the challenges head-on. (DACcelerate, Deliverable 4.2, 2022).

The costs of IVG for the constituent components are in many cases very difficult to pinpoint and monetize, depending on local cost structures and the design of the concept regarding e.g. single or double track construction and the number of cameras. The implementation costs of an IVG are mainly focused on the initial costs for the gate's physical construction and the IT-system needed. Nevertheless, the costs of IVG installation involves the administrative preparation, the equipment, the building of the gate, electric installation and connection to IT systems. Purchasing of new software and hardware, support during the installation and preparations of the local terminal management systems, in order to be able to communicate with the IVG,

Expected changes in fixed costs are mainly related to the fact that IT systems are expected to increase due to licenses and fees for using a common information-exchange platform. Other fixed costs are not expected to change such as the costs for transshipment equipment at terminals or shunting equipment at yards, land area, fence, lighting poles, rail track(s), office/buildings, rail connection to the network and realisation costs (total infrastructure and pavement).

Variable costs expected to change include costs related to administration, employees, energy, insurances, maintenance, and support for IT-systems and management/manager(s).

There are no expected changes in variable costs regarding security, interest rate, network fee for rail access and terminal licenses or other taxes (Mitrovic et al., 2018).

The functional feasibility of the implementation of IVG has been tested in the project FR8HUB, WP4 Intelligent Videogate, in laboratory environment and full-scale demonstrations were carried out in Sweden and Germany within the framework of the sub-sequent Shift2Rail project "FR8RAIL III WP3 Demogate". The image processing functionalities developed were also tested with real images obtained on-site with two different cameras, which also provided successful results in the detection and identification of LU and UIC codes, as well as different dangerous cargo signs. The concept is currently being further developed in EU-Rail FP5 TRANS4M-R project within WP29 "Standardised European Checkpoints", where the concept is being rolled out also in other European countries, now also including Netherlands, Spain and Austria. Moreover, another operational stop apart from intermodal terminals and yards is considered, namely borders. This in order to facilitate seamless cross border traffic. Additional functionalities are also investigated, mainly regarding developing algorithms for damage inspections as well as improved the algorithms for detection of codes and dangerous goods.

Establishing IVG at intermodal terminals and freight yards can have several positive effects. From the perspective of the terminal operator (TO), the IVG concept would imply an improvement in operational efficiency, mainly due to (Kordnejad et al., 2019);

- Faster arrival process. Handling deviation and identification of wagons and cargo carriers with higher degree of automation during arrival processes, e.g. check-in (document handling) / damage claims / handling of dangerous goods.
- Faster departure process. Higher degree of automation at departure e.g. departure control, improved safety and handling of dangerous goods.
- Improved and faster operational management when sequence of wagons and loading units (LU) (and any deviations from pre-arranged sequence) are known in advance, which enables optimized transshipment plans and a more seamless interface toward road transporters.
- Obviously improved services at terminals imply an improved and more attractive range of services, which in the long perspective should lead to a higher degree of customer satisfaction. Improved monitoring capabilities is also beneficial for infrastructure managers, enabling an improved efficiency in network management, in particular for cross border traffic.

6.2.4 Smart Container

When a container is capable of retrieving and emitting data thanks to its incorporated IoT devices such as sensors, it is known as a Smart Container. It allows real-time tracking of the content and the smart container itself and embracing IoT at this level provides greater visibility for various sectoral stakeholders, which helps them in the decision-making process. This technology can even be combined with others such as blockchain to facilitate trading and, as mentioned before, the need for unambiguous message exchange standards is needed. For this purpose, UN/CEFACT proposes that the data elements of the smart container follow the MMT Reference Data Model (see section 6.4.1) and to facilitate this action, it has incorporated more than 120 new data elements related to sensors and geographical information.

6.2.4.1 Benefits of smart containers

The potential advantages of implementing this technology in the rail sector are several, the main identified ones being:

- **Advanced monitoring and security:** Smart containers enable real-time tracking of cargo, offering precise monitoring of location and status throughout the transportation phase. Alerts for unauthorized access, unexpected incidents (e.g., door openings), or deviations from planned routes improve security and asset protection. In this way, Supply Chain Stakeholders can react proactively, plan container operations or cargo logistics accordingly and determine bottlenecks. Furthermore, as the status of the container is known at all stages, in case of any deviation or accident the responsible party can be determined by the time and the place of the exception.
- **Predictive maintenance and quality assurance:** Unexpected temperature or humidity changes in the container can put the quality of the content at risk. The early detection of these and other potential issues allows proactive maintenance, reducing the risk of equipment failures and ensuring smooth operations. Containers forward a daily status message which is useful for the container operator to have valuable information to compute usage ratio, show sitting versus moving volumes, determine import or export phase, etc. In addition, knowing the exact number of operation hours helps avoid unnecessary pre-trip inspections and performing them only after predefined operation hours or detected irregularities of performance.
- **Efficient operations and compliance**: Automation of data collection and reporting streamlines operations ensures compliance with regulatory standards and contractual agreements. Accurate tracking of transit times and condition monitoring facilitates operational efficiency and regulatory compliance. The trip data (time and routing points passed) can be provided on demand to the Supply Chain Stakeholders as well as insurance and bank institutions to check the fulfillment of the container routing contract. Moreover,

the timing of the handling of intermodal changes can be monitored to detect unexpected events due to container mishandling and, possibly, improve the handling procedures.

- **Informed decision-making and traceability:** Real-time data and analytics empower stakeholders to make informed precise decisions. Enhanced visibility and traceability of cargo movements from origin to destination enable efficient resource allocation and logistical planning. For instance, increased cargo traceability could help cross-border regulatory authorities speed up the customs clearance process by providing quick and reliable risk assessments comparing the declared journey with the executed one.

As shown, all parties involved in the supply chain would benefit from the implementation of the smart container and it has been demonstrated that the correct implementation of IoT technologies can greatly contribute to the improvement and growth of international trade.

Smart containers, equipped with IoT sensors and blockchain-based tracking, naturally complement the objectives of DTLF Regulation 2020/1056, which governs electronic freight transport information (eFTI). By ensuring that the data they generate—such as location, environmental conditions, and cargo status—is accessible in harmonised formats, smart containers support seamless information exchange while complying with regulatory requirements for security and data accessibility. These containers also offer the added advantage of automating authorisation processes and ensuring data integrity through immutable records, which aligns with the regulation's focus on secure, interoperable systems across the European Union.

In the same way, the compatibility of smart container systems with ISO/IEC 19845:2015 ensures that the information they provide can integrate smoothly into globally recognised logistics frameworks. By adhering to the syntax and semantics of the Universal Business Language (UBL), smart containers facilitate consistent electronic communication across supply chain actors. This extends to generating standardised digital documents, such as waybills and consignment notes, which streamline logistics operations and reduce manual intervention.

Together, the regulatory framework and the UBL standard create a cohesive environment where smart containers can thrive, enabling real-time, transparent, and standardised communication while meeting the demands of modern freight transport systems. This dual alignment ensures operational efficiency, regulatory compliance, and enhanced collaboration across global logistics networks.

6.2.4.2 Smart Container Tracking and Tracing (Maritime-Rail-Road)

Definition: Smart technology in container logistics enhances supply chain visibility and efficiency by integrating advanced tracking and tracing capabilities, thus reducing lost shipments, and optimizing resource allocation. They are also known as Intelligent Container Monitoring or Automated Cargo Tracking.

The integration of green concepts into global maritime logistics operations is increasingly essential for enhancing efficiency and environmental performance. Efimova and Saini (2023) advocate for continuous monitoring and tracking of container shipments at ports to reduce carbon emissions and improve environmental sustainability. They propose utilizing near real-time RFID data tracing and tracking through automated monitoring systems, which has shown to significantly reduce fuel consumption and carbon emissions between ports and container freight stations (CFS). Specifically, the study reveals a 6% reduction in emissions from port to CFS and 23% from CFS to ports, highlighting the effectiveness of green logistics practices.

In a related context, Muñuzuri et al. (2016) emphasized the importance of efficient operations in intermodal container terminals, stressing the necessity for integrated information systems to streamline data exchange among stakeholders. Their proposed system aims to centralize information and enhance scalability, incorporating components like geo-positioning systems, automatic guidance systems, and integration of container positioning data with planning capabilities. These systems offer value-added services such as real-time container location viewing, strategic decision-making support, and pre-notice of container arrivals, thus optimizing logistics operations.

Furthermore, Miler (2015) underscored the significance of real-time container tracking systems in ensuring supply chain security and management. Such systems enable immediate reporting of container intrusion or tampering to authorities, thereby reducing the risk of theft, piracy, accidents, and damage. By integrating advanced software and hardware solutions, these tracking systems empower practitioners to monitor global fleets of containers efficiently, reduce costs, and enhance security benefits. The research findings provide actionable insights for carriers, forwarders, logistics, and IT companies, offering opportunities to increase competitiveness and improve container management practices.

At European level, the SMARTCM project (European Commission, 2022) aimed to revolutionize container door-to-door transport by enhancing efficiency, security, market orientation, and competitiveness. Its comprehensive approach involved analysing current processes, devising innovative concepts for processes and technologies, and demonstrating them through world-scale Demonstrators across four supply chain corridors. Leveraging Container Security Device (CSD) technology, the system monitored the status of containers securely closed by authorized personnel at their origin. The journey towards achieving this involved reaching agreements on information sharing and design specifications, followed by rigorous real-world testing across various transport corridors operated by the project partners DHL, K&N, COSCON involved major ports around the globe: Antwerp, Rotterdam, Singapore, Ningbo, Dubai, Nhava Sheva (India). Validation operations to EU ports from China, India, and Thailand underscored the system's robustness, leading to a consensus on minimum standards crucial for global supply chain security. Although the project concluded in 2011, development efforts have persisted, focusing on fostering greater agreement among public authorities and businesses to enhance trade and security within this vital sector.

6.3 Digital Twin solutions to boost rail freight

In recent years, digital twins (DTs) technology has been highlighted as "the one" promising technology that can significantly improve many rail sector operations and contribute significantly to achieving the goal of Rail 4.0 (In-Depth Focus, 2021). The use of DT technology in combination with other disruptive information and communication technologies, in particular artificial intelligence (AI), blockchain technology (BC) and 5G communications (UNIFE, 2020), could also digitalise asset management and enable the planning of infrastructure and rolling stock use and maintenance activities at the right time (ERRAC, 2019). As DTs provide a highly accurate digital copy of the physical asset, process or system (UNIFE, 2020) that can be observed and tested in the real environment under different conditions, independently of its physical (real) twin and without interrupting ongoing processes, DT can also be of great help in planning, designing, building and manufacturing railway assets, monitoring, detecting and predicting infrastructure faults and failures, as well as proper train operation, real-time scheduling and rescheduling. Another major advantage of DT, highlighted by UNIFE (2020) and ERRAC (2019), is that DTs technology covers the whole life cycle of assets and enables the tracking of railway assets from design to recycling phase.

Although DT technology is very popular in many industries, it has only recently been applied in the railway sector (Vieira et al., 2022; Johnson et al., 2021). From the conclusions of some previous studies (Bustos et al., 2021; Spiryagin et al., 2023) DT in the railway sector is mainly focused on infrastructure and traffic management. No DT studies on rail freight transport were found in the literature reviewed. According to Jeschke et al. (2021) and Sahal et al. (2021), the larger number of DTs as proprietary solutions and prototypes are mainly realised in the manufacturing and production industry and thus at an early stage.

Through the literature review the main railway areas or domains can be categorised as infrastructure, including track infrastructure and infrastructure facilities; rolling stock; power supply; telecommunications; ticketing and fare collection; signalling, operation and train control; data and information. Based on this categorization in literature most studies examine the infrastructure aspect of the railway system. Investigation is the fundamental activity in maintenance, which of course was most often highlighted as the phase that will benefit most from a DT. Half of all DTs presented were developed and most of them were validated in a real railway use case. Almost all studies presented the development of an individual DT.

In the last years, from the literature overview can be realized that most DTs are developed in field of investigation, simulation and modelling. The investigation is mainly related to the maintenance of tracks, rails and/or wheels. This DT purpose is related to maintenance, as good maintenance and fault analysis are prerequisites for safe and proper railway operation.

For improvement and optimisation, only one DT was developed, which focuses on movable components such as turnouts (Kampczyk & Dybel, 2021). Simulation and modelling are used as a central part of the development of DT or to investigate the feasibility of DT. In the railway sector, simulation is a common approach to explore new concepts or possibilities. For example, DTs for the rolling stock domain were developed mainly to monitoring states, conditions and damage to vehicles and locomotives and some of their parts. Also, for maintenance and development DT approaches increased over the years. Some portion of studies deal with the integration of different DTs into collaborative DTs, which has only recently become of interest to the research community. The exchange of data and information has been an essential part of railway operations since the early days of the railway and is the most important component of railway operations today. Some of the studies were concerned with the development of DTs for the exchange, storage and management of data. This is particularly important for railways, a well-known transport system with the worst data assets. Collecting and sorting data is crucial for all components to ensure smooth railway operations. Nevertheless, the representation of data sharing through DT would be useful for the purposes, especially between physical and movable rail components and within the physical and movable components themselves (Pool, 2021).

In addition to the studies that looked at DT for specific components or purposes, there are also studies that provide DT initiative for the entire railway system. From the perspective of the whole system, DT is more useful than a separate system as it incorporates data from different sources and also historical data to reflect the real-time state and behaviour of the railway assets. In addition, DT provides synchronisation of the many properties and behaviours of each real object for the whole system.

Each specific DT also has a scope covering the life cycle phase (LC) or stage of the railway asset under consideration. The phases introduced describe for which stage of the rail asset a DT has been developed or in which stage it has the greatest impact or its benefits are greatest. DTs can support all the initial phases of asset development, i.e., planning, design and construction, their main phase, i.e., operation, assist in decision-making regarding upgrades, replacements and capacity expansions, and their decline at the end of their life cycle.

6.4 Smart contracts

As railways around the world embrace digitalization, the need for seamless integration with other modes of transport is becoming increasingly apparent. However, challenges remain, especially in data integration and security across organisational boundaries. In that sense, Distributed Layer Technology (DLT) and smart contracts are emerging as a possible solution, as it offers opportunities to improve security and data integration.

DLT fundamentally redefines how data is stored and shared, offering a decentralized and immutable ledger that promises enhanced transparency and security. In this section, the upcoming innovations related to the application of Blockchain as DLT within the context of freight railway are addressed.

While blockchain offers added security and decentralization, its adoption rate may be moderate, and challenges relating to data privacy and granularity need to be addressed. Thus, the challenges related to these technologies are also highlighted in this section. Nevertheless, if carefully considered and strategically implemented, blockchain can revolutionise freight transport and offer a pathway to a more efficient and interconnected future.

6.4.1 Assessment of innovations related to smart contracts.

Within the innovative ecosystem of Shift2Rail (S2R), smart contracts started to emerge as pivotal tools for transforming digital transport agreements. Empowered by blockchain technology, smart contracts could revolutionize how stakeholders engage, execute, and uphold agreements within the transport sector. Implementing smart contracts in transportation operations promises swift transaction execution, enhanced safety through encryption and tamper-proof features, improved trust by eliminating intermediaries, increased autonomy over agreements, and substantial cost savings by reducing administrative overhead. This integration is a significant step forward in the transport sector and therefore some S2R projects have paid attention to the implementation of this technology in the rail sector.

SMARTRAIL (http://smartrail-project.eu/), a S2R project that took place between 2015 and 2018, addressed the potential of smart contracts to help move towards a system of systems for data exchange in rail freight. Some innovations were made with a demonstration application and the benefits of using smart contracts and DLT in the railway sector were showcased.

- **One final responsible coordinating entity:** This entity oversees the entire service, ensuring alignment of operational activities among rail stakeholders involved in providing the service. This helps streamline operations and improve coordination.
- **Cross-fertilisation with R&I from other sectors:** This involves leveraging research and innovation from other industries to harmonize standards and regulations in the rail sector, promoting a level playing field among different modes of transportation.
- **Dynamic APIs:** Development and provision of dynamic APIs that interact with a Blockchain based environment could facilitate easier system connectivity, enhancing interoperability and avoiding reliance on framework contracts, thus promoting flexibility and responsiveness.
- **Data sharing:** Implementing blockchain infrastructure leads to an increased situational awareness and optimizes data sharing across stakeholders. In fact, it is considered to be a near real-time data sharing process. Once data is uploaded onto the blockchain and incorporated into a block, it becomes immediately accessible to all stakeholders. If all rail freight participants share their event data, it provides a clearer picture of the physical situation, leading to better decision-making by all involved parties.
- **Private transactions options:** Various options for private transactions, such as channelling and tokenizing, is available in certain Blockchain platforms such as Hyperledger Fabric. They provide ways to keep sensitive information secure while allowing relevant stakeholders access to necessary data without revealing it publicly. Furthermore, also a specific method for storing encrypted data using keys could be implemented so only the desired actors are able to decrypt the data published.
- **Storing encrypted data:** Implementing secure exchange of encryption keys ensures only desired actors can decrypt published data, enhancing data security and privacy.
- **Milestone measurement with smart contracts:** By integrating milestone measurement capabilities with smart contracts, the automated verification and execution of predefined actions after reaching specific milestones can be achieved. Smart contracts can autonomously trigger actions such as payment releases or status updates based on the recorded milestones, facilitating logistics and supply chain management processes.

As well as SMARTRAIL, (B4CM)(Blockchain for Conditions Monitoring) is a S2R project that took place between 2018 and 2022. This project aimed to develop a blockchain-based testbed for determining data costs across organizational boundaries. It demonstrates this framework within the European Rail Industry, providing a practical foundation for future developers to expand upon. Thus, many interesting conclusions can be drawn from their results that complement the findings of the SMARTRAIL project:

Hyperledger Platforms (Fabric, Sawtooth, or Iroha) over Ethereum: These Blockchain platforms offer more flexible user roles, which are essential for managing access to sensitive railway data among different stakeholders such as operators, regulators, and maintenance providers. This enhanced privacy and access control are crucial for maintaining the security and integrity of railway operations data. Although private transactions can be implemented on Ethereum by making use of certain tools, it is much simpler with Hyperledger Platforms. In Table 19, a comparison between the platforms can be found.

Table 19 Blockchain platforms comparison

	Ethereum	**Hyperledger (Fabric)**
Open source	Yes	Yes
Description	Generic blockchain platform	Modular blockchain platform
Mode of operation	Permissionless. Public or private	Permissioned. Private.
Governance	Ethereum developers	Linux Foundation
Consensus	POW (Proof Of Work)	Multiple approaches
Smart contracts type	Ethereum smart contract	Chain-code in Fabric
Smart contracts code	Solidity	Go, Java
Currency	-Ether -Tokens via smart contract	-None -Currency and tokens via chain-code

- **Iroha to complement Fabric and Sawtooth:** By providing specific components for IoT integration, Iroha enhances the ability to collect and analyse data from various sensors and monitoring devices used in railway infrastructure. This allows for more comprehensive condition monitoring of tracks, trains, and other critical assets, improving maintenance planning and operational efficiency.
- **Access agreement model and accounting model:** Defined models for access agreements and accounting ensure fair and transparent transactions between railway stakeholders. Different possible malicious behaviour are found and illustration of different methods of revoking an agreement are proposed.
- **IoT-related innovations:** Reviewing the innovations related to the connectivity between devices can be found. Iftekhar et al. (2021) introduced an Attribute-Based Access Control framework that utilized the Hyperledger blockchain to manage reliable access control among IoT devices. In dynamic IoT environments, Putra et al. proposed a blockchain-powered Trust and Reputation System (TRS) for monitoring and controlling IoT access to the chain. This system continually evaluates and quantifies the trust and reputation levels of IoT nodes in a self-adapting and reliable way.
- **Demonstration application:** B4CM developed a Proof of Concept that is available as open source. The project repository containing everything that is necessary for the local blockchain deployment used by the demonstration. Having access to this information is of utmost importance and can serve as a basis for future developments.
- **IoT Integration in the Proof of Concept:** Two use cases were discussed by making use of sensors to monitor axle bearings and track conditions. In the first case, the sensors were statically mounted on the track and in the second one, they were mounter on-board a passenger vehicle to monitor track condition. Data drawn from both systems is used to prove the concept of managing data exchanges on this type through a distributed ledger. The generated data from all sensors is hashed and appended to the blockchain, it is also stored in the database and processed if needed. There are many communication protocols that can be applied by the local bridge to connect devices to the server such as Bluetooth, ZigBee, WiFi, and 2G/3G/4G cellular.
- **Recommendations:** The project team experiences had shown that, although it is possible to migrate frameworks built on top of blockchain platforms between machines, it requires deep knowledge of the blockchain technology. This factor can stop people from experimenting with this technology and, therefore, it was suggested that the design is compatible with commercial blockchain providers, such as the Ethereum Virtual Machine. Thus, the B4CM team recommended that the applications to be developed in the near future should prioritize the use of proper virtual environments so that portability is secured and, therefore, the changes needed in migration across physical platforms are minimised.

This is one of the main reasons why the ESEP4FREIGHT team considers Ethereum to be one of the most suitable blockchain platforms available for the purpose of this project.

IN2DREAMS is another S2R project that took place between 2017 and 2019 and provided valuable innovations in the topic of smart contracts implementation for asset management (Europe's Rail, 2024e). More specifically, they employed smart contracts to manage the maintenance jobs workflow so that the rules and clauses of the maintenance contracts between the Infrastructure Manager and the Contractor could be automatically enforced. The interactions between the actors present in the processes related to asset maintenance were defined and, once the activities diagram workflow was created, the blockchain architecture was established. This work is believed to be relevant and innovative and it could be used as a basis for the architectural development of relevant proof of concepts.

Along with the set of upcoming technologies presented in this section, there is a need for developing new and dynamic data exchange standards for key documents accompanying goods in various modes of transport that could facilitate the implementation of new technologies. For that purpose, the UN/CEFACT Multi-Modal Transport Reference Data Model (MMT RDM) (UNECE, n.d.) was proposed by the United Nations Economic Commission for Europe (UNECE) as the basis for the definition of the necessary data so that the problem of fragmentation of digitalization efforts is solved. This reference data model relies on the UN/CEFACT Core Component Library (CCL)(UN/CEFACT, 2024) and it brings together the data exchange needs of international multimodal transport operations, including trade, insurance, customs, and other regulatory documentation requirements. This integration is based on trade facilitation and e-business best practices, ensuring practical alignment with industry standards. For instance, smart containers data elements and message structures proposed by UNECE are based on this RDM and it helps converting data from different key documents accompanying goods. For instance, the EU's eFTI (Electronic Freight Transport Information) Regulation uses MMT RDM for interoperability, which carried about the move from document exchange to data sharing. Furthermore, all commonly used railway documents and data elements fit these standards and the diagram below (Figure 23) illustrates how a transport instruction (IFTMIN) from any of these documents, adhering to the UN/EDIFACT standard, can be processed.

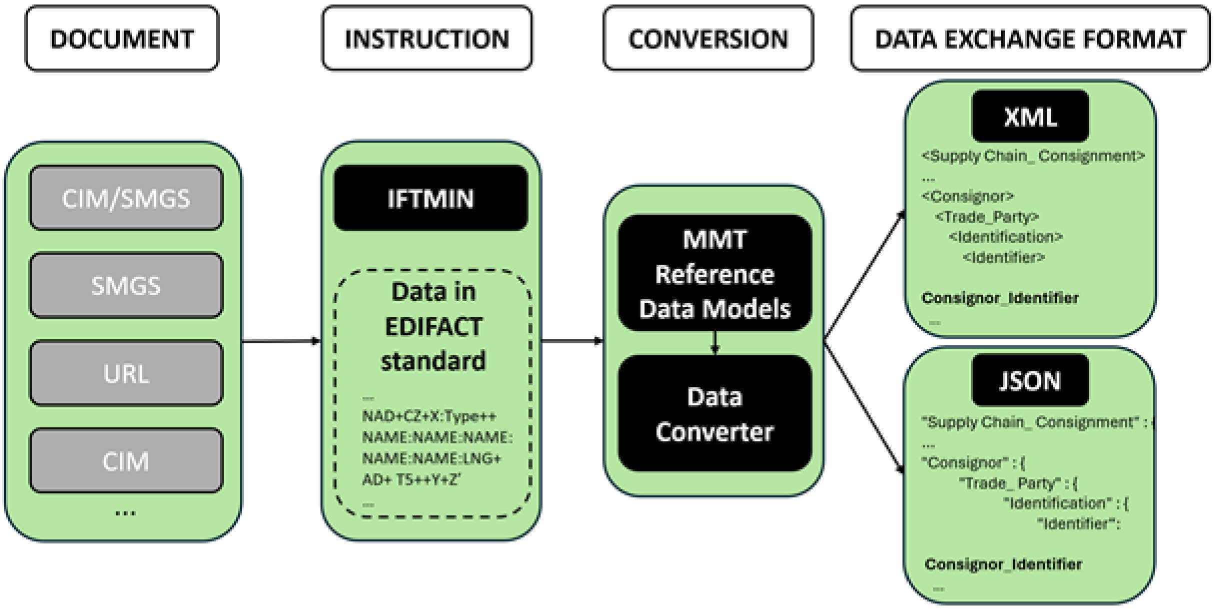

Figure 23. Reference data model use case example Source: Adapted from UNECE.

It must be pointed out that the UN/CEFACT's Core Component Library (CCL) in which the MMT RDM is integrated is extensible and can evolve to meet the needs of the particular sector. For instance, numerous data elements related to sensors were added to count up for possible IoT implementations such as smart containers. By making use of this extensible framework, the rail sector can effectively integrate smart contract technology, ensuring compatibility with IoT devices and facilitating the seamless execution of automated processes within the industry.

There are some existing solutions regarding Smart Contracts and digital documentation handling which will be addressed in this project deliverable D2.1. related to the definition of the Smart contract´s architecture definition.

6.4.2 Challenges of smart contracts

Based on the preceding information, it is evident that smart contracts represent a significant advancement in digital transport agreements and their implementation could greatly benefit the rail sector by facilitating a transition in freight transport from road to rail. However, the adoption rate of this technology is limited by its associated challenges. These range from privacy concerns to legal complexities and scalability limitations, and understanding and mitigating these challenges is crucial for harnessing the full potential of smart contract technology. Therefore, it is of utmost importance to understand these challenges to be able to propose innovative and valuable solutions.

- **Protecting privacy and ensuring granularity:** Smart contracts are powerful for protecting data quality and there are many conceivable use cases for smart contracts in the rail sector, but they are not suitable for protecting privacy. For instance, an infrastructure manager may deploy a smart contract to allocate train paths automatically after receiving the required documentation from the railway undertaking entities. This action helps to improve trust between actors but does not satisfy the granularity requirement. The level of detail in the information given should vary based on roles, but public Blockchain platforms like Ethereum display information uniformly to all nodes, hindering granularity. Nevertheless, various options for private transactions exist as discussed in the previous section.
- **Legal challenges and confrontation against legal contracts:** Smart contracts are neither a replacement of legal contracts nor a way to enforce them; they are just self-executing instructions which legal assessment vary significantly depending on the function they are expecting to fulfil. Participants in a smart contract system must give valid consent to its operation and, therefore, relevant questions about the legal implications of such consent are raised. It can be disputed whether it constitutes a legally enforceable agreement and what its subject-matter is. Additionally, smart contracts are not yet regulated in many countries and their inherent immutability may complicate their adaption to changes in law or new agreements. Nevertheless, smart contracts could be useful to automate parts of the performance of the contract by the parties. This may include encouraging the debtor to comply or imposing a sanction on a non-compliant party.

- **Reliance on oracles**: Blockchain oracles are entities that connect blockchains to external systems, thereby enabling smart contracts to execute based on inputs and outputs from the real world (Al-Breiki et al., 2020). Smart contracts are excellent at securing the immutability of the stored and published data and in case of a node getting hacked, it will not be possible to change the information in the blockchain. However, the hacked node may take part in the creation of the external data sources that smart contracts rely on to see that some of the criteria of a contract are met (oracles) and therefore, hackers could log false information that will become immutable in the blockchain. In this sense, policies will have to be created to account for erroneous data.

- **Portability of the solution**: To migrate frameworks built on top of Blockchain, considerable knowledge in the working of this technology is required and, therefore, commercial blockchain providers such as the Ethereum Virtual Machine are recommended to facilitate the shift from traditional methods.

- **Impact and scalability challenges**: Blockchain platforms are not yet suitable for processing large amounts of transactions. For instance, Visa can handle around 24,000 transactions per second while Ethereum can handle only 14 transactions a second (Khan et al., 2021). The scalability problem arises primarily due to consensus mechanisms that require every participant to validate and store all transactions. This issue becomes more pronounced as the number of nodes and transactions increases. While this approach ensures decentralization and security, it results in limited transaction throughput.

6.4.3 Digital transport agreements

In relation with digital document handling, there has been some industry solutions that tackle the same or similar technological requirements for document handling.

The main objective for these kinds of solutions is usually to supress all physical documents to be shared when making a goods transportation among different companies.

For this, several harmonized solutions have been used during past years depending on the mode of transport which had their own harmonization. For example, the use of CMR in road transport is widely spread as well as the use of a CIM document for the railway freight products.

Traditionally, this set of harmonized documents are physical documents to be exchanged between giver and receiver of the cargo to transport. The digital transport agreements developed have aimed to eliminate this physical part. One of the main technological solutions for this is the use of a so-called e-CMR.

This solution pretends to substitute the CMR document exchange by having a digital platform which exchange these set of documents electronically, without making the driver or anyone on the transport supply chain exchange any document and just having the same information by acknowledging events on the digital platform.

The main issue with these kinds of solutions is the ownership of the developed platform. Nowadays, being an industry development without any public organism making any kind of standardization on these forces the companies to subscribe to the individual solution made by the digital platform developer.

This means that, to be able to use the solution, dispatcher and receiver must be signed or subscribed to the same digital platform provider.

The intention from the regulatory side is to adapt or establish basic requirements for these digital platforms to have a common ground for the operation amongst them.

In order to harmonize these digital solutions, in parallel to private companies developed document handling solutions, there have been some European and international directives to set up a common basis for commerce and transportation.

The Universal Business Language ISO/EIC 19845:2015 sets out a common language as well as schemes of procedures to define commercial interactions amongst parties. It sets out, on a xml format, business documents that can be restricted or extended to meet the requirements of particular industries. This helps to set a harmonized framework on business procedures and documents that could optimize these kind of procedures if embraced by the industry.

The DTLF REGULATION 2020/1056 sets a legal framework for the electronic communication of regulatory information between economic operators and competent authorities. This establishes the requirements for the eFTI (electronic freight transport information) which enables to hold of the issued documents in electronic format.

On deliverable 2.1 of this project, we will go through a market exploration on existing digital transport solutions to observe the market trends and the already accessible solutions offered by different companies.

There are also some developments worth highlighting that, even though these solutions don´t fulfil every requirement on multi modal transportation they can be used in some of its features. This, as an example, could be the case of PEPOOL, a developed network for invoicing which sets a harmonized framework amongst different companies.
From their webpage peepol.com we can extract the following information:
First and foremost, PEPPOL is a way to send invoices to customers in the public sector. It is an extremely secure, international network that allows companies to exchange business-critical electronic documents with everyone who has registered as a part of the PEPPOL network.

PEPPOL was developed as an EU standard. As a result, most businesses in the network are based in Europe. However, operators in countries all over the world have already adopted the standard as well – including companies in Canada, New Zealand, Singapore and the United States, to name but a few.It means that the EU has laid down a set of specifications that an invoice, for example, must fulfil in order to be sent via the PEPPOL network. All public authorities in the EU have undertaken to be able to receive your electronic invoices as long as they comply with the stated specifications.

6.4.4 Quantification of improvements related to smart contracts and digital transport solutions

Given the status of this upcoming innovation, given that is a recent innovation, there is not much information shared for the quantification of the improvements. Apart from that, this innovation, stated for document management in which includes information regarding sensitive data of the companies such as prices, contract clauses etc is not easily shared by the industry, making more difficult its quantification. This is also predictable given that precisely one of the enhancements of the innovation would be privacy in these kinds of information exchange which is one of the most desired upgrades for document management.

Given this, with the support of the activities developed for dissemination and data gathering, some surveys have been spread out to the Stakeholders Group, as well as the dedicated webinar on document management held by consortium partner UIRR on February 20th, 2024.

In this first survey, the project wanted to find out the willingness of the industry to use these kinds of innovations.

On the said webinar, some already existing solutions were addressed and at the end of the webinar, a small survey was conducted to gather the information.

Figure 24. Document management webinar´s survey

One of the first questions was to evaluate what kind of company, in the multimodal freight traffic environment was giving the answers, given that it is much related the kind of company with the innovation they are interested in, as the project could verify on the stakeholder meeting in Verona.

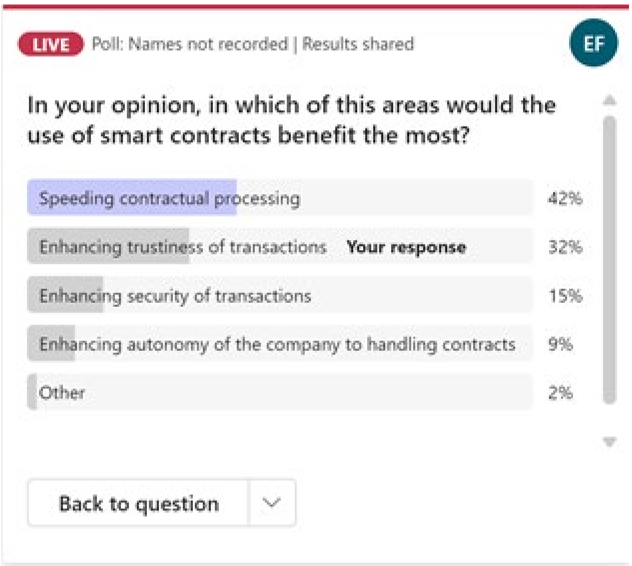

Figure 25. Benefits of smart contracts´ answer

As we can observe in the Figure 25, the main upgrade for this innovation is considered by the webinar attendees to be the speeding processing of contractual arrangements, based on a harmonized contractual framework, some of the typical clauses for the industry can be harmonized, as intended in task 2.1 ESEP4Freight.

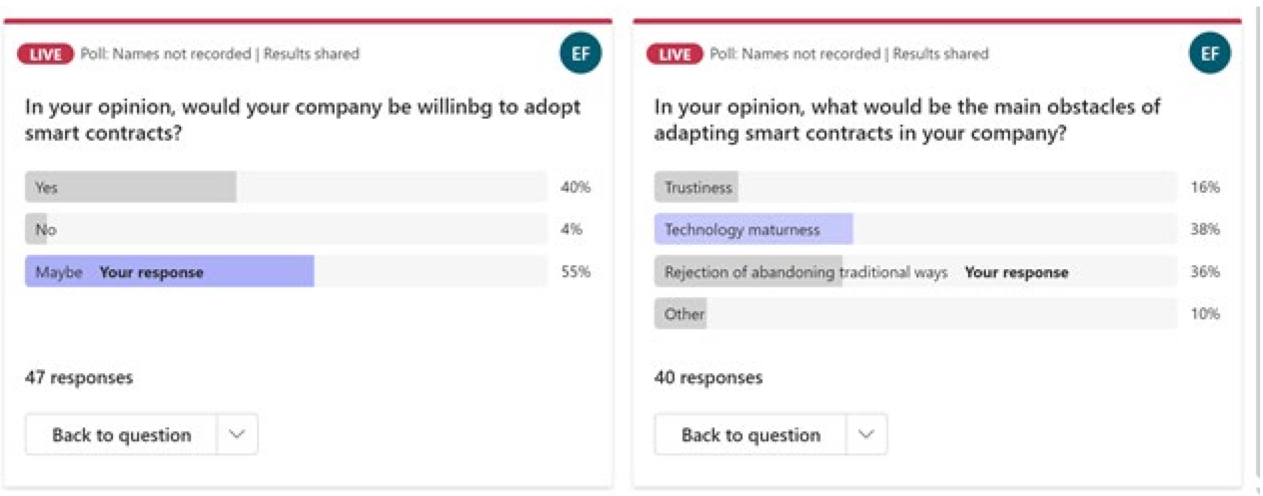

Figure 26. Adoption of smart contract solutions willingness

The main information extracted for the industry´s response to this upcoming innovation can be observed in the Figure 26.

As it can be observed, nowadays, the willingness of embracing this innovation would be less than half of the responses collected from the webinar attendees. For them, the main rejection would be, as it can be seen, the low technology matureness but, really close to another important drawback when an innovation is brought up to the market, the rejection of abandoning traditional ways or as it can be translated, the fear of implanting new working ways within a company, not knowing or not seeing clear either the benefits of the innovation or the easiness of adoption within the organization.

Besides this short survey launched on document managing webinar, the consortium organised another survey to try to quantify the upcoming innovation on document handling. The used platform was Google forms, which gave a possibility of gathering anonymous answers given the fact that some critical information was asked to the public.

The survey was spread mainly for the Stakeholder Group, as well as to the attendees of the mentioned webinar. Amongst these actors there are different profiles as logistics service providers, shippers, port authorities, rail freight traffic, digital document handling providers, clients and other profiles related to multi modal transport operation.As well as the anonymous feature, the results of the survey form can be exported to an Excel file. This way we can relate the answers to a specific user, even though we don´t know who is answering, it is very interesting to know the different responses answered by the same user.

With all the answers given (see Appendix 1) we can have the following conclusions:

From the answers given in question *Approximately, what is your company´s average volume of T.E.U. managing per year?*

With this first question the consortium tries to identify the volume and size of the company that is answering the question. This way, we can relate the expenses asked in further questions to the companies´ volume.

From the answers given in question *Can you give an approximate value of the maximum percentage cost per operation due to delays in contract arrangement?*

It can be observed that, with the volume of answers managed, there is no obvious relation between the size of the company and the delay clause fee the companies usually arrange.

From the answers given in question *On average, how many days does it take your organization to complete the entire contract lifecycle, from initiation to final approval?*

As it can be observed by the answers provided, most of the companies, mindless on their nature in the multimodal transport operation, spend around a week from initial contacts with client/provider to final arrangement of the contract.

From the answers given in question *Have there been investments made by your organization in ensuring data integrity for contract-related transactions? If yes, please provide an approximate annual expenditure.*

As it can be observed, regardless of the company size, the investment on data integrity is less than

200k€ for each company. If we observe as well the volume of T.E.U.s managed, we can conclude it is not a major investment for the companies.

From the answers given in question *How much, in percentage of a contract, does your organization typically spend on resolving contract disputes?*

Given the answers gathered for this question, it can be concluded that for most companies, the cost of resolving contract disputes is up to 2% of the contract value.

From the answers given in question "*What is the average annual expenditure on legal and compliance-related aspects of contracts in your organization?"*

In this question, as seen in others, most of the answers given reflect a cost of less than 100k€ for legal and compliance aspects regardless of the company size or nature.

From the answers given in question *How much in percentage of contract value, is the delay on accomplishment clause arranged with the clients?*

Also, for this question, the answers are almost inline for every answer varying from a 1% to a 2% of contract cost defined in delay clause.

From the answers given in question *In the past year, approximately, how much has your organization spent on traditional security measures for contract processes in your organization?*

Again, we find an almost unanimous answer for security measures on contract processes, less than 100k€.

From the answers given in question *How much does your organization spend annually on monitoring and ensuring compliance with contract terms and regulations?*

Again, for this aspect of contract compliance, companies usually spend less than 100k€ on monitoring and ensuring compliance with the contract terms and regulations.

From the answers given in question *What is the percentage of the contract cost related to monitoring and ensure compliance?*

The previous question relates to this one so we can find a relation in between the cost per contract related to monitoring and compliance. Companies that answered around 1% on contract related costs declared an annual expenditure of less than 100k€ for this aspect. The company that answered a greater value for annual expenditure also has a greater cost percentage per contract to address this compliance.

From the answers given in question *Can you provide an estimate of the fees paid to intermediaries or third parties involved in your organization's contract processes?*

In this answer, we can observe a great difference within one of the companies that answered the survey. If we observe the nature of the company, which is a multimodal transport organizer, we can conclude that the costs related to the shipping and travel costs may be included due to subcontracting processes. For the rest there are two transport nodes and a customer answer. The comparison between the two transport nodes can be made in terms of volume, it seems that the user spending greater amount on this regard is due to subcontracting given it size, while the other transport node seems to have allocated own resources for these tasks, which makes their cost lower.

From the answers given in question *Are there costs associated with training staff on contract-related processes and compliance? If yes, please provide an estimate of the annual expenditure*

As we can observe, these aspects for contract related processes and compliance are not very much addressed in terms of formation of employees. All the answers give a low expenditure in this regard which could also mean that they hire people with that expertise and do not bother on formation.

From the answers given in question *Can you provide an approximate annual expenditure on personnel involved in contract management within your organization?*

Again, the costs reflected on this answer does not seem to be one of the main expenditures in the companies. Though is probably a mandatory cost to have personnel dedicated to contract management, the expenditure reflected by the companies would give the impression of having two or three people annual salary dedicated to this task.

From the answers given in question *Approximately, how much percentage of the income of your organization is expended on personnel for contract management?*

In relation with previous answers, it can be observed how the companies that declared a higher cost declare as well to have a greater percentage of the income related to this aspect.

From the answers given in question *Can you give an approximation on what are the annual costs related to paper-based record-keeping for contracts in your organization, including storage and retrieval expenses?*

As it can be observed here, the cost related to record-keeping is less than 100k€ for almost every company that answered the survey.

From the answers given in question *Approximately, what is the estimated financial impact related to the income of contract delays on your organization?*

Here it can be seen how, the related impact for the income due to contact delays is around 1-2% of the income of the company.

From all these answers, it can be estimated that, at least, a 5% cost of the contract could be reduced using new technologies that could provide an easy and secure way of document management.

Though these costs are not to be overlooked, it may be not enough motivation for the companies to switch to a new way of managing documents, given also the answer on the webinar´s survey which reflected that almost 40% of the fear of switching to these new technologies would be abandoning traditional procedures.

Given this, we must also address the time saved per operation. In the transport domain, time is one of the most critical variables to handle since it is directly related to contract costs as we observed on the costs per delay clause as an example. This time-saving could finally boost the new technology embracing if it gives an impact, given that a time saved per operation could be multiplied by the number of operations giving a no noteworthy amount of time that will directly be related to companies´ costs.

In the following, we can observe a real case study in which it is addressed the cost and time saving using one of the market solutions for these kinds of document-handling technologies.

As it was stated before, the recent development of these kind of solutions leads to have little proof of the benefits forecasted. One use-case was developed in Spain for the client Freixenet. S.A. This use-case, which was eased to the consortium by the company CIMALSA, we can observe conclusions within the time and cost related savings. We can observe the report table on Appendix 4. In this use-case they gathered the data for a multi-modal trip between Spain and Germany and forecasted this data to an expected generation of documents of 10.000.

The cost comparison includes the cost of the company´s smart contract/e-CMR service provision which would not be taken on account if this development for a common platform was held by public entities.

One of the most important conclusions for the innovation this new technology handling would be the time difference between manual handling and e-doc, besides the cost savings on printing, this 38,5% saving on time for the generation of documents would have a great impact if it was a general benefit.

The use-case presentation and conclusions were presented in a report on pilot test usage of e-CMR by Freixenet S.A., supported by WIDOIT/Pionira, Multimodal transport road/rail/road Spain to Germany (Amigó, Lluc, 2021). This report was as well-handled to the project consortium by CIMALSA to use the data for the project´s activities.

6.5 Artificial Intelligence (AI)

According to Russell and Norvig (2021, pp. 1–4), Artificial Intelligence (AI) is a branch of computer science focused on creating and investigating techniques and software that allow machines to understand their surroundings and utilize learning and intelligence to perform actions that enhance their likelihood of reaching specified objectives. Machines matching the previous definition are typically called AIs.

Following the same trend as in other sectors, AI, frequently based on the use of machine learning, is being used or planned to be used in a growing number of applications in the rail system. The most comprehensive work on AI in the rail sector has been carried out in the framework of the Shift2Rail project RAILS (AI integration in the rail sector "Roadmaps for AI Integration in the Rail Sector) (2024). According to a review on AI in rail sector carried out during the project (Tang et al., 2022), from the seven fields analysed, rail maintenance and inspection was the field where AI had a greater relevance in the analysed period (2010 to 2020). The second field with the second highest number of works was traffic planning and management. Safety and security, autonomous driving, and control and passenger mobility had a reduced number of publications dedicated to the topic and no research was found for the fields of revenue management, and transport policy.

After searching through technical magazines, several industrial applications of AI in the railway sector as a whole have been identified. For the search carried out for this section, the following applications have been found. AI is being used for the generation of inventory of track elements such as signal and switches with the help of image recognition AI algorithms (Bartsch et al., 2022), the development of tools to optimize traffic management system in real time (Biembacher et al., 2023) and energy consumption (Hemzal et al., 2021), the development of innovative passenger information systems (Bahn Manager, 2022), for predictive maintenance (Hemzal et al., 2021), and for track inspection (Winkler, 2023).

It is also expected that AI contributes in the future to key research topics such as the implementation of moving block operation (Biembacher et al., 2023) and the full automation of the train operation (Fiack et al., 2024).

After the general overview of AI in the rail sector, next we look at the applications of AI in the rail freight sector in particular. To do so we have analysed the available scientific publications on the topic and, to map the practical implementation of AI, a selection of technical magazines has been analysed. This search has been complemented with the main outputs of the RAILS project and with a search in the CORDIS database to identify relevant European research projects.

The selection of relevant publications has been carried out by consulting two databases:

- Web of Science: this database has been used to identify relevant topics in the scientific literature. The search string "artificial intelligence" AND "rail freight" has been used to filter publications. Due to the reduced number of publications found, the previous search has been complemented with the results from the search string "machine learning" AND "rail freight", "artificial intelligence" AND "freight train" and with the publications from RAILS project review.

- Eurailpress database: this database belongs to the most important German-speaking publishing house specializing in technical magazines for railways. It has been used to identify applications of AI in the rail freight industry between 2020 and 2024. The search string "künstliche Intelligenz" (Artificial intelligence) AND "Güterverkehr" (freight transport) has been used to filter publications.
- CORDIS database: a search of the strings "artificial intelligence" AND "rail freight transport" did not yield any result. Additional search with the strings "artificial intelligence" AND "rail transport" has been carried out.

The search in Web of Science using the search string "artificial intelligence" AND "rail freight" only yielded 10 articles. From these, 6 were considered relevant. The complementary search using "machine learning" instead of "AI" yielded 4 additional relevant results. In addition, the search using "artificial intelligence" AND "freight train" yielded 5 relevant results The list has been complemented with the 5 works identified in the review by Tang et al. (2022) carried out during the RAILS project. The publications can be clustered in the following five fields:

- Optimisation:
  - Timetable rescheduling after traffic disruption (Wang et al., 2024)
  - Conductors assignation to freight transport orders (Brezulianu et al., 2023)
  - Energy efficiency and operational safety of freight trains (Hu et al., 2022)
  - Optimal position of freight wagons in a train (Hirashima, 2010)
- Forecast:
  - Forecast of rail freight transport (Mrówczyńska et al., 2017; Scarişoreanu & Ghiculescu, 2023a, 2023b)
  - Forecasting of customer abandonment (Zhao et al., 2023)
  - Forecasting expected time of arrival (ETA) (Barbour et al., 2018; Prokhorchenko et al., 2019)
  - Modelling of freight train derailment (Lotfi et al., 2023)
- Image recognition:
  - Monitoring of emissions of polluting particles of coal trains (Ostro et al., 2023)
  - Damage assessment of railway wagons (Hütten et al., 2022; Liu et al., 2016a, 2016b)
- Simulation- based machine learning:
  - Traffic management (Bretas, Mendes, Chalup, et al., 2023; Bretas, Mendes, Jackson, et al., 2023)
  - Impact of vulnerabilities of the network (Johnson et al., 2022)
  - Post processing of acoustic emission data (Carboni & Crivelli, 2020)
- Cybersecurity
  - Application of AI for cyberprotection of IoT (Hatzivasilis et al., 2021)

The search in Eurailpress database yielded 35 articles published since 2020. This date has been selected as Tang et al. review on AI application on rail (2022) includes publications up to 2020. From these articles, 5 have been considered specifically relevant for the rail freight transportation. Other articles from this search of interest for the sector as a whole have been used in the previous paragraph dedicated to the industrial applications of AI in the rail sector.

The main current and expected future industrial applications of AI in the rail freight sector have been summarised below:

- Optimization:
  - Optimisation of freight wagon disposition (Stahlhut, 2022)
- Forecasting:
  - ETA forecasting and transportation time forecast (Stahlhut, 2022)
- Image recognition:
  - Track monitoring and obstacle detection for Grade of Automation 3 and 4 (GoA3 and GoA4) (Suwalsky & Wünsche, 2021)
  - Image recognition for shunting operations (Wilder, 2023). More information can be found on the manufacturer's web site (RailVision, 2024).
  - Damage assessment of freight wagon (Rees, 2023). More information can be found on the manufacturer's web site (Vossloh RailWatch, 2024).

Despite there is currently yet no AI application in brake tests in freight trains, AI is also expected to contribute in the future to this field (Pfaff, 2020).

The search in CORDIS has yielded no results of projects specifically focussed on AI on rail freight transport. The string "artificial intelligence" AND "rail transport" has yielded 8 projects. The European research projects that can be relevant for rail freight transport[1] are mainly related to asset management. This includes the Horizon Europe project "Development of prescriptive AnalYtics baseD on aRtificial intElligence for iAMS" (DAYDREAMS) and the Europe's Rail JU projects "Holistic and Integrated Asset Management for Europe's RAIL System" (IAM4RAIL). IAM4RAIL also covers topics of application of AI on energy consumption and optimisation of traffic management. In addition to these two projects, the Horizon 2020 project "Data-based analysis for SAFETY and security protection FOR detection, prevention, mitigation and response in trans-modal metro and RAILway networkS" (SAFETY4RAILS) focussed on AI applications on safety and security of the rail network and rail operations.This section has offered an overview of the fields of application of AI in the rail sector in general and in the rail freight sector in particular. However, as highlighted by Tang et al. (2022) in his review, AI is a broad field with numerous sub-domains of applications and it is not possible in this document to assess all the subdomains in depth.

6.5.1 Challenges

Challenges and problems relate to the usage of AI in rail freight transportation are similar to those faced by usage of AI in rail transport in general. The main challenges in the implementation of AI in the railway sector have been summarise below.

Firstly, training AI systems requires vast amounts of data and advanced IT infrastructure, including platforms with multiple petabytes of storage and high-performance computing resources (Biembacher et al., 2023). The complexity of the railway environment, with its diverse conditions,

[1] Shift2Rail RAIL project also appeared in the search but it has not been included as it has previously analysed.

requires extensive data collection. Data collection and generation is expected to increase with the spread of digital twins to simulate scenarios that cannot be captured through real-world data alone. This should facilitate that the AI can handle a wide range of situations, from commons to rare events, across different weather, time, and location variables (Fiack et al., 2024).

Secondly, the deployment of AI in safety-critical areas of railways will face difficulties due to the lack of established procedures for demonstrating the functional safety of AI components. AI systems operate on statistical principles and lack the binary decision-making clarity of traditional software, which will lead to challenges in specifying their expected behaviour and creating comprehensive test specifications. Furthermore, AI's decision-making processes are often not transparent, making it difficult to trace and interpret the reasoning behind its actions, especially in regulated environments where explainability is crucial (Hemzal et al., 2021).

Moreover, the risk of attacks on AI systems presents a significant security concern. Machine learning models can be manipulated with subtle, undetectable inputs that lead to incorrect outputs, posing a threat to critical functions such as obstacle detection in autonomous trains. This vulnerability requires robust protection and traceability measures during both the training and operational phases to prevent malicious exploitation and ensure the reliability of AI-driven systems in railways (Heinrich et al., 2022).

Finally, the broader adoption of AI in railways is hindered by challenges related to data availability, quality, and standardization. Legacy IT systems, disconnected assets, and manual processes make the collection of relevant data needed for AI applications difficult. Regulatory considerations, such as data privacy laws and evolving AI regulations, add another layer of complexity. Additionally, the lack of industry-wide data standards and concerns over skills loss due to automation will complicate the integration of AI. Addressing these issues requires coordinated efforts in data governance, regulatory compliance, and workforce training to fully realize the benefits of AI in the railway sector (Gesualdi, 2024).

6.5.2 Conclusions

Following the general trends toward an expansion of AI applications, it is expected that AI usage also become increasingly popular in rail freight transportation in the next years. The overview of AI scientific publications and applications from this chapter provides a few hints of the rail domains with higher potential for an expansion of AI on the short term.

In comparison of the number of existing applications of AI in the rail sector as a whole, the number of specific applications for the rail freight transport is still relatively reduced. Image recognition techniques is a key enabler for many innovations in rail freight such as automated shunting. Another very relevant aspect, such as the cost reduction by optimising wagon inspection is also being improved with the help of image recognition techniques such as IVG explained in detail in section 6.2.2. It is also expected that AI play a central role in the vision of the future rail freight system, as for example for fully automated freight trains at grade of automation 4 (GoA4). A critical topic in freight, such as increasing the reliability and punctuality of services with AI-based ETA forecasting techniques is already being implemented by logistics operators. Machine learning is being used in optimisation and operations research contributing to a better utilisation of operative resources and has a great potential in supporting the staff in critical decisions of the traffic management and in many forecasting activities. Finally, the application of AI to combat threats related to cybersecurity in IoT devices is a promising topic.

It is important to highlight, that despite we have focused on this section on explicit applications of AI in the rail freight sector, many of the uses of AI on the rail sector in general, such as optimising the inspection of the infrastructure or rail traffic, will also contribute to improve the rail freight transport.

However, the widespread implementation of AI in rail freight transport must first to overcome challenges associated to the needed infrastructure for data processing, cybersecurity threads and legal and sociotechnical issues linked to the existing problems on the transparency and traceability of AI outputs.

6.6 Multimodal freight transport technologies focus within the rail mode

6.6.1 Cargo Load Optimization (Road-Rail)

Definition: Cargo Load Optimization (CLO) are models targeting the minimization of handling time, container reshuffling, and energy consumption, enhancing sustainability and efficiency in freight transport. In the literature are also known as: *Cargo Loading Process Optimization (CLPO), Freight Load Efficiency (FLE), Full Truck Load (FTL); or Container Transfer Systems (CTS).*

To reduce carbon emissions from inland freight, one way is to encourage rail transportation instead of truck transportation. Some studies discussed highlight various strategies for reducing carbon emissions in inland freight transportation, primarily focusing on shifting from truck to rail transportation.

Wang and Zhu (2019) emphasized the importance of optimizing loading sequences in rail–truck intermodal terminals to minimize energy consumption. Optimizing the loading sequence to reduce energy consumption from empty crane movements and rearranging crane movements was the key to improving the energy efficiency of outbound container loading in rail–truck intermodal terminals. Using data from a particular rail-truck intermodal terminal in China, computational tests were conducted to offer an optimization model that minimizes both the overall handling time and the durations required for rearranging containers during container loading jobs. The loading procedure can be optimized to considerably minimize handling times, reshuffle times, and energy consumption. It also performs well for varying sizes.

Li and Zhang (2020) proposed an integrated optimization approach involving pricing, volume management, and policy adjustments to enhance the competitiveness of railway freight services, leading to substantial modal shifts and carbon emission reductions. A real case study based on a nine-node rail service network in China shows that the proposed approach can achieve a modal shift of 39.27 % from road-to-rail and 37.09 % reduction in CO_2 emissions.

Additionally, Chen et al. (2022) addressed the optimization of container transfer station selection and train timetables, decreasing the number of road-rail transfer stations, transport costs, and transport delay penalty costs and increasing the average utilization ratio of the rail capacity. Using as case studies for the model's application The China-Europe transcontinental railway network and China's high-speed railway network. The outcomes demonstrate that, with a rail capacity utilization rate of above 79.57%, the integrated optimization approach produces train schedules that can concurrently lower the transportation expenses and the transportation delay penalty costs. Resulting in reduced transportation costs and increased rail capacity utilization. These findings collectively underscore the significance of multifaceted strategies in achieving sustainable freight transportation and mitigating environmental impacts.

This technology has also been analysed and tested of some European initiatives. For instance, the NEXTRUST project seek to improve sustainability and logistics efficiency by creating reliable, interconnected networks of collaboration across the whole supply chain. These networks, which are set up both vertically and horizontally, combine intermodal operators, logistics service providers (LSPs), and shippers as equal partners. NEXTRUST concentrated on combining freight quantities and moving them from road transportation to multimodal rail and waterway networks in order to attain high sustainability standards. The NEXTRUST intermodal demonstrator convert FTL road shipper flows to intermodal rail service through trusted collaboration, matching up supply and demand. In the analysis of results, the FTL resulted in a reduction of around 30% to 60% on GHG emissions, depending on the overall travel time and distance.

Another European initiative was the Horizon 2020 project: Safe-Green Logistics (SAFEGL, https://safegl.eu/) in which they create their own multimodal transportation system through patents and establishing their own intermodal freight technology. SAFEGL brings a high level of autonomy to intermodal operations, where the driver is capable to exchange containers between train and truck – enabling a dramatic reduction of intermodal operation times from many hours (up to 8h) with today' technologies to less than 20 min for a complete trainset using SAFEGL. This system offers a competitive substitute for traditional single-carrier freight by completely integrating and implementing the Container Transfer System (CTS). It only requires the same base level to exchange containers between trucks and trains horizontally, avoiding the use of container cranes. According to SAFEGL project, this technology could cut CO_2 emissions by more than 60%, based on a multi-modal freight model with electric powered trucks for first mile and last-mile distribution, by reducing truck routes to a maximum of 100 km per run day (50 km per trip). This would boost further the societal and environmental gains – enabling zero-emissions freight transports.

6.6.2 Single Logistics Windows (Maritime-Rail-Road)

Definition: The Single Logistics Windows is a centralized data management system designed to streamline logistics operations by consolidating information and processes, reducing administrative work, and enhancing operational transparency.

Port congestion frequently occurs due to inefficient procedures. Achieving faster and more efficient customs clearance depends on improving trade facilitation (UNCTAD, 2022). Thus, the implementation of a Single Logistics Window system becomes imperative. This system embodies a trade facilitation concept wherein diverse governmental agencies engaged in trade and logistics processes collaborate, consolidating their procedures within a unified electronic platform. This platform allows traders to submit all necessary information and documents related to import, export, and transit processes just once, rather than separately to each relevant agency. It aims to simplify and expedite the clearance process, reduce duplication of efforts, and enhance transparency and efficiency in international trade, demonstrating reductions in cargo waiting times, and thus emissions, as in the case of Ghana and Netherlands (OECD, n.d.).

Efforts to streamline international trade processes have seen significant advancements through initiatives like the Single Window system. While some nations have fully embraced this system, others employ it alongside traditional paper-based methods (Tijan et al., 2019). Recognizing the importance of cohesive collaboration, multilateral interoperability projects are underway to foster cooperation among national Single Window systems at a regional level. This endeavour is particularly crucial for the maritime transport sector, a linchpin of global trade. Despite strides made, achieving universal standardization remains an ongoing challenge, even in advanced economies like Singapore and Japan. Nevertheless, surmounting these obstacles promises benefits such as reduced costs and heightened efficiency for all stakeholders involved in international trade.

In parallel, alternative research focuses on implementing National Single Window (NSW) systems to streamline information exchange across diverse transport modes and Port Community Management applications. Niculescu and Minea (2016) advocate for integrating existing telematic applications like SafeSeaNet and River Information Services into NSW frameworks, navigating the complexities of European and national regulations in the process. Their proposal introduces a concept for a National Single Window Integrated Platform, designed to support multimodal transport seamlessly. However, the complexity of such an endeavour necessitates robust political will, meticulous planning, adequate funding, and support from entities like the EU.

6.7 Industry vision on upcoming innovations

For the sake of having feedback from the industry, ESEP4Freight organized a presently meeting held in Verona on February 27th, 2024.

The stakeholder meeting held in Verona on 27 February 2024 brought together a diverse group of participants representing various organizations within the freight and logistics sectors. Present at the meeting were Jaime Adrover from GPA, Serge Schamschula from Transporeon, Nuria Lacaci from ACE (Asociación de Cargadores de España), Niklas Andersson from Jernhusen, and Julian Madsen from GATX Rail. Also in attendance were Steffen Nestler from DGG, Alicia Casart from the General Council of Chambers of Commerce of Catalonia, Torben Weck from P&G, and Rosa Prenafeta from Allways. Joining them were Aldo Croci from Hupac, Matteo Boschian from the Centre for Innovation in Transport (CENIT), Noelia Martin from the Port of Barcelona, Josep Carles Terés from Ferrocarrils de la Generalitat, Simó Batlle from CIMALSA, and Massimo Arnese from CIM. The meeting provided an invaluable opportunity for these stakeholders to collaborate and share insights on advancing freight transport and logistics innovation.

One of the activities was to set some round tables to find or receive feedback within the activities of the project. In this regard, a round table to talk on upcoming innovations in freight was settled, in which the project could gather the industry vision on these innovations. As they were small talks and there was not much time to address every innovation related to rail freight that could boost multimodal transport, only some innovations were addressed, mainly the ones addressed in this deliverable

They highlighted that for rail freight it is important to know the possibility to depart trains earlier, reduce waiting time for shippers. For them is important to have accountable freight plans (frequency, operators info collection, data management, faster operations - for each corridor-this is important for shippers to update operators and Freight Forwarders)

For the DAC innovation,

- DAC is a kind of blackbox that some shippers do not want as it is.
- DAC is fine and will bring benefits in future. Nevertheless, it should not be the focus because they do not know when it will be in operation.
- DAC is considered as an option if it increases capacity.
- From the operator side DAC and IVG are more important to increase the efficiency of the terminal.
- DAC, IVG and smart containers are also important. From the operator side it is important to know wagon information and the content of the container to collect data and fix safety issues

For the IVG innovation:

- IVG is a promising technology.
- From the operator side DAC and IVG are more important to increase the efficiency of the terminal.
- DAC, IVG and smart containers are also important. From the operator side it is important to know wagon information and the content of the container to collect data and fix safety issues
- Regarding IVG, the use of OCR technologies for wagon recognition was not that new to them and all the group was aware of OCR applications for freight rail. This technology was piloted around 10 years ago, and it has started to be installed in several terminals a few years ago. It looks that is already state of the art and will further expand in the next years
- This technology is estimated that saves around 30 minutes of work related to the identification of the wagon by the staff

For Smart Container innovation:

- Smart containers are a good option and important for transport processes as they provide real-time visibility.

- Smart containers provide information on what is transported and what is the origin, as well as optimization route. However, smart containers provide information from one container, while IVG gives info from more wagons

Other Rail-freight innovations:

- For operators is important AI to forecast schedules as it helps to organize terminal and final customers.
- Blockchain is more complicated and is based on information provided. Blockchain as operator is not relevant.
- Possible relevance of AI in the future. One logistic operator described an application for forecasting ETA when there are delays at some point of the network. He considered these tools are very useful when only uncertain or incomplete information is available

As it can be observed, depending on the nature of the industry´s actor, some of the innovations would have greater importance to their daily activities than the others. Shippers and carriers are more interested in traceable transport while marshalling yard and terminal operators would benefit more from innovations such as DAC or IVG, since these would speed up some of their processes.

7. Freight market and freight flows: current status and future trends

Transport is a fundamental sector for and of the economy. Efficient transport services and infrastructure are vital to exploiting the economic strengths of all regions of the European Union, to supporting the internal market and growth, and to enabling economic and social cohesion. The main challenges for the transport sector in the EU include creating a well-functioning Single European Transport Area. The European Commission has taken several initiatives to further foster the development of the Single European Transport Area. Progress towards this goal has been made, e.g. with: the 4th Railway Package; the Blue Belt initiatives for maritime transport; the proposed Single European Sky II; the EU Aviation Strategy; and the NAIADES Programme for inland waterways. Therefore, European Commission seeks to address shortcomings, particularly in the market integration of road transport, through a set of initiatives for a socially fair transition towards clean, competitive and connected mobility (European Commission, 2019). The Green Deal is a new European Union strategy to shift to climate-friendly transport and achieve zero net emissions in 2050, giving top priority to rail freight as the most environmentally friendly mode of transport.

Due to its environmental sustainability, rail freight transport is the key to reducing greenhouse gas emissions in the European transport market. To further reduce emissions, 30% of freight is recommended in the White Paper on Transport (EU) to be shifted from road transport to rail. The main reasons for rail's dominance in terms of environmental sustainability are its emission efficiency, the dominance of e-mobility and its continuous improvement potential. Nevertheless, despite its environmentally friendly characteristics, rail freight's share of the transport market is still low. The demand for rail freight on the European transport market has not increased compared to the demand for road transport on the transport market. Furthermore, rail freight transport has not shown a growth trend and, despite a policy of support, still does not occupy a respected position in the transport market (Pastori et al., 2020). In 2020, the share of rail freight inland transportation reached a low 16.8%, a decrease of 0.9% compared to 2019. In the 2010-2020 period, rail freight peaked in 2011 with a 19.2% share of tonne-kilometres (Eurostat, 2024). The stagnant trend in conventional rail freight is not limited to the European market, and it is related to the increasing competition from road freight (Woodburn, 2021), the time-consuming organization of rail transport, and the poor integration with other modes of transport (Godward, 2018). Although at the European level share of rail freight on transport market has not increase through past years, the changes are more obvious at country level. Looking at the data presented by Eurostat share of rail freight on country level varies significantly. One reason of the stagnating rail freight share on transport market is availability level of the rail mode of transport. In 2021 rail freight modal share was the highest in was the most important in in Lithuania, with a share of 52.8 %. The status of rail freight transport with a relatively high share in countries with maritime transport were Slovenia (29.6 %), Latvia (25.9 %), Romania (20.0 %) and Poland (19.8 %). Nevertheless, countries without maritime transport such as Slovakia had the highest share of rail transport, at 31.8 %, followed by Austria (29.6 %), Hungary (26.1 %) and Czechia (22.7 %) (ERFA, 2022). The main obstacles to the growth of rail transport are infrastructural differences and territorial fragmentation, i.e. the lack of standardisation. In contrast to road transport, which operates seamlessly across borders, rail freight transport often encounters obstacles at national borders due to different technical standards and regulations. Possible measures to improve competitiveness with road transport include investment in infrastructure, which can contribute to the modernisation and harmonisation of rail networks across Europe, and track electrification, which will improve both the environmental performance and operational efficiency of rail freight transport. To further improve rail performance, it is necessary to encourage the trend towards increased infrastructure investment to improve efficiency and connectivity across the continent, further progress in automation and digitalisation, increased efforts in standardisation and to maintain an increase in rail's share of the overall freight market in Europe (RailFreightForward 2020; ERFA 2022).

In order to evaluate the status of rail freight in Europe, a clustering of rail freight flows from origins to destinations was undertaken for this report. The potential increase in rail's share of the transport market was simulated based on the EU strategy to shift freight transport over 300 km to road (Lóránt A. Tavasszy, 2011). The KPIs from Table 3 in Section 5.1 were used to obtain an overview of the current status of rail freight transport on the transport market and the potential for modal shift, as well as to cluster the transport flows.

7.1 Linear interpolation method

In order to achieve the ambitious goals of the European Green Deal in the transport sector, the modal shift to rail is one of the most important pillars of the EU strategy (Serafimova, 2022) (Teodora Serafimova, 2022). The basis for a modal shift is the reduction of the negative externalities of road freight transport (Johanna Takman, 2021). The main objective of European transport policy is to shift long-distance road freight transport (over 300 km) to rail, as this transport distance in particular can take advantage of economies of scale and distance (Lóránt A. Tavasszy, 2011).

The methodology developed by (Yan Zhou, 2017) was used to estimate the potential shift of goods to rail transported by road over 300 kilometres. Data was collected from Eurostat (Eurostat, 2023) for European countries for twenty groups of goods transported by road. Goods transported by road were classified by distance, i.e. 50 km, 50 to 149 km, 149 to 499 km and 500 km or more. The data was linear interpolated using equation (5) (LIE) to estimate the potential shift of over 300 km of goods transported by road to rail. The current situation of the share of rail and road in the transport market and the potential growth of rail are presented in section 7.4.

Linear interpolation formula $y = y_1 + (x - x_1)\frac{(y_2 - y_1)}{(x_2 - x_1)}$ (5)

Results of the interpolated data and described methodology are provided in section 7.4.

7.2 Clustering of freight flows

7.2.1 Clustering methodology

To analyse the current status of rail freight transport in Europe, a clustering approach was applied. Clustering is an unsupervised machine-learning method. The main application of clustering is to find hidden patterns of an unlabelled dataset, in this case, to categorize rail freight flows in clusters based on their similarity in terms of volume transported in different years. The clustering approach uses origin-destination (O-D) flow data for rail freight transport between different regions, then, the flows are clustered based on their volume.

The clustering method for this project comprised four main stages: 1) Data pre-processing, 2) Algorithm selection, 3) Algorithm Implementation, and 4) Visualization. A brief description of the stages is given below.

7.2.1.1 Data pre-processing

Data for clustering was collected from Eurostat (RT-NIrailway goods, 2022). The O-D flows of rail freight volumes are registered in Eurostat for 5-year periods from 2005 to 2020. The regions for origin and destinations of freight flows in EU are based on NUTS level 2 classification (Eurostat, n.d.). The data was extracted by developing a Python code using Eurostat (European Commission, 2024). The major task in preparing this data was handling the missing values; some volumes were missing for different regions and links in different years. Clustering as a machine learning approach requires a sufficient amount of adequate and reliable data. Therefore, the missing values were important to be handled properly since we aimed to analyse how much volume was transported between regions and how much it had changed throughout the 5 years periods. The missing value imputation was handled by two methods: constant values and random forest regression. Using the constant value method, the missing values are replaced by zero and the median of the non-missing values in the same feature. It is a simple method but can reduce the variability of the data. The random forest regression imputation uses a random Forest model to handle both non-linear relationships and interactions between features. Therefore, it has the advantage of higher accuracy since it captures complex patterns in the data. Additionally, it is more robust to outliers and overfitting. These two ways of handling the missing values led to two scenarios for later clustering algorithm implementation. All data pre-processing was coded by Python.

7.2.1.2 Algorithm selection

There are various methods for clustering in statistics and machine learning with different approaches, assumptions, and applications. Statistical methods focus more on understanding the underlying structure of the data and hypothesis testing, whereas machine learning methods focus on predictive models and optimizing algorithms to group data for practical applications. Statistical methods assume particular distributions for the data, tend to use parametric models to estimate clusters, and are best suited for small to medium datasets, whereas machine learning methods make fewer assumptions regarding data distribution and can handle large and high-dimensional data. Statistical methods determine whether the clusters are statistically significant or not, whereas machine learning methods use validation metrics like silhouette score and cross-validation for robustness.

Our dataset was large with many missing values for transported volumes for specific regions in different years; considering these characteristics and the specific application of grouping regions based on their transported volumes in different years, we selected

the partitioning method in machine learning clustering. Machine learning is more suitable compared to statistics our case due to: 1) scalability for large datasets: machine learning clustering methods, such as K-means or DBSCAN, can scale well to large datasets, 2) Flexibility in handling missing values: missing values in freight data might be structured (e.g., missing for specific regions or years due to reporting practices). Machine learning allows for applying robust imputation to preserve patterns, 3) Nonparametric nature: machine learning algorithms, such as K-means and DBSCAN, do not assume specific distributions in the data, which make them better options for incomplete data.

Among the available clustering algorithms in partitioning, we chose K-Means clustering algorithm because it is straightforward to implement, understand, and interpret. In terms of computation time, it is efficient. Therefore, advantageous for even future applications of big O-D data analysis of this problem. It has flexibility in finding cluster shapes, and it identifies cluster centroids inherently. It is adaptable to a variety of feature spaces. Finally, it can be a foundation for more complex clustering methods implementation in the case of adding more features to the data. In the case of outliers and noise in the data, K-medoids can be applied which is similar to k-means, but it chooses centroids differently. In k-means, the centre of the cluster (centroid) is the mean of all the points from that cluster which makes the algorithm sensitive to outliers because the mean is not a robust statistic and is impacted by outliers. K-medoids chooses actual data points as centres (medoids), this choice of centroids is more robust to noise and outliers. In addition, medoids are more interpretable since they represent actual data points. The main drawback of K-medoids compared to K-means is that it is more computationally intensive and complex. It takes much more time to cluster by K-medoids.

7.2.1.3 Algorithm implementation

K-Medoids clustering algorithm was implemented on KNIME Analytics Platform (https://www.knime.com/knime-analytics-platform), which is an open-source analytics platform (Berthold et al., 2009). KNIME has a visual interface and can be integrated easily with input from programming languages, in this project, Python. Projects implemented in KNIME, called workflows, are easily shared and reproducible, which makes the use of these project results more available. K-Means algorithm implementation has dedicated nodes in KNIME; the hyper-parameters that were optimized through the implementation phase were the number of clusters and sensitivity to the initial centroid. The performance quality of the algorithm was evaluated using the Silhouette score.

Figure 27 below shows a schematic view of one of the scenarios modelled in KNIME.

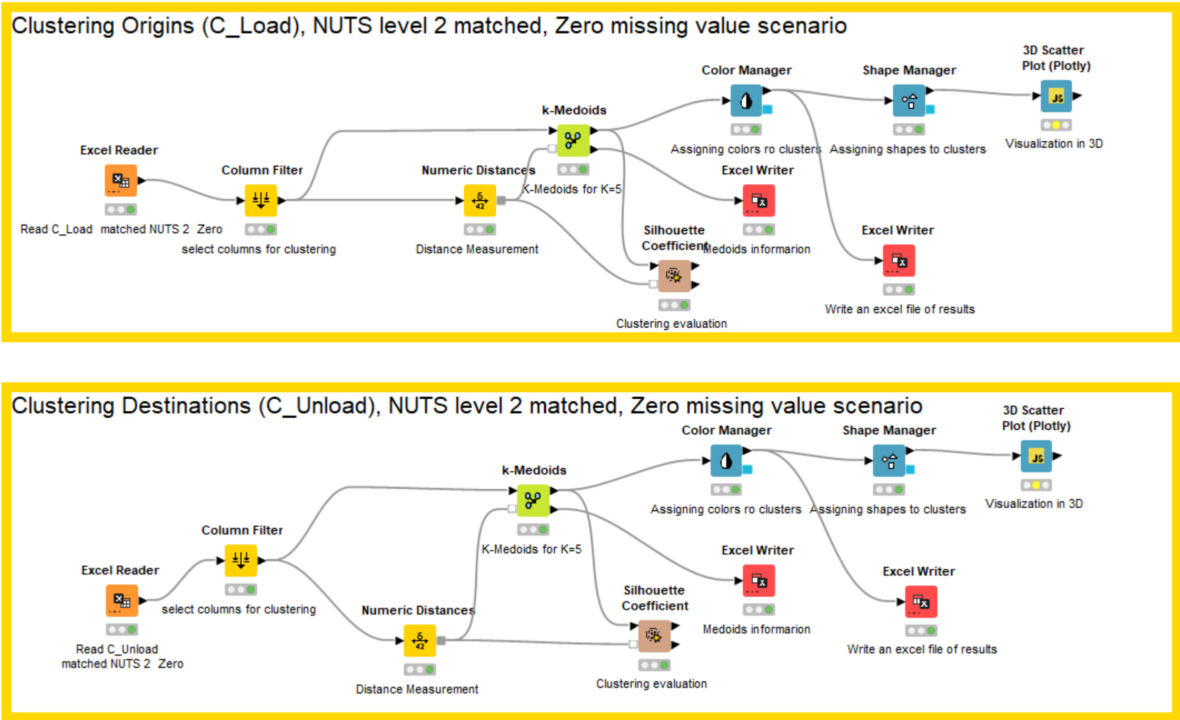

Figure 27. Schematic view of one of the clustering scenarios modelled in KNIME

We defined three scenarios for clustering based on how we imputed the missing values; scenario zero, scenario median, and scenario random forest regression. Scenario zero is the base scenario and it assumes that the missing values show that no volume was transported. Scenario median represents that the missing values were the median of the volume transported in the representative year. Thus, this scenario assumes more volume compared to scenario zero. In scenario random forest regression missing values are predicted from the patterns in the non-missing value data. Basically, by capturing the volumes transported between origins and destinations in 2005, 2010, 2015, and 2020, the missing values for each year were predicted. This scenario is the most ideal scenario because it might actually optimistically predict volumes by assuming that there was a pattern in each O-D freight flows, whereas in reality the volumes were much lower or non-existent. However, since this scenario predicts the missing volumes based on learning the patterns in the data, it can be an interesting scenario to analyse potential freight volumes in origins, destinations, and links. It is important to mention the limitation of this clustering which is based on the transported volumes due to lack of access to other data comprising more parameters. Extending this clustering by inclusion of more variables would be interesting to explore if data is available in the future.

7.2.1.4 Visualization

Visualizing clustering results is important to show the discovered patterns in the data based on the purpose of the clustering. The main types for this purpose are scatter plots, pair plots, heatmaps, dendrograms, clustered heatmaps, bubble charts. The final visualization of the clustering will be presented in final dissemination results.

7.2.2 Clustering Results

In this section, the results of the clustering are presented in tabular form and by means of illustrations. The origins and destinations of freight flows are matched with the NUTS level 2 codes for 2021 to represent freight flows. Table 20 and Table 21 show the results of clustering for origins and destinations. Figure 28, Figure 29, and Figure 30 provide an overview of the results. For a better overview, the results will be integrated into a web platform that can be explored dynamically.

Row ID shows the unique ID for the origin or destination in the original dataset, and it is also used as cluster name to show the clusters in Figure 28, Figure 29, and Figure 30. It is also equivalent for the medoids in the next column. The medoids column shows the centre of the cluster, which the representative of all regions in the cluster. Country code and NUTS label columns show the information on the region. Basically, the medoids show that any NUTS level 2 region in that cluster have more or less a similar pattern in freight volumes according to the data the model was trained on. It might be that there are regions that have higher or lesser volumes, but the majority are similar in terms of volumes to the medoid of the cluster. The year columns show the volume transported by the origin/destination medoid in that year, and finally, the partition size column shows how many regions were clustered in that cluster. The higher value shows that cluster was more common and comprised more regions, we call it the majority cluster. In all scenarios, the majority cluster had the least amount of the transported volume, which means that regions with less volume were more common in the data. Now, we describe clusters per each scenario for origins, destinations:

For both origins and destinations scenarios zero and median show similar results. The random forest regression scenario has different clusters with slightly different cluster size.

In scenario zero for origins, Sweden- Mellersta Norrland is the medoid and it has volumes of less than 50,000 tonnes per year. Whereas for destinations, Italy-Lazio is the medoid for the majority cluster which has volumes less than one million. Then, we have Germany- Darmstadt as the second cluster with volumes of less than 3,500,000 tonnes. The equivalent for the destination is Germany-Schwaben with volumes of less than 4,500,000 tonnes. After this cluster, the volumes in the clusters increase substantially, but we see fewer regions in them, which shows that regions with extremely large volumes (over 6,500,000 tonnes for origins and over 8,500,000 tonnes for destinations) are less common. Basically, the sum of the number of regions with multi-million volumes is less than the majority class for origins. For example: 77 origin regions have volumes over one million compared to 142 regions for the majority class. Comparing origin and destination clusters also shows that the medoids for destination clusters have much larger volumes than the ones for origins. There is also one cluster for origins that has one region Poland- Śląskie that has a much larger volume. This cluster has extremely large volumes – over 69 million tonnes only for 2020. Even if this is a peculiar case, it shows that this large volume is possible in Europe.

Scenario median for origins is similar to scenario zero; the medoids are the same and the number of regions per cluster is almost the same, whereas it is different for destinations. The medoids change for destinations in scenario median; the medoids represent less transported volumes. Germany- Braunschweig represents the cluster that has the extremely large volumes. Sweden-Stockholm is the medoid for the majority class and it has volumes of less than 400,000 tonnes. After that Germany- Lüneburg is the second cluster with volumes less than 3 million tonnes.

The scenario of random forest regression for origins and destinations shows more balanced partition sizes. For both, the majority cluster has less regions, which means that some regions have higher predicted values which has put them in clusters with higher volumes. For origins, clusters with higher volumes have more regions: Croatia- Jadranska Hrvatska (over 8 million tonnes) and Germany-Lüneburg (over 4 million tonnes), 26 and 64 respectively. There is also a cluster over 16 million tonnes: Germany-Dresden, which was not present in the previous scenarios. Basically, this scenario predicts regions with higher volumes compared to previous scenarios. For destinations, like origins, clusters with higher volumes have more regions: Germany- Detmold with approximately 3 million tonnes, Poland- Pomorskie with around 18 million tonnes, and Austria – Steiermark with approximately 9 million tonnes.

Table 20. Results of clustering of origins of freight flows from three scenarios

Cluster name	Scenario Zero							
Row ID	Origin (Medoids)	Country code	NUTS label	2005 (tonne)	2010 (tonne)	2015 (tonne)	2020 (tonne)	Number of NUTS 2 regions
Row 210	SE32	Sweden	Mellersta Norrland	39,483	51,913	37,287	16,9087	142
Row 50	DE71	Germany	Darmstadt	3,112,971	2,735,599	3,442,900	3,286,661	50
Row 57	DE94	Germany	Weser-Ems	6,553,949	8,482,151	7,956,460	6,648,377	18
Row 49	DE60	Germany	Hamburg	20,745,863	27,602,308	27,936,505	29,165,126	8
Row 175	PL22	Poland	Śląskie	61,387,560	65,231,203	88,331,167	69,331,126	1
	Scenario Median							
Row ID	Origin (Medoids)	Country code	NUTS label	2005 (tonne)	2010 (tonne)	2015 (tonne)	2020 (tonne)	Number of NUTS 2 regions
Row 210	SE32	Sweden	Mellersta Norrland	162,767	115,471	177,741	376,735	141
Row 50	DE71	Germany	Darmstadt	3,370,417	3,018,721	3,893,179	3,949,981	51
Row 57	DE94	Germany	Weser-Ems	6,869,411	8,759,495	8,410,870	7,403,985	18
Row 49	DE60	Germany	Hamburg	21,014,187	27,818,983	28,337,212	29,759,230	8
Row 175	PL22	Poland	Śląskie	61,808,176	65,450,767	88,764,922	70,577,014	1
	Scenario Random forest regressio n							
Row ID	Origin (Medoids)	Country code	NUTS label	2005 (tonne)	2010 (tonne)	2015 (tonne)	2020 (tonne)	Number of NUTS 2 regions
Row 166	NL22	Netherlands	Gelderland	645,961	498,497	545,725	637,048	109
Row 56	DE93	Germany	Lüneburg	4,426,808	3,659,464	4,149,900	4,188,715	64
Row 126	HR03	Croatia	Jadranska Hrvatska	12,694,034	8,811,798	8,361,513	8,782,717	26
Row 67	DED2	Germany	Dresden	16,619,086	14,803,463	16,201,931	16,770,337	12
Row 49	DE60	Germany	Hamburg	31,802,528	35,882,092	33,726,358	35,257,854	8

Table 21. Results of clustering of destinations of freight flows from three scenarios

Cluster name	Scenario Zero							
Row ID	**Destination (Medoids)**	**Country code**	**NUTS label**	**2005 (tonne)**	**2010 (tonne)**	**2015 (tonne)**	**2020 (tonne)**	**Number of NUTS 2 regions**
Row 158	ITI4	Italy	Lazio	953,065	654,533	813,931	940,004	109
Row 44	DE27	Germany	Schwaben	3,597,395	3,876,870	4,035,983	4,370,414	50
Row 49	DE71	Germany	Darmstadt	9,213,623	8,653,877	8,215,499	8,912,133	34
Row 183	PL63	Poland	Pomorskie	19,234,461	14,493,480	16,162,724	18,771,474	21
Row 53	DE91	Germany	Braunschweig	20,077,698	38,004,012	40,222,387	37,327,679	4
	Scenario Median							
Row ID	**Destination (Medoids)**	**Country code**	**NUTS label**	**2005 (tonne)**	**2010 (tonne)**	**2015 (tonne)**	**2020 (tonne)**	**Number of NUTS 2 regions**
Row 204	SE11	Sweden	Stockholm	153,028	99,835	205,149	362,279	127
Row 55	DE93	Germany	Lüneburg	2,822,660	2,755,011	2,494,450	2,872,866	52
Row 66	DED2	Germany	Dresden	5,926,001	6,629,783	8,663,916	7,980,005	25
Row 65	DEC0	Germany	Saarland	15,511,919	14,002,296	16,065,494	15,316,854	11
Row 53	DE91	Germany	Braunschweig	16,994,758	35,792,725	37,253,071	33,614,517	3
	Scenario Random forest regression							
Row ID	**Destination (Medoids)**	**Country code**	**NUTS label**	**2005 (tonne)**	**2010 (tonne)**	**2015 (tonne)**	**2020 (tonne)**	**Number of NUTS 2 regions**
Row 122	FRK2	France	Rhône-Alpes	784,694	621,213	422,086	391,154	91
Row 60	DEA4	Germany	Detmold	3,424,633	3,571,128	3,186,735	3,142,075	62
Row 4	AT22	Austria	Steiermark	8,664,635	7,799,396	8,298,757	9,119,443	40
Row 183	PL63	Poland	Pomorskie	19,234,461	14,493,480	16,162,724	18,771,474	21
Row 53	DE91	Germany	Braunschweig	20,077,698	38,004,012	40,222,387	37,327,679	4

Table 22 shows the results of the clustering for selected links. Origins and destinations of the links are based on matching with NUTS level 2 codes. For scenario zero, the majority cluster medoid is Spain (Región de Murcia)-Spain(Galicia) with zero values representing the O-Ds with least volumes transported although not all O-Ds have zero values. The next cluster is represented by Netherlands(Zeeland) to Germany(Lüneburg) for a trend of from 6,405 tonnes to 34,965 tonnes. Then, there are clusters with higher volumes but fewer O-Ds. The highest volumes are transported in the cluster represented by Czech Republic(Severozápad) to Czech Republic(Severozápad). This cluster represents freight transported over 3 millions.

Table 22. Results of the clustering of the links of freight flows

Cluster name	**Scenario Zero**		**Year**				
Row ID	**Links (Medoids)**	**Country(NUTS label) O-D**	**2005 (tonne)**	**2010 (tonne)**	**2015 (tonne)**	**2020 (tonne)**	**Partition Size**
Row 5461	"NL34"-"DE93"	Netherlands(Zeeland)-Germany(Lüneburg)	6,405	38,299	54,524	34,956	1246
Row 8080	"ES62"-"ES11"	Spain(Región de Murcia)-Spain(Galicia)	0	0	0	0	11859
Row 3530	"DE60"-"DE23"	Germany(Hamburg)-Germany(Oberpfalz)	125,371	203,230	272,282	255,197	482
Row 3248	"DE60"-"DE21"	Germany(Hamburg)-Germany(Oberbayern)	609,804	830,967	1,157,041	982,016	128
Row 1972	"CZ04"-"CZ04"	Czech Republic(Severozápad)-Czech Republic(Severozápad)	6,736,120	7,826,780	6,173,821	3,926,738	18
Cluster name	**Scenario Median**						
Row ID	**Links (Medoids)**	**Country(NUTS label) O-D**	**2005 (tonne)**	**2010 (tonne)**	**2015 (tonne)**	**2020 (tonne)**	**Partition Size**
Row 3875	"DE94"-"DE26"	Germany(Weser-Ems)-Germany(Unterfranken)	30,409	47,805	102,164	81,970	899
Row 3972	"CZ07"-"DE27"	CzechRepublic(StředníMorava)-Germany(Schwaben)	3,626	2,890	4,131	5,768	12386
Row 4632	"DE60"-"DE71"	Germany(Hamburg)-Germany(Darmstadt)	216,205	346,265	357,488	334,846	354
Row 8356	"ES51"-"ES51"	Spain(Cataluña)-Spain(Cataluña)	873,557	1,190,240	1,578,857	1,560,124	77
Row 1972	"CZ04"-"CZ04"	Czech Republic(Severozápad)-Czech Republic(Severozápad)	6,736,120	7,826,780	6,173,821	3,926,738	17
Cluster name	**Scenario Random forest regression**						
Row ID	**Links (Medoids)**	**Country(NUTS label) O-D**	**2005 (tonne)**	**2010 (tonne)**	**2015 (tonne)**	**2020 (tonne)**	**Partition Size**
Row 13633	"CZ07"-"SK04"	Czech Republic(StředníMorava)-Czech Republic(Severozápad)	81,038	57,150	52,581	44,818	2473
Row 2322	"HU31"-"CZ06"	Hungary(Észak-Magyarország)-Czech Republic(Jihovýchod)	3951	2455	3,234	4433	10533
Row 1317	"BE21"-"BE34"	Belgium(Prov. Antwerpen)-Belgium(Prov. Luxembourg (BE))	348,575	377,666	358,536	365,147	580
Row 5945	"ITH3"-"DEA2"	Italy(Veneto)-Germany(Köln)	1,511,127	1,428,243	1,314,012	1,256,887	120
Row 11507	"PL22"-"PL42"	Poland(Śląskie)-Poland(Zachodniopomorskie)	8,057,735	5,505,123	4,882,679	5,774,449	27

For median scenario the majority cluster is represented by Czech Republic (Střední Morava) to Germany (Schwaben) and includes higher number of O-Ds. The second largest cluster is represented by Germany (Weser-Ems) to Germany (Unterfranken). Transporting larger volumes represents less number of O-Ds in the clusters. The highest volumes are transported are represented in the cluster Czech Republic (Severozápad) to Czech Republic (Severozápad) which is the same also for scenario zero.

Random forest regression scenario shows more balanced number of O-Ds in each cluster because it has predicted the missing values based on the hidden patterns in the data. The majority cluster is represented by Hungary (Észak-Magyarország) to Czech Republic (Jihovýchod). The second large cluster is represented by Czech Republic (Střední Morava) to Czech Republic (Severozápad). The cluster with highest volume sis represented by Poland (Śląskie)-Poland (Zachodniopomorskie).

These results can be used to define plans for an increase in the rail freight share for regions and links. The choice of the cluster to focus on may be based on strategic plans, current capacities, and limitations in a region or link. For example, if a region is clustered in the cluster with volumes of less than 500,000 tonnes and plans to reach volumes of over 3 million, it can conduct a benchmarking study with regions in the higher cluster. Figure 28, Figure 29, and Figure 30 show a schematic of clusters depicting how the volume changes between clusters.

It is also worthy to note that results from scenarios zero and median represent a more current picture of rail freight transport, whereas results for the random forest regression scenario represent more future potentials in a more realistic way since they are based on the prediction from the patterns in all volumes transported. Between scenarios zero and median, results from the scenario median may be more optimistic because they assign a median value to the missing values. Therefore, depending on the objective of the analysis or modelling, these scenarios can be used in future models for estimation of potential future fright flows.

A complete version of the clustering results in Excel format will be available as open data for future research on more comparison between scenarios. It is also possible to include these results into future clustering with more comprehensive data. The data will be available after an embargo period that will finish once articles related to these data have been published.

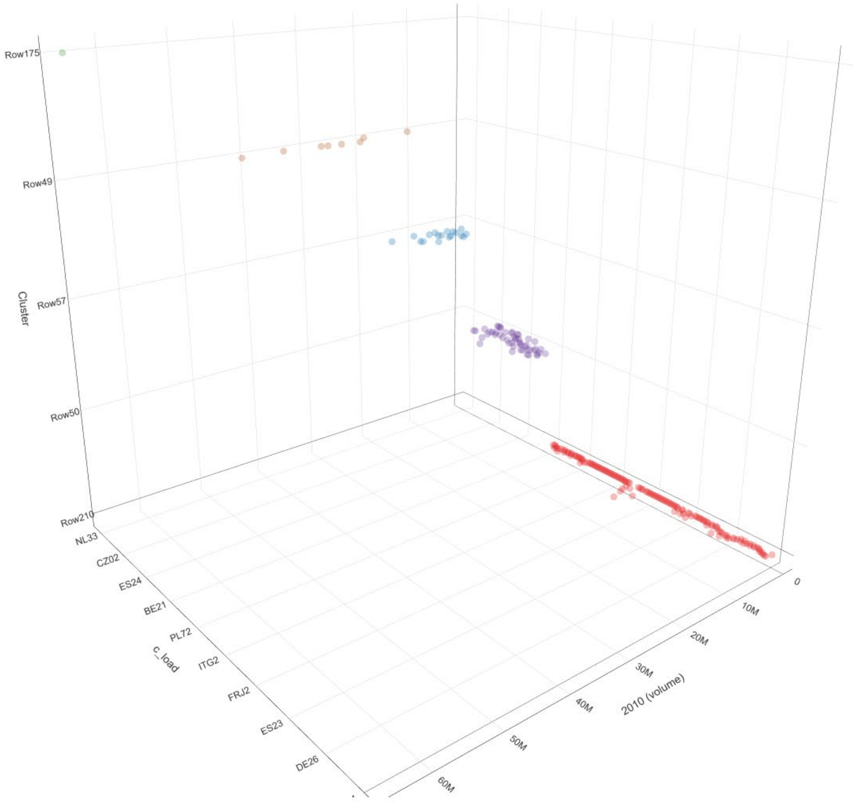

Figure 28. A 3D plot of the clustering for zero scenario for year 2010, c_load axis shows the origins of the freight flows, 2010 shows the volume transported in 2010, Cluster shows the cluster with the unique ID for the centre of the cluster

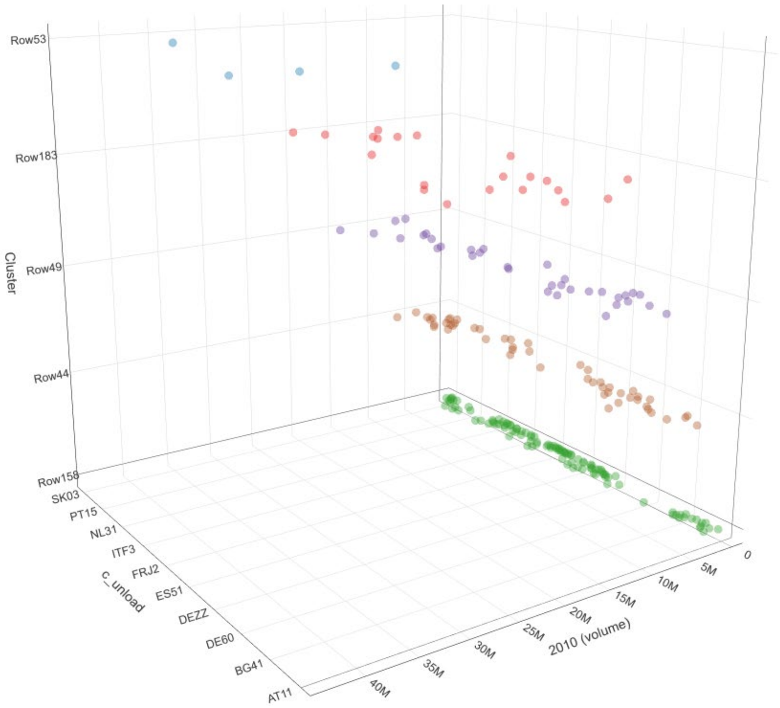

Figure 29. A 3D plot of the clustering of the destinations, c_unload axis shows the destinations of the freight flows, 2010 shows the volume transported in 2010, Cluster shows the cluster with the unique ID for the centre of the cluster

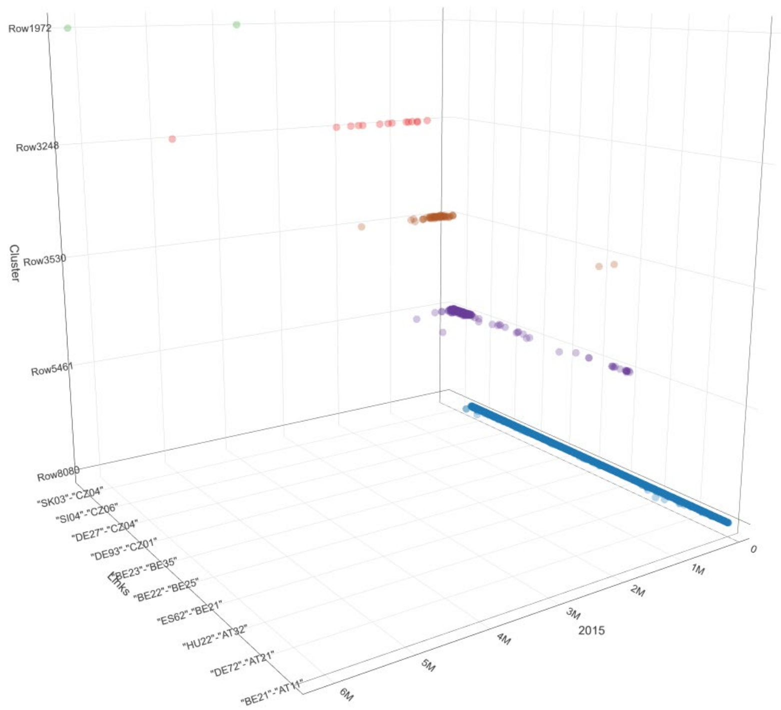

Figure 30. A 3D plot of the clustering of the links, Links axis shows the link of the freight flows, 2010 shows the volume transported in 2010, Cluster shows the cluster with the unique ID for the centre of the cluster

7.3 Potential of shifting freight to rail

In the European Union, road vehicles are responsible for one- fifth of Europe's total greenhouse gas emissions. Heavy-duty vehicles are responsible for 27% of CO2 emissions and almost 5% of the EU's GHG emissions. To reduce emissions, the European Commission proposes to shift freight transport to environmentally friendly modes such as rail freight, which is slowly recovering (Djordjevic and Ghosh, 2023). A target of the European Commission's Roadmap for Transport 2050 is to shift 30 % of road freight transport over 300 km to other modes such as rail or waterborne transport, and more than 50 % by 2050 (EC, 2011). To estimate the potential shift of road freight transport over 300 kilometres to rail, the method developed by Yan Zhou (2017) was used in this report. This method was adopted as it enables the estimation of the modal shift of goods suitable for transport over 300 kilometres. The potential modal shift of goods to rail over shorter distances was not considered. Therefore, this report estimates the modal shift potential for certain types of goods. Semi-finished and finished goods, which require faster and more reliable transport and typically have a lower density and higher value, have not been analysed (Zunder and Islam, 2018). Nevertheless, the suitability of rail as a mode of transport should be considered for these products. In addition, the availability of data for such an estimate should be taken into account.

Data was collected from Eurostat (Eurostat, 2024 for European countries on country level for twenty groups of goods transported by road. Goods transported by road were classified by distance, i.e. 50 km, 50 to 149 km, 149 to 499 km and 500 km or more. The data was linear interpolated using equation (5) to estimate the potential shift of over 300 km of goods transported by road to rail.

Linear interpolation formula $y = y_1 + (x - x_1)\frac{(y_2 - y_1)}{(x_2 - x_1)}$ (5)

The potential of shifting road transport to rail within EU was analysed using official data for rail and road transports for 2022 from Eurostat (2023, 2023b). To identify the potential, it was assumed all road transports over 300 km could be shifted to rail. In this chapter the potential is presented based on goods types according to the Standard goods classification for transport statistics, NST-2007 (Eurostat, n.d.). and country wise (EU 27). Finally, the countries with the highest potential of shift goods from road to rail are presented, showing the potential per goods types.

The existing rail transport in the listed countries is 1.5 million tonkm and the total potential is one million tonkm, that is 66 %. Figure 31 shows the actual transport of goods by rail transport and potential shift of each group of goods transported over 300 km by road to rail transport. The largest potential volumes are found in "metal ores and other mining and quarrying products", "food, beverages and tobacco products", and "products of agriculture, hunting, and forestry; fish and other fishing products".

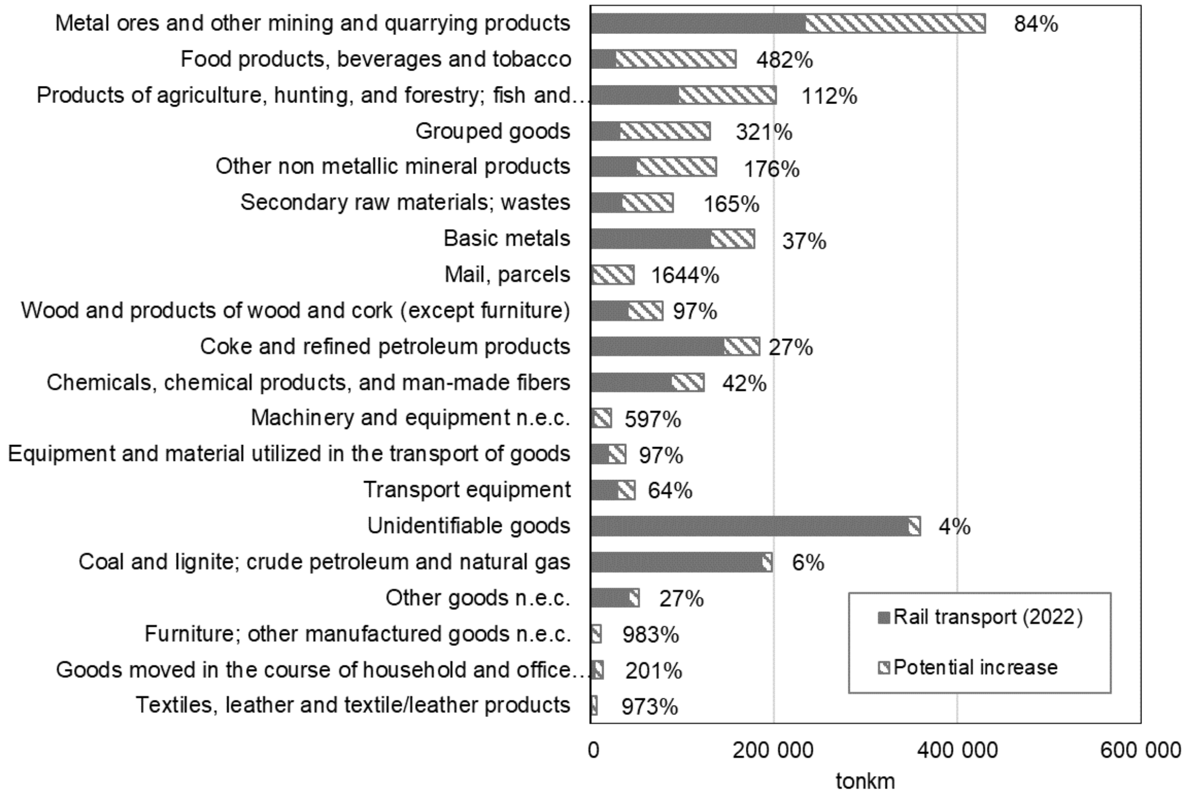

Figure 31. Existing rail transport in EU per goods type, and potential increase, if shifting all existing road transports over 300 km to rail

The countries with the largest potential of rail freight utilisation in ton-km are Germany (200 000 tonkm, corresponding to 58% of the existing German rail transports), France (168 00 tonkm, corresponding to 188% of existing French rail transports) and Spain (140 000 tonkm, corresponding to 560% of existing Spanish rail transports). In Figure 32 the potentials of each country are listed with the highest potential in top. As can be seen the countries with the highest percentage potential are Greece, Ireland, Spain, France, Denmark, the Netherlands and Portugal. Nevertheless, from the figure it can be seen that there are countries with the very small potential of shift to rail such as Lithuania and Estonia.

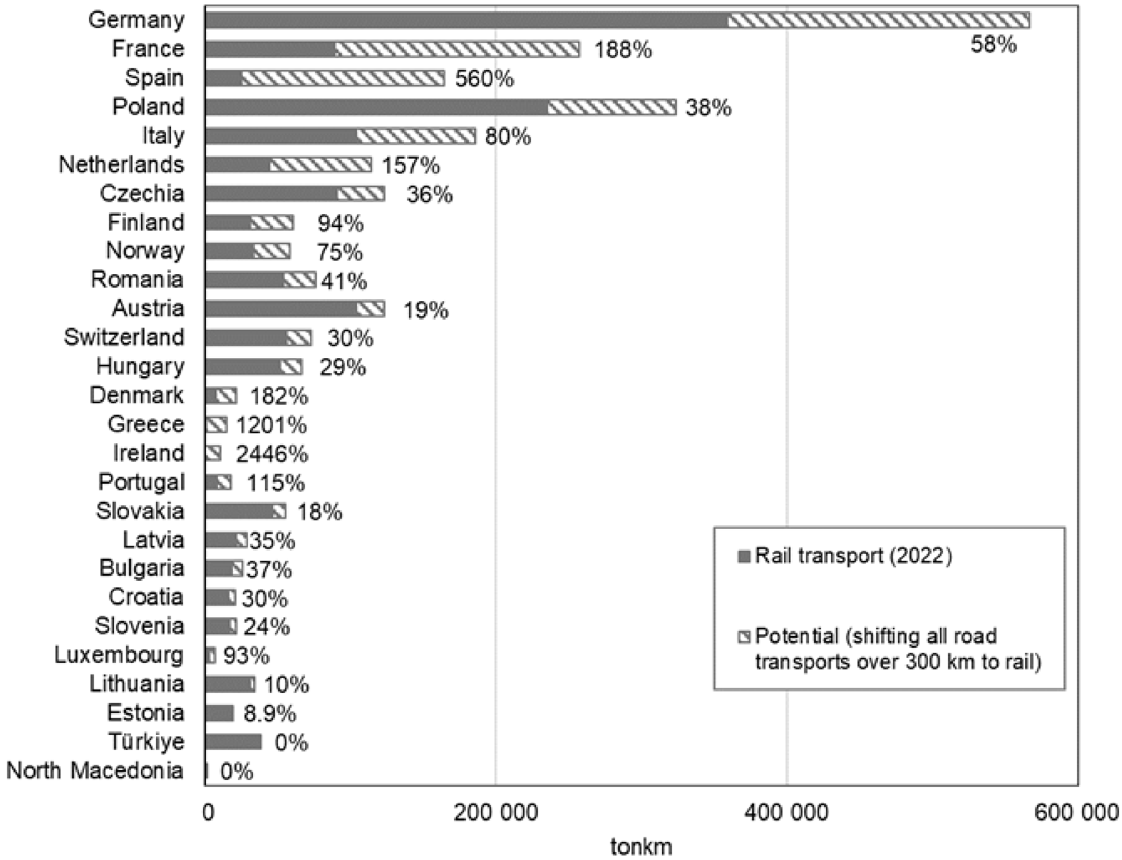

Figure 32. Overview of potential increase of rail transport on country level, if shifting all national road transported over 300km to rail transport (except for Turkye and Nort Macedonia that have no road data over 300km)

The results for the six countries with highest potential Germany and France can be seen in Figure 33 respectively Figure 34. In Germany the highest potential for shifting to rail is in the goods grouped as metal ores and other mining products, see Figure 33. While in France the highest potential has the group of grouped goods, see Figure 34. Nevertheless, groups such as products of agriculture and metal products have also high potential for shifting to rail transport.

The potential of shifting goods to rail transport in Spain and Poland can be seen in Figure 35 and Figure 36. It is interesting to see that for almost all groups of goods there is a potential to be shifted to rail. This directly means that dominant mode of transport in Spain is road transport. Similar situation can be seen for Netherlands as well, see Figure 36.

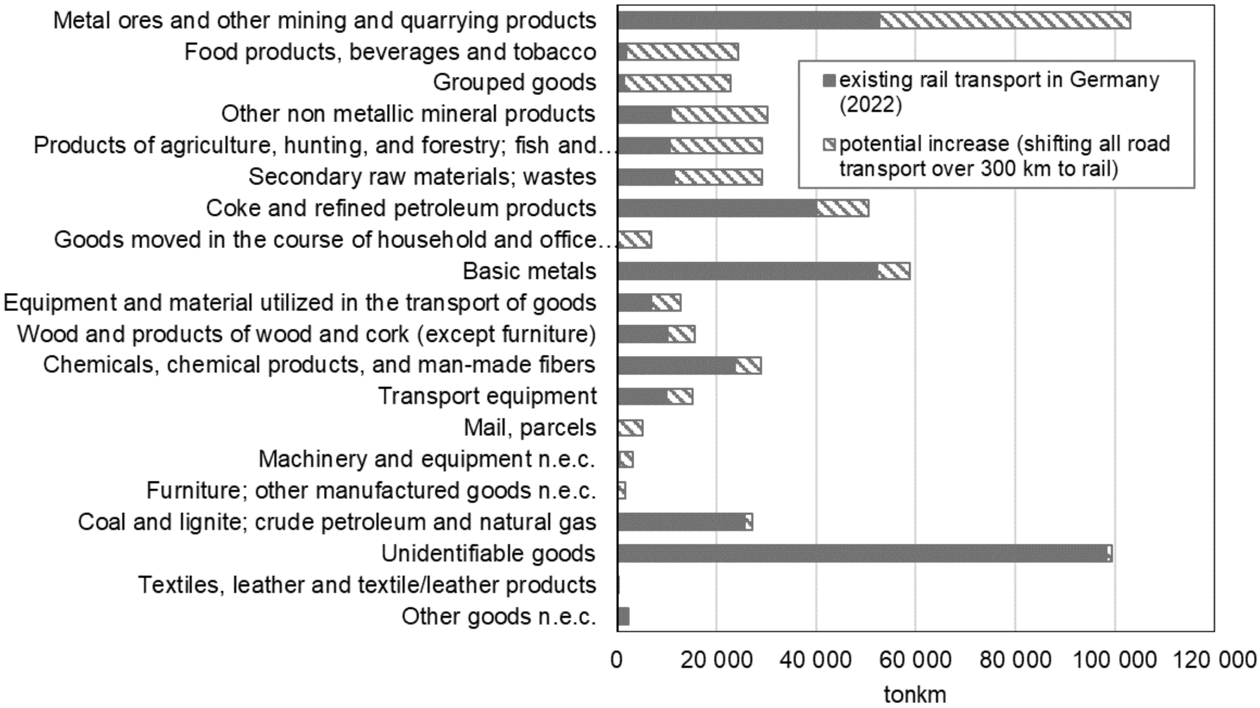

Figure 33. Potential shift of goods transport to rail in Germany

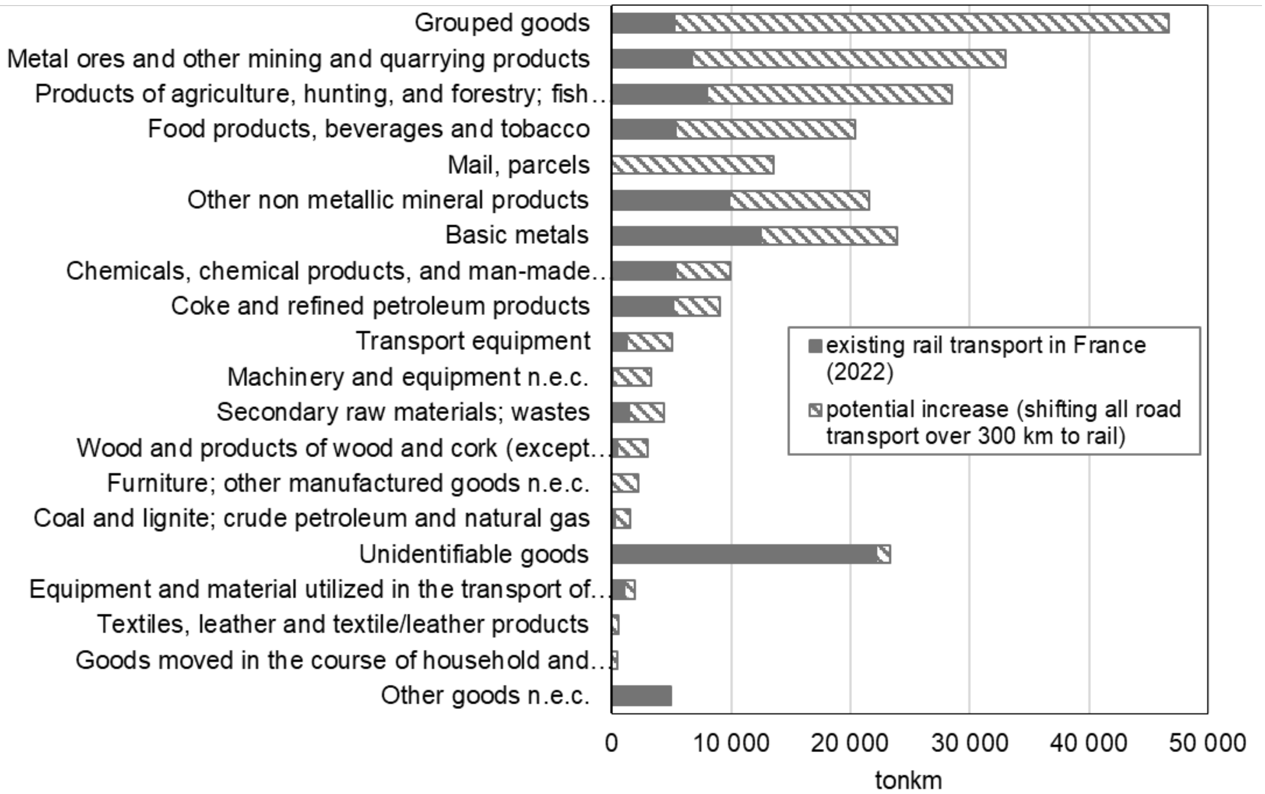

Figure 34. Potential shift of goods to rail in France

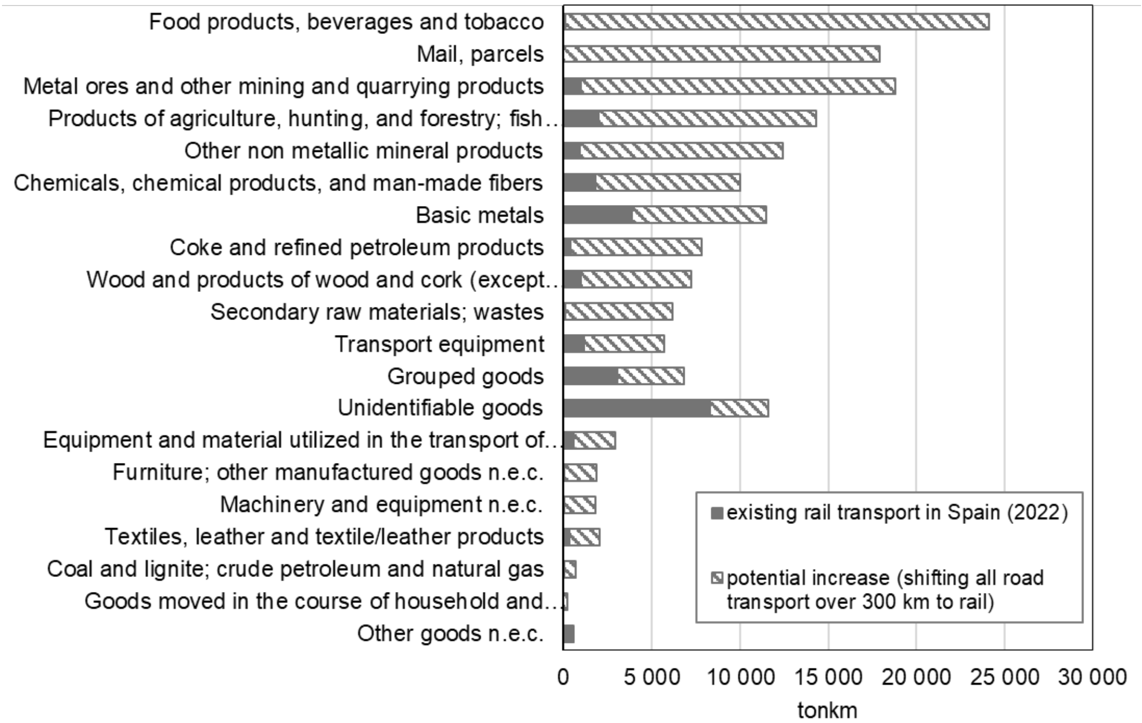

Figure 35. Potential shift of goods from road to rail in Spain

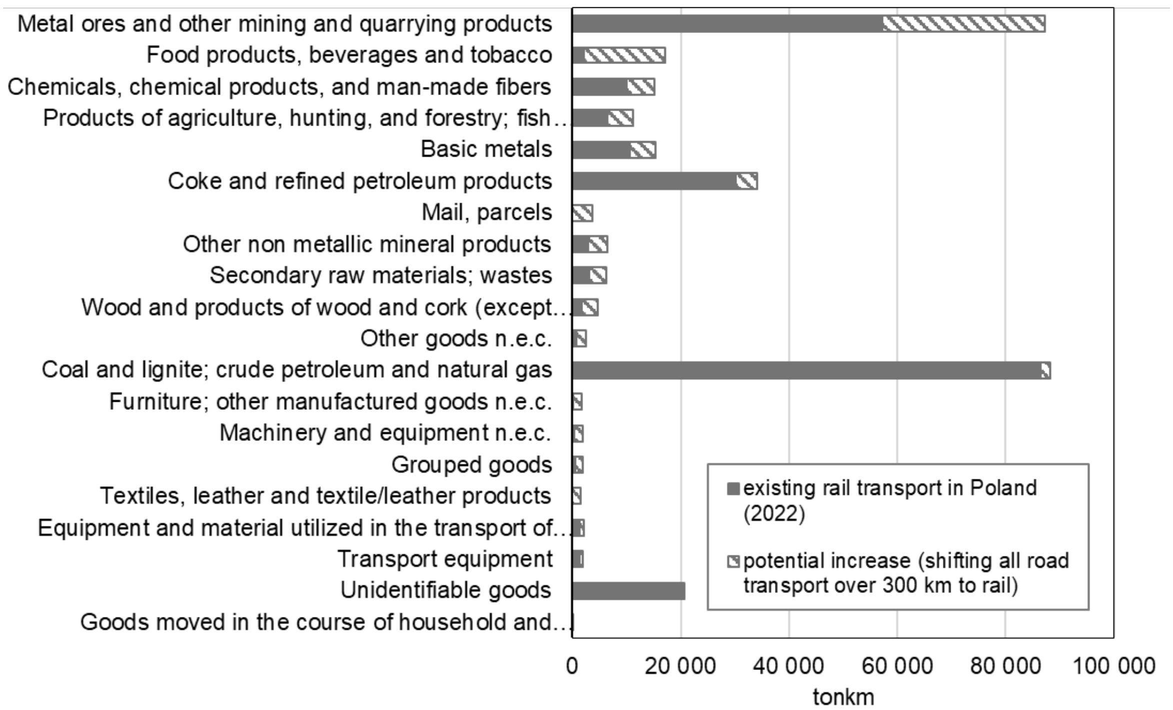

Figure 36. Potential shift of goods from road to rail in Poland

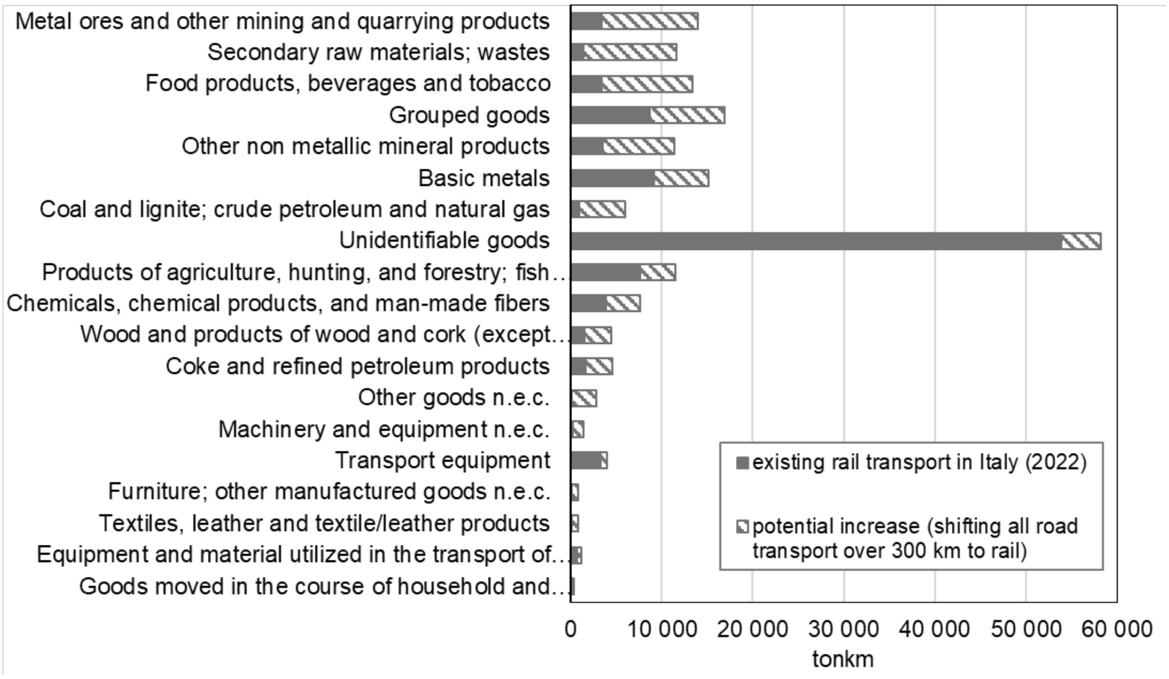

Figure 37. Potential shift of goods from road to rail in Italy

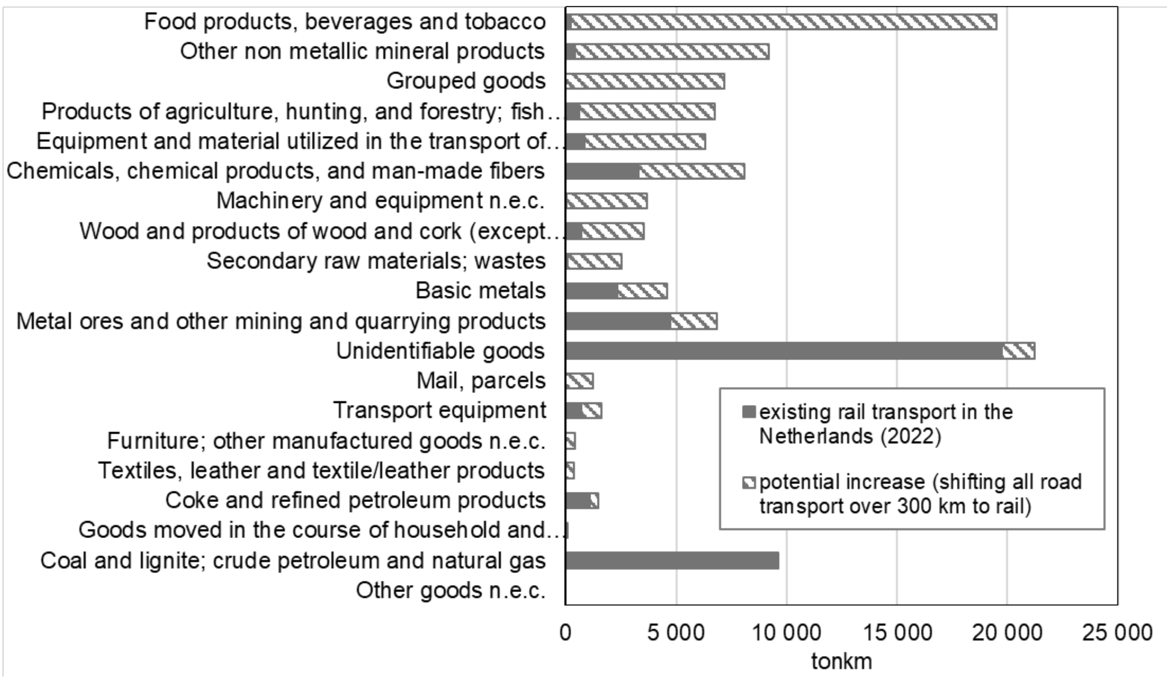

Figure 38. Potential shift of goods from road to rail in the Netherlands

7.4 Measures for improving rail freight

7.4.1 Optimisation of rail freight running time

The essential strategy for improving capacity utilisation and corridor efficiency is to schedule and find the shortest route for freight trains. The shortest route for freight trains was found by minimising their travel times. A mixed-integer linear optimisation model is developed (see Appendix 3) to determine the optimum train path and travel time. The Swedish rail network (the southern part of Sweden) is used as a case study since most of the problems occur in the southern part where there are a lot more stations, tracks and trains travelling. Therefore, only the regions Gävle, Stockholm, Hallsberg, Norrköping, Göteborg and Malmö were involved in this analysis. Using the R language, the model is first tested and executed on small rail networks, but also on the real Swedish rail network. With the aim to illustrate the mode results the test of the model has been tested on Swedish rail route from Stockholm to Göteborg. Since the Hallsbergs marshalling yard connects these two cities and is used for train processing, yard presents the middle point and model tested from Stockholm to Hallsberg and from Hallsberg to Göteborg.

To identify the effect of extension infrastructure measures such as double track on the travel time, longer and heavier trains were tested with linear programming model presented in Appendix 3. All the results were obtained by model run using the R language in RStudio.

7.4.1.1 Results of freight train routing and scheduling

The results of routing and scheduling of 3 trains from Stockholm to Hallsberg are put in Table 23, and the results for routing and scheduling 3 trains from Hallsberg to Stockholm are put in Table 24.

Table 23. Results for routing 3 trains from Stockholm to Hallsberg

Station	**Train 1** **Arrival-> Departure**	**Train 2** **Arrival-> Departure**	**Train 3** **Arrival-> Departure**
Stockholm central	0->2	2->4	3->5
Stockholm södra	3->4	5->6	7->7
Årstaberg	5->5	7->7	8->9
Älvsjö	7->8	8->9	10->11
Flemingsberg	11->11	12->13	14->14
Södertälje syd övre	16->16	18->18	19->20
Järna	20->20	22->22	23->24
Flen	40->40	41->42	43->43
Katrineholms central	47->47	49->49	50->51
Hallsbergs personbangård	67->68	69->70	71->71
Hallsbergs rangerbangård	69->69	71->71	72->73

Table 24. Results for routing 3 trains from Hallsberg to Stockholm

Station	Train 1 Arrival-> Departure	Train 2 Arrival-> Departure	Train 3 Arrival-> Departure
Hallsbergs rangerbangård	0->1	1->2	3->4
Hallsbergs personbangård	2->3	3->4	5->6
Katrineholms central	23->23	24->25	26->27
Flen	30->30	32->32	34->34
Järna	49->50	51->52	53->54
Södertälje syd över	53->54	55->56	57->57
Flemingsberg	59->59	61->61	63->63
Älvsjö	62->63	64->65	66->67
Årstaberg	64->65	66->67	68->69
Stockholm södra	66->67	68->68	70->70
Stockholm central	68->70	70->72	72->74

Now, the results of routing and scheduling of 3 trains from Göteborg to Hallsberg are put in Table 25, and the results for routing and scheduling 3 trains from Hallsberg to Göteborg are put in Table 26.

Table 25. Results for routing 3 trains from Göteborg to Hallsberg

Station	Train 1 Arrival-> Departure	Train 2 Arrival-> Departure	Train 3 Arrival-> Departure
Göteborg central	0->1	2->3	4->5
Olskroken	3->5	5->6	7->8
Göteborg Sävenäs	5->6	8->8	9->10
Sävedalen	8->8	9->10	11->12
Herrljunga central	37->37	39->39	41->41
Falköping central	47->49	49->51	51->52
Skövde central	58->58	60->60	61->62
Gårdsjö	75->75	77->77	79->79
Laxå	82->83	84->85	86->87
Hallsbergs rangerbangård	92->93	94->95	96->97

Table 26. Results for routing 3 trains from Hallsbergs to Göteborg

Station	Train 1 Arrival-> Departure	Train 2 Arrival-> Departure	Train 3 Arrival-> Departure
Hallsbergs rangerbangård	0->1	2->3	4->5
Laxå	10->10	12->12	14->14
Gårdsjö	17->18	19->19	21->21
Skövde central	35->35	36->37	38->39
Falköping central	44->45	46->47	48->49
Herrljunga central	55->56	57->58	59->59
Sävedalen	85->85	87->87	89->89
Göteborg Sävenäs	86->87	88->89	90->91
Olskroken	88->90	90->91	92->93
Göteborg central	91->93	93->95	95->96

7.4.2 Effect of double track on freight train running time the routing and scheduling

To identify the effect of double track on travel time of the trains route from Göteborg to Malmö has been used as a case study. Table 27 illustrates the outcomes when one train is requested to be routed from Göteborg to Malmö, while the second train is requested to be routed from Malmö to Göteborg.

Table 27 Results for the routing of 1 train from Göteborg to Malmö and 1 train from Malmö to Göteborg

Station	Train 1 Arrival->Departure	Train 2 Arrival->Departure
Göteborg central	0->1	117->119
Almedal	5->8	112->113
Varberg	32->33	87->88
Torebo	43->44	76->77
Furet	57->58	62->63
Halmstad central	59->60	60->61
Kistinge	62->62	58->58
Eldsberga	64->64	56->56
Ängelholm	78->78	42->43
Kattarp	82->82	38->38
Helsingborg godsbangård	92->93	27->28
Kävlinge	105->106	14->15
Lund central	109->110	10->11
Arlöv	113->113	7->7
Malmö godsbangård	114->115	5->6
Malmö central	118->120	0->2

In the case of a single train in each direction between Göteborg and Malmö, it can be demonstrated that the optimal solution is to introduce a delay for the first train prior to the crossing (in this instance, the delay is implemented within the Almedal station) in order to facilitate simultaneous crossing at the Halmstad central station (60 minutes). The addition of double tracks will be considered to ascertain whether their presence will affect the outcome of the optimisation process. Table 28. Table 28 presents the results of the optimisation process when one train is routed in each direction between Göteborg and Malmö, with the inclusion of double tracks.

It is evident that the double tracks have resulted in a notable improvement in the efficiency of the rail service. Train 1 is no longer required to wait at Almedal, and both trains are now able to complete their journeys from their respective origins to destinations without any need for intermediate stops. The second train, which utilises the double track between Kistinge and Halmstad Central, is using the second tracks between minutes 58 and 60. Train 1, meanwhile, takes the first track between minutes 59 and 61 minutes.

Table 28. Results for the routing of 1 train from Göteborg to Malmö and 1 train from Malmö to Göteborg and double tracks (*Kistinge is a station where two trains are meet)

Station	**Train 1 Arrival->Departure**	**Train 2 Arrival->Departure**
Göteborg central	0->1	117->119
Almedal	5->6	112->113
Varberg	31->32	87->88
Torebo	42->42	76->77
Furet	55->56	62->63
Halmstad central	58->59	60->61
Kistinge	61->61	58->58*
Eldsberga	63->63	56->56
Ängelholm	76->77	42->43
Kattarp	81->81	38->38
Helsingborg godsbangård	91->91	27->28
Kävlinge	103->104	14->15
Lund central	107->108	10->11
Arlöv	111->112	7->7
Malmö godsbangård	113->114	5->6
Malmö central	117->119	0->2

7.4.3 Potential and effect of longer and heavier freight trains

In order to improve the status of rail freight in the transport market, the competitiveness of rail freight should be improved by increasing reliability and creating more capacity while minimising operating costs. To meet this requirement, the MARATHON project analysed the impact of longer and heavier trains on railway capacity. As part of the project, the traffic on the network has been analysed by coupling two classic trains of 750metert and testing the braking system on the 1500meter long trains (Castagnetti and Toubol, 2014). The need for longer and/or heavier and/or faster freight trains and their feasibility in the European context was analysed by Islam and Mortimer (2017). According to Nelldal (2017), longer trains are one of the most promising measures that can improve capacity quite significantly. In combination with improved locomotives, waggons and heavier trains, train capacity and line capacity can be significantly increased.

One of the key benefits identified with the introduction of the DAC, and presented in Deliverable 7.1 of the DACcelerate project (DACcelerate Deliverable 7.1, 2023), is the operation of longer and heavier trains. These advantages are related to the ability of DAC to transmit higher longitudinal forces than screw couplers. The report points out that higher tractive and compressive forces with DAC can provide additional benefits for operating heavier trains, reducing the risk of derailment, increasing train speeds through higher braking forces and a simpler and lighter waggon frame design. However, in addition to the benefits and potential productivity gains of longer trains with DAC, limitations and constraints must also be considered. These constraints are either related to operating regulations or infrastructure limitations.

For analyse the potential of introducing longer trains, which directly increase train weights in the European rail freight market, a corridor approach was used from DACcelerate Deliverable 7.1 (2023). The main conclusion from a corridor approach is that it does not make sense to adapt a complete corridor for longer train lengths and that therefore only suitable sections of rail freight corridors should be considered for adaptation to longer train lengths. European corridor, i.e. the Scandinavian-Mediterranean rail freight corridor, and two routes, the Pannonian east-west link Záhony - Vienna and Terespol/Malaszewicze - Central Poland, were analysed. These lines were selected since infrastructure developments to meet the requirements for longer trains were presented and possible future improvements were recommended in technical reports.

To verify the increase in productivity by increasing train length which directly increase overall train weight (neto mass), the efficiency of the Scandinavian-Mediterranean was measured in Deliverable 7.1 of the DACcelerate project (DACcelerate Deliverable 7.1, 2023). Data Envelopment Analysis (DEA)model was used to monitor the efficiency of ScanMed corridor locations from München to Verona (North to South direction). From the initial results the most efficient and inefficient sections on the corridor have been identified.

In order to investigate efficiency improvement and the influence of increasing train length, the values of train length were increased for all sections. The results in Figure 39 show that the efficiency of the first 11 sections improved significantly, while the efficiency of the last 7 sections was significantly lower compared to the previous sections with unchanged train length values..

However, the inefficient sections Kufstein arr., Bolzano arr., Bolzano dep. and Verona arr., would become more efficient as the number of trains increases.

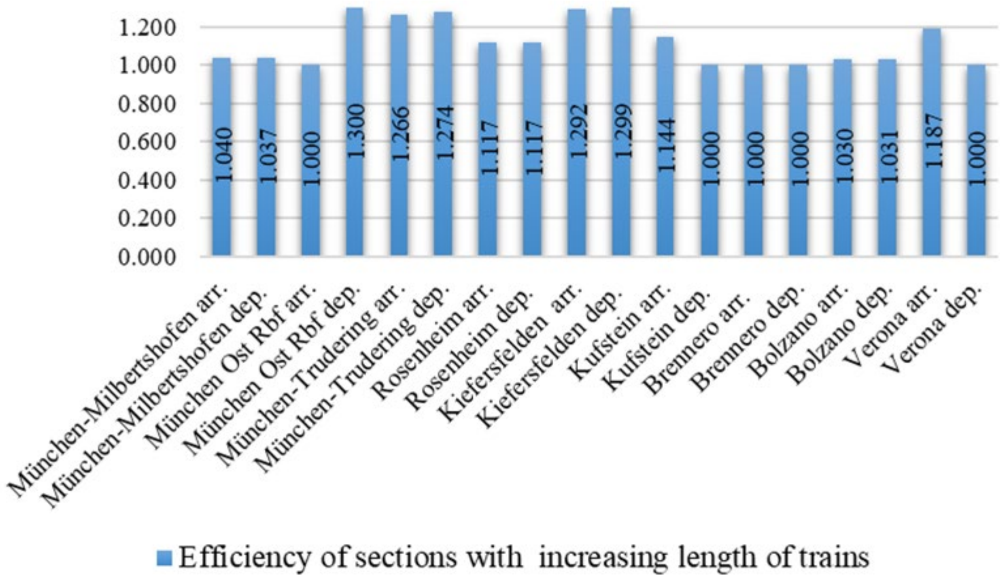

Figure 39. Results of sections efficiency with additional increasing length of trains

For the purpose of this deliverable, using the mixed-integer optimisation model given in Appendix 2 effect of longer and heavier trains on train running time and rail capacity utilisation were evaluated. Therefore, the effect of longer trains was tested on the Swedish railway network. The objective was to analyse the results based on different alternatives with replacing the length of the trains from 700m to 800m to ascertain whether there is a difference in the results of routing and scheduling several trains.

With the same objective using the AnyLogic simulation tool effect of longer trains in combination with manual coupling and decoupling, as well as DAC level 4 and DAC level 5 for Hallsberg marshalling yard was analysed. Three scenarios have been created as AnyLogic models with the objective of evaluating the benefits in terms of time of the various DAC strategies or of the different maximum authorised lengths for a train. The first scenario was that a train with a length of 740 metres arrived at the marshalling yard and had manual couplings. In scenario 2, trains with a length of 740 metres arrive at the marshalling yard and are equipped with DAC type 4, while in scenario 3 the trains are 740 metres long and equipped with DAC type 5. The strategy was to always place new trains in the arrival yard as soon as a track became available and to classify the trains in the order they arrived. Once a track was full in the classification yard, the shunting engine was instructed to move the newly formed train to the departure yard. In the departure yard, trains were dispatched as soon as they were ready. To ascertain the benefits of each scenario, the cumulative number of trains that have reached each specific yard has been counted after each hour for a duration of 10 hours. Three tables illustrate the results of simulations involving trains with a maximum of 30 cars. The results of the three different scenarios are presented in Table 29, Table 30 and Table 31. Table 30 shows a number of trains in arriving, classification and departing yards.

Table 29. Results for the Scenario 1 (Actual + long train) in the Hallsberg's marshalling yard

Number of trains which have reach each yard	Arrival yard	Classification yard	Departure yard
1h	7	1	0
2h	10	3	0
3h	12	5	1
4h	14	6	2
5h	15	8	4
6h	17	9	5
7h	18	11	7
8h	20	12	8
9h	21	14	10
10h	23	15	11

With DAC type 4, the number of trains is increased in all three parts of the marshalling yard in scenario 2, as can be seen in Table 30 in comparison to scenario 1. However, the number of trains increases further with the introduction of DAC Type 5 compared to the previous scenario (see Table 31).

Table 30. Results for the Scenario 2 (DAC4 + long train) in the Hallsberg's marshalling yard

Number of trains which have reach each yard	Arrival yard	Classification yard	Departure yard
1h	7	2	0
2h	11	4	0
3h	13	5	1
4h	15	7	3
5h	16	9	5
6h	18	11	6
7h	19	12	8
8h	21	14	9
9h	22	16	11
10h	24	18	13

Table 31. Results for the Scenario 3 (DAC5 + long train) in the Hallsberg's marshalling yard

Number of trains which have reach each yard	Arrival yard	Classification yard	Departure yard
1h	7	2	0
2h	11	4	1
3h	13	6	2
4h	15	8	4
5h	17	10	5
6h	19	12	7
7h	21	14	8
8h	23	15	10
9h	25	17	12
10h	27	19	14

8. Conclusions

Following the objectives and defined tasks, Deliverable 1.1 in Chapter 5 provided an overview of a comprehensive set of existing KPIs in the literature for intermodal transport. Based on the results of the review, numerous KPIs can be seen in Table 3, grouped into clusters and sub-clusters. In Table 3, a certain number of KPIs used in Tasks 1.2 and 1.3 have been labelled with "X". Certain KPIs were selected from the set of defined KPIs in order to achieve the objectives of other tasks. To achieve the second objective, for example, a mixture of KPIs was used in task 1.2. KPIs from the infrastructure and operations clusters were used to assess the impact of DAC and IVG on train handling time and operations in the marshalling yard. In order to achieve the defined objective, certain methods were applied in Task 1.3, which primarily include KPIs of clusters such as transport market, accessibility and connectivity. As part of the same task infrastructure improvements and other measures that could improve rail operations in Europe were analysed. Defined KPIs were used to carry out these activities in order to achieve the 3rd objective of WP1. The last defined objective in WP1 is the part of deliverable 1.2. This objective was mainly achieved with the help of the KPIs defined in this deliverable. Based on the requirements for the development of the web platform, mainly infrastructural and operational KPIs were used for data collection.For the development of the Web Platform that informs freight customers about available rail freight services in Europe, different modules are integrated into an interactive map. KPIs should be used to provide the necessary input for the modules and the output for the customers. In Table 3, the potential use of KPIs in the web platform and in other WPs has also been indicated.

As mentioned earlier, some indicators from the set were used as part of equations to assess or monitor the impact of innovation on rail freight performance. The way to improve rail freight performance and competitiveness in the freight market is increasing automation and digitalisation through the introduction of promising advanced technologies. Chapter 6 looked at promising innovations that can improve the status of rail freight transport, such as IVG, DAC, IoT, AI, DT, smart contracts and container, digital transport agreements and multimodal solutions. In order to identify the potential of upcoming innovations to improve the status of rail freight transport in D1.1, DAC and IVG were provisionally selected. The results in section 6.2.1 show that DAC has a positive influence on time consumption in the marshalling yard. In section 6.2.2, the results of estimating the impact of IVG also show a positive impact on reducing the time required to examine the transport units. In addition to the positive impact of these technologies, potential challenges were also identified in D1.1. Furthermore, other emerging innovations such as IoT, digital twins and the use of artificial intelligence were considered as a means to boost rail freight transport and improve the performance of rail freight transport and rail terminals. Based on the overview of current practise, these innovations can significantly improve the quality of rail freight transport.

With regard to smart contracts and transport agreements (section 6.4), the main advantages of this innovation in intermodal transport are that it offers opportunities to improve security and data integration. Smart container also offer benefits and are related to real-time monitoring and security, predictive maintenance, efficient operations, informative decisions and traceability (see section 6.2.3). To further improve the quality and share of rail freight transport through multimodality, various technologies were developed (section 6.6) that aim to minimise handling time, reloading of container and energy consumption, thus improving sustainability and efficiency in freight transport. The information and results of the innovation assessment will be useful for other working groups to raise customer awareness of possible improvements through the use of such technologies.

In D1.1, Chapter 7 analysed the status of rail freight and freight flows with the aim of identifying the potential for further improvements. In order to strengthen the role of rail freight transport in the transport market, it is necessary to attract the attention of freight customers. One way to raise the profile of rail freight transport is to offer customers a high-quality service. One aim of D1.1 was therefore to analyse the potential of upcoming innovations to improve rail freight performance and overall competitiveness.

A clustering of origins, destinations and connections was undertaken to determine the potential for improving rail freight's share of the transport market. The results show that the largest cluster is the one with the lowest transport volume. Meanwhile, there is at least one cluster with less than five instances in each scenario. This cluster represents the origins and destinations that had an extremely high volume that was exceptional, the value is extreme and cannot be clustered with other points.

Therefore, the idea of shifting more than 300 km of freight transport from road to rail was addressed in this report. The results in section 7.2 show that the countries with the highest percentage potential are Greece, Ireland, Spain, France, Denmark, the Netherlands and Portugal, while the lowest potential for a modal shift to rail is in Lithuania and Estonia, while there is no potential for Turkey and North Macedonia.

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Appendices

Appendix 1. SG Anonymous survey on Smart Contracts Solutions

Question 1

User	In which organizational kind does your company fit better?	Approximately, What is your company´s average volume of T.E.U. managing per year?
1	Transport Node Manager	Between 5.000.000 and 10.000.000 T.E.U.
2	Freight Village	Between 100.000 and 500.000 T.E.U.
3	Transport users (and others...) association	I do not have this information, sorry
4	Customers	Between 10.000.000 and 100.000.000 T.E.U.
5	Multimodal Transport Organizer	More than 1 million tons
6	Customers	Between 100.000 and 500.000 T.E.U.
7	Consultant	does not apply
8	Transport Operator	Up to 10.000 T.E.U.

Question 2

User	Can you give an approximate value of the maximum percentage cost per operation due to delays in contract arrangement?
1	Around 3%
2	Around 2%
3	I do not have this information, sorry
4	Around 2%
5	Between 5% and 10%
6	Between 5% and 10%
7	does not apply
8	Around 2%

Question 3

User	On average, how many days does it take your organization to complete the entire contract lifecycle, from initiation to final approval?
1	Between 3 and 5 days
2	Between 1 week and 2 weeks
3	We do not manage these contracts directly, and we do not survey our associates on this matter, sorry
4	1 day
5	Between 3 and 5 days
6	More than a month

7	not applicable we work for consultancy projects
8	Between 5 and 7 days

Question 4

User	Have there been investments made by your organization in ensuring data integrity for contract-related transactions? If yes, please provide an approximate annual expenditure.
1	Between 100k€ and 200k€
2	Less than 100k€
3	Does not apply
4	N/A
5	Less than 100k€
6	Between 100k€ and 200k€
7	not applicable we work for consultancy projects
8	Less than 100k€

Question 5

User	How much, in percentage of a contract, does your organization typically spend on resolving contract disputes?
1	Around 2%
2	Around 1%
3	Does not apply
4	N/A
5	Around 2%
6	Around 4%
7	not applicable we work for consultancy projects
8	Around 2%

Question 6

User	What is the average annual expenditure on legal and compliance-related aspects of contracts in your organization?
1	Less than 100k€
2	Less than 100k€
3	Does not apply
4	N/A
5	Less than 100k€
6	Between 200k€and 500k€
7	Less than 100k€
8	Less than 100k€

Question 7

User	How much in percentage of contract value, is the delay on accomplishment clause arranged with the clients?
1	Around 2%
2	Around 1%
3	Does not apply
4	Around 2%
5	Around 1%
6	Around 4%
7	not applicable we work for consultancy projects
8	Around 2%

Question 8

User	In the past year, approximately, how much has your organization spent on traditional security measures for contract processes in your organization?
1	Less than 100k€
2	Less than 100k€
3	Does not apply
4	N/A
5	Less than 100k€
6	Less than 100k€
7	not applicable we work for consultancy projects
8	Less than 100k€

Question 9

User	How much does your organization spend annually on monitoring and ensuring compliance with contract terms and regulations?
1	Less than 100k€
2	Between 100k€ and 200k€
3	Does not apply
4	N/A
5	Less than 100k€
6	Less than 100k€
7	Less than 100k€
8	Less than 100k€

Question 10

User	What is the percentage of the contract cost related to monitoring and ensure compliance?

1	Around 2%
2	Around 4%
3	Does not apply
4	N/A
5	Around 1%
6	Around 1%
7	less than 1% (not applicable we work for consultancy projects)
8	Around 1%

Question 11

User	Can you provide an estimate of the fees paid to intermediaries or third parties involved in your organization's contract processes?
1	Less than 100k€
2	Between 200k€and 500k€
3	Does not apply
4	
5	More than 5M€
6	Between 100k€ and 200k€
7	not applicable we work for consultancy projects
8	

Question 12

User	Are there costs associated with training staff on contract-related processes and compliance? If yes, please provide an estimate of the annual expenditure
1	
2	Less than 100k€
3	Does not apply
4	N/A
5	Less than 100k€
6	Less than 100k€
7	not applicable we work for consultancy projects
8	

Question 13

User	Can you provide an approximate annual expenditure on personnel involved in contract management within your organization?
1	Less than 100k€
2	Between 100k€ and 200k€

3	Does not apply
4	N/A
5	Between 100k€ and 200k€
6	Between 200k€and 500k€
7	not applicable we work for consultancy projects
8	Between 100k€ and 200k€

Question 14

User	Approximately, How much percentage of the income of your organization is expended on personnel for contract management?
1	Around 1%
2	Around 2%
3	Does not apply
4	N/A
5	Around 1%
6	Around 4%
7	not applicable we work for consultancy projects
8	Around 2%

Question 15

User	Can you give an approximation on what are the annual costs related to paper-based record-keeping for contracts in your organization, including storage and retrieval expenses?
1	Less than 100k€
2	Between 100k€ and 200k€
3	Does not apply
4	N/A
5	Less than 100k€
6	Less than 100k€
7	not applicable we work for consultancy projects
8	Less than 100k€

Question 16

User	Approximately, what is the estimated financial impact related to the income of contract delays on your organization?
1	Around 1%
2	Around 2%
3	Does not apply
4	Around 2%

5	Around 1%
6	Around 3%
7	not applicable we work for consultancy projects
8	Around 1%

Appendix 2. DEA model

The CCR model is described as follows:

$\min_{\theta,\lambda} \theta$ (6)

Subject to

$\theta x_0 - X\lambda \geq 0$ (7)

$\lambda Y \geq y_0$ (8)

$\lambda \geq 0$ (9)

in this model, it is assumed that there are n RFCs, m outputs, and s inputs. X represents a set of input vectors and Y represents of a set of output vectors. λ is a vector of variables and θ is an indicator of technical efficiency, where θ∈ (0,1) (Djordjević et al., 2021). θ indicates by how much the RFC being evaluated could potentially reduce its input vector proportionally to as small value as possible while keeping the output vector constant (Cooper et al., 200appen6). The RFCs were the valuation units of the model, and the indicators from the data under study were divided into inputs and outputs.

Appendix 3. Mixed-integer linear optimization model

The train routing and scheduling optimisation model created is a mixed-integer linear optimisation model. The goal function is given in equation (10) and states that all trains should arrive at their final destination as soon as possible. The descriptions and names of all the parameters and variables are explained in Table X.

$$Min\ Z = \sum_{t\in T} A^t_{sd_t} \quad (10)$$

Subject to:

$$\forall t \in T,\ D^t_{so_t} \geq E + W_{so_t} \quad (11)$$

Constraint (11) stipulates that each train is prohibited from departing before the earliest authorised departure time plus the dwelling time at the origin station of the train.

$$\forall t \in T,\ \sum_{i\in S} X^t_{i,sd_t} = 1 \quad (12)$$

$$\forall t \in T,\ \sum_{j\in S} X^t_{so_t,j} = 1 \quad (13)$$

Constraints (12) and (13) stipulate that each train must arrive at the destination and depart from the origin.

$$\forall t \in T,\ \forall\ s \in S,\ D^t_s \geq\ A^t_s + W_s \quad (14)$$

Constraint (14) ensures that the train cannot depart from a station before its arrival plus a minimum time to cross the station.

$$\forall t \in T,\ \forall\ (i,j) \in S^2, A^t_j -\ D^t_i\ \geq\ T_{i,j} - M(1 -\ X^t_{i,j}) \quad (15)$$

Constraint (15) represents the travel time of the train on the track from i to j.

$$\forall t \in T,\ \forall\ s\ \in S\backslash\{so_t, sd_t\},\ \sum_{i\in S\backslash\{s\}} X^t_{i,s} =\ \sum_{j\in S\backslash\{s\}} X^t_{s,j} \quad (16)$$

Constraint (16) formulates that if a train enters a station, it must leave it, except for the origin and destination stations.

$$\forall\ (i,j) \in S^2, if\ T_{i,j} =\ \emptyset\ then\ \forall t \in T,\ X^t_{i,j} = 0 \quad (17)$$

Constraint (17) permits the trains to utilise only those tracks that are physically present in the real world.

$$\forall t1 \in T,\ \forall t2 \in T\backslash\{t1\},\ \forall (i,j) \in S^2,\ D^{t2}_i - D^{t1}_i \geq h_{i,j} - M(1 - Y^{t1,t2}_{i,j}) \quad (18)$$

The headway parameter is employed in constraint (18) to guarantee that if train t1 is traversing the track i->j prior to train t2, then the departure of train t2 from station i must be at least subsequent to the departure of train t1 plus the minimum headway on this track.

$$\forall t1 \in T,\ \forall t2 \in T \backslash \{t1\},\ \forall (i,j) \in S^2,\ Y_{i,j}^{t1,t2} \geq \frac{1}{M}\left(A_i^{t2} - A_i^{t1} + \varepsilon^{t1,t2}\right) - M(2 - X_{i,j}^{t1} - X_{i,j}^{t2}) \qquad (19)$$

The value of $Y_{i,j}^{t1,t2}$ is determined by the equation 10. In the event that both t1 and t2 are traversing the same track from i to j, it is necessary that $Y_{i,j}^{t1,t2}$ be strictly superior to 0. This is equivalent to a value of 1, as it is a binary variable (Equation 19), only if train t1 arrives at station i before train t2, or if both trains arrive at the same time and t1 has priority over t2.

$$\forall t1 \in T,\ \forall t2 \in T \backslash \{t1\},\ \forall (i,j) \in S^2, Y_{i,j}^{t1,t2} + Y_{i,j}^{t2,t1} \leq 1 \qquad (20)$$

Constraint (20) ensures that, in the event that t1 traverses the track i->j prior to t2, t2 will subsequently traverse the same track in after t1.

$$\forall t1 \in T,\ \forall t2 \in T \backslash \{t1\},\ \forall (i,j) \in S^2,\ D_j^{t2} \geq A_j^{t1} - M(1 - Z_{i,j}^{t1,t2}) \qquad (21)$$
$$\forall t1 \in T,\ \forall t2 \in T \backslash \{t1\},\ \forall (i,j) \in S^2,\ D_i^{t2} \geq A_i^{t1} - M(1 - Z_{i,j}^{t1,t2}) \qquad (22)$$

Constraints (21) and (22) ensure that if train t1 departs from station i before the train t2, and the two trains traverse the track between the two stations, then train t2 must wait until the train t1 has reached its next station before leaving the station where t2 is.

$$\forall t1 \in T, \forall t2 \in T \backslash \{t1\}, \forall (i,j) \in S^2,$$
$$Z_{i,j}^{t1,t2} \geq \frac{1}{M}\left[(A_j^{t2} + W_j) - (A_i^{t1} + W_i) + \varepsilon^{t1,t2}\right] - M(2 - X_{i,j}^{t1} - X_{j,i}^{t2}) \qquad (23)$$

The value of $Z_{i,j}^{t1,t2}$ calculated using the equation 23. In the case of two trains taking the same track in opposite directions, $Z_{i,j}^{t1,t2}$, must be strictly superior to 0, thus equal to 1 (equation 23). This occurs only if the train t1 is available at station i before the train t2 is available at station j, or if both trains are available at the same time and t1 has priority over t2. In this context, the concept of availability is employed instead of the arrival time, given that the dwelling time at the two stations may influence the time at which each train is ready to depart.

$$\forall t1 \in T,\ \forall t2 \in T \backslash \{t1\},\ \forall (i,j) \in S^2, Z_{i,j}^{t1,t2} + Z_{j,i}^{t2,t1} \leq 1 \qquad (24)$$

Finally, constraint (24) is analogous to constraint (20) and ensures that if the train t1 traverses the track i->j prior to the train t2 traversing the track j->i, then the train t2 is precluded from traversing the track j->i prior to the train t1 traversing the track i->j.

$$\forall t \in T,\ A_s^t, D_s^t\ \in R^+, s\ \in S \qquad (25)$$
$$\forall t \in T,\ X_{i,j}^t\ \in\ \{0,1\}, (i,j) \in S^2 \qquad (26)$$
$$\forall (t1,t2) \in T^2,\ Y_{i,j}^{t1,t2}\ \in\ \{0,1\}, (i,j) \in S^2 \qquad (27)$$
$$\forall (t1,t2) \in T^2,\ Z_{i,j}^{t1,t2}\ \in\ \{0,1\}, (i,j) \in S^2 \qquad (28)$$

Constraints (25), (26), (27) and (28) define the permissible range of values for all decision variables.

Table1: List of variables and parameters

Notations	Definitions
$\boldsymbol{S}$	Set of stations
$\boldsymbol{T}$	Set of trains
$\mathbf{A_s^t}$	Arrival time of the train t at station s, $s \in S,\ t \in T$
$\boldsymbol{D_s^t}$	Departure time of the train t from stations, $s \in S,\ t \in T$
$\boldsymbol{X_{i,j}^t}$	Binary variable (1 if the train t goes from i to j, 0 otherwise), $(i, j) \in S^2$, $t \in T$
$\boldsymbol{Y_{i,j}^{t1,t2}}$	Binary variable (1 if the train t1 goes from i to j before the train t2, 0 otherwise),$(i, j) \in S^2,\ (t1, t2) \in T^2$
$\boldsymbol{Z_{i,j}^{t1,t2}}$	Binary variable (1 if the train t1 goes from i to j before the train t2 goes from j to i, 0 otherwise),$(i, j) \in S^2,\ (t1, t2) \in T^2$
$\boldsymbol{so_t}$	Origin station of train t, $so \in S,\ t \in T$
$\boldsymbol{sd_t}$	Destination station of train t, $sd \in S,\ t \in T$
$\boldsymbol{E^t}$	Earliest departure time of train t, $t \in T$
$\boldsymbol{D_{i,j}}$	Distance between station i and station j, $(i, j) \in S^2$
$\boldsymbol{Sp_{i,j}}$	Speed limit on the track from i to j, $(i, j) \in S^2$
$\boldsymbol{T_{i,j}}$	Travel time from station i to station j, $(i, j) \in S^2$
$\boldsymbol{h_{i,j}}$	Minimum headway between two consecutive trains on the track i-> j, $(i, j) \in S^2$
$\boldsymbol{\varepsilon^{t1,t2}}$	A very small positive number ($\varepsilon^{t1,t2} \ll 1$), $\varepsilon^{t1,t2} \neq 0$ if t1 has priority over t2, 0 otherwise, $(t1, t2) \in T^2$
$\boldsymbol{M}$	A big number ($M \gg 1$)

The two sets in this model are the set of stations as well as the set of trains to be routed and scheduled.

In terms of variables, this model comprises five variables, two of which are continuous and three of which are binary. This makes it a mixed-integer model. The two continuous variables (A_s^t and D_s^t) represent the arrival and departure times of each train at each station. The first binary variable ($X_{i,j}^t$) is equal to one if and only if the train t is actually using the track between stations i and j. The second binary variable, $Y_{i,j}^{t1,t2}$, represents, for two trains taking the same track, which one is going first. Finally, $Z_{i,j}^{t1,t2}$, represents the order of precedence for two trains traversing the same track in opposite directions.

The parameters of this model are origin and destination stations of each train, the earliest authorised departure time for each train. The distance, speed limit and time it takes to reach each couple of stations. The parameter $h_{i,j}$ represents minimum headway between two consecutive trains, and it is calculated as follows:

$If\ D_{i,j} > 4.7, then\ h_{i,j} = \frac{2*2+0.7}{Sp_{i,j}}$, which represents the time required for a train to traverse the two blocks of 2 kilometres, in addition to the length of the train (700 metres) at the maximum authorised speed.

$If\ D_{i,j} \leq 4.7, then\ h_{i,j} = T_{i,j}$, signifying that the subsequent train must await the arrival of the preceding train at the next station.

The last parameter introduced in TRSOM is $\varepsilon^{t1,t2}$, which is a small positive number representing that if two trains arrive at the same time in a station, t1 has priority over t2 to leave the station.

Appendix 4 Digital solution use case

CALCULO AHORRO COSTES DOCUMENTO E-DOC		
TRANSACCIONES ANUALES PREVISTAS: (Nº de documentos)	**10.000**	widoit PIONIRA NV

CALCULO ESTIMADO COSTE EMPRESA PERSONAL		
Coste empresa personal anual	**Horas Jornada**	**Coste/hora**
€ 30.000,00	1.800	**€ 16,67**

CALCULO COSTE PIONIRA	
Coste Anual gestión Pionira/Widoit	**Coste mensual Pionira/Widoit**
€ 6.217,80	**€ 518,15**

Tiempo gestión papel/ud. Personal	**Minutos**	**Horas anuales**	**Coste personal**
Manual (Incluye manipulación y archivo)	**13**	2.166,67	**€ 36.111,11**
E-doc	**8**	1.333,33	**€ 22.222,22**

Coste formularios (impresos)	
Coste CMR	**€ 0,15**
Coste Albaranes	**€ 0,00**

COMPARATIVO COSTES MANUAL-EDOC				
CONCEPTO	**COSTES CONFECCION MANUAL**	**CONFECCION E-DOC**	**Diferencia**	**% Ahorro**
Coste personal anual	€ 36.111,11	€ 22.222,22	13.888,89 €	
Coste formularios (impresos)	€ 1.500,00	€ 0,00	1.500,00 €	
Coste Widoit/Pionira Anual	0	€ 6.217,80	-6.217,80 €	
TOTAL COSTE	**€ 37.611,11**	**€ 28.440,02**	**9.171,09 €**	**24,4%**

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