

**Document Version**

Final published version

**Licence**

CC BY

**Citation (APA)**

Altun, A., Elbert, R., & Saeednia, M. (2026). Innovative freight wagons in single wagon load transport: Potentials and impacts on improvement of competitiveness. *Research in Transportation Business and Management*, 66, Article 101611. <https://doi.org/10.1016/j.rtbm.2026.101611>

**Important note**

To cite this publication, please use the final published version (if applicable).  
Please check the document version above.

**Copyright**

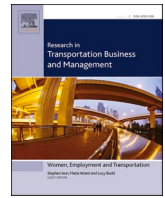
In case the licence states "Dutch Copyright Act (Article 25fa)", this publication was made available Green Open Access via the TU Delft Institutional Repository pursuant to Dutch Copyright Act (Article 25fa, the Taverne amendment). This provision does not affect copyright ownership.  
Unless copyright is transferred by contract or statute, it remains with the copyright holder.

**Sharing and reuse**

Other than for strictly personal use, it is not permitted to download, forward or distribute the text or part of it, without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license such as Creative Commons.

**Takedown policy**

Please contact us and provide details if you believe this document breaches copyrights.  
We will remove access to the work immediately and investigate your claim.



# Innovative freight wagons in single wagon load transport: Potentials and impacts on improvement of competitiveness

Aylin Altun<sup>a,\*</sup>, Ralf Elbert<sup>a</sup>, Mahnam Saeednia<sup>b</sup>

<sup>a</sup> Chair of Management and Logistics, Technische Universität Darmstadt, Hochschulstraße 1, 64289 Darmstadt, Germany

<sup>b</sup> Faculty of Civil Engineering and Geosciences, TU Delft, Stevinweg 1, 2628 CN Delft, Netherlands

## ARTICLE INFO

### Keywords:

Single wagon load transport  
Innovative freight wagons  
Intermodal transport  
Rail freight  
Interview study  
Case study

## ABSTRACT

The climate objectives necessitate a modal shift of freight transport from road to rail, with single wagon load (SWL) transport playing a critical role due to its direct competition with truck transport. This paper investigates the impact of innovative freight wagon concepts on enhancing the competitiveness of SWL transport. Interviews with professionals from the SWL sector were conducted using a qualitative single-case study approach.

The findings reveal that retrofitting conventional freight wagons with innovative designs can significantly influence operational processes, including wagon disposition planning, turnaround times, and other key performance metrics. These improvements are likely to boost the competitiveness of SWL transport, contributing to an increased share of rail in the modal split.

This study adds to the literature on SWL transport by offering a focused analysis of how innovative freight solutions can address the sector's operational challenges. Furthermore, it provides practical insights for managers, emphasising the importance of adopting innovative wagon technologies to optimise efficiency, reduce costs, and strengthen the market position of SWL transport in the evolving freight sector.

## 1. Introduction

Rail freight transport is increasingly gaining more significance in the context of achieving climate goals. The essential reduction in greenhouse gas emissions in the freight transport industry is only attainable through a modal shift of freight transport from road to rail (Islam et al., 2016). In 2022, Germany's modal split of rail freight transport was 19,3% compared to other forms of surface freight transport like road, sea, and pipelines. While it is predicted to decrease slightly by 2027 to the benefit of road freight transport (BALM, 2024), the goal of the Federal Republic of Germany is to increase it to 25% by 2030 (BMDV, 2020). Regarding European rail freight transport, the aim for 2030 is even higher at a modal split of 30% (European Commission, 2011). To address this discrepancy, it is essential to examine rail freight and its various production forms individually.

Rail freight consists of three distinct production forms: block train, combined transport, and single wagon load (SWL) transport. Block train refers to a dedicated train operating from one starting point to its destination without interruption or change of composition. Combined transport refers to cargo in containers and swap-bodies transported via road on the pre- and post-haulage to a terminal, where it is loaded on a

train for the long-distance main haulage. SWL transport refers to the transport of single wagons and groups of wagons from customers on a feeder train to the nearest shunting yard, where the wagons are consolidated to form a block train to be transported over a multilevel transport network and reach their destinations via feeder trains (Islam et al., 2016).

While these models have transport performances of approximately 50% of tonne-kilometres (tkm) for block trains and 25% each for combined transport and SWL in Europe (Islam et al., 2016), the situation in Germany, the country with the highest rail freight transport performance in the EU (European Commission, 2022), looks different: the modal shares are rather distributed in shares of 40%, 44%, and 16%, respectively (Roland Berger, 2021), making SWL transport the weakest in performance.

The decline in the modal share of SWL transport, concurrent with the growth of other transport modes, particularly road transport by trucks, can be attributed to several factors: higher costs and lead times, unreliable SWL services, lack of flexibility, and limited infrastructure access (Marinov et al., 2012; Pittman et al., 2020; Rokicki et al., 2021). A significant contributor to these issues is the use of outdated freight wagons – over 200 different types are currently in operation (DB Cargo,

\* Corresponding author.

E-mail address: [altun@log.tu-darmstadt.de](mailto:altun@log.tu-darmstadt.de) (A. Altun).

2026b) – originally designed for heavy industry loads. Additionally, the unreliable nature of SWL services stems from problematic cycles of tactical and operational management (Marinov et al., 2012).

To address these challenges and adapt to the evolving market, particularly the rise in containerised traffic, new concepts and technologies are imperative (Marinov et al., 2012). Innovative freight wagons are essential to prevent further erosion of SWL's market share (Hecht, 2014). Despite the significance of this issue, there is a notable research gap concerning the development and impact of innovative freight wagons. This gap exists even as several wagon manufacturers, such as Innofreight, TransANT, DB Cargo, and VTG, have begun to focus on developing specialised freight wagons for SWL transport. Comprehensive research is needed to fully understand the potential and impacts of these innovations.

The objective of this paper is to address how innovative freight wagons impact the competitiveness of SWL transport and how these innovations can help improve SWL's current market dynamics, leading to an increase in its modal share. This issue is investigated by conducting interviews with professionals of DB Cargo, a subsidiary of Deutsche Bahn AG (DB), a railway undertaking with the largest European rail network for SWL with around 12,000 freight wagons per day and various SWL services (DB Cargo, 2026a).

The paper is structured as follows. Firstly, an overview of the current state of SWL transport and recent technologies are introduced. Secondly, the methodology of the interview study is explained, including the single case study approach. Subsequently, the results of the interviews are outlined, demonstrating seven impacts of innovative freight wagons on the competitiveness of SWL transport. The last section describes the implications for managerial practice, offers a critical review and validation of the findings, and concludes with limitations and the contribution of this study to scholarly knowledge.

## 2. The state of the art of single wagon load transport

SWL transport has been a traditional form of production in rail freight transport ever since the railways were created (Marton & Koháni, 2007). The product is defined by single wagons or groups of wagons belonging to different senders being transported through a system of hubs to their respective recipients. Its multilevel network consists of smaller railway stations to larger shunting yards, allowing wagons from different origins (with different destinations) to be rearranged into outgoing trains with wagons with one specific destination (Saeednia et al., 2015). The SWL transport emphasises serving customers with direct rail network access to their premises. Industries such as steel, chemicals, and wood, which constitute the primary clientele for SWL transport, typically exhibit high traffic and cargo volumes. Consequently, they are more inclined to possess dedicated railway sidings, enabling more efficient handling of these volumes (Schäfer & Rabet, 2012).

Depending on their business models and cargo volumes, companies with their own railway sidings are likely to utilise block trains or SWL transport. From an economic perspective, the utilisation of SWL transport is more suitable in case of lower cargo volumes not suitable for block train composition. It eliminates the need to collect and store a sufficient quantity of goods, a process typical in block train transport. This results in a higher transport frequency in the SWL production form, as individual wagons and smaller groups of wagons can be loaded and transported more flexibly (Krauth & Haalboom, 2022). Moreover, SWL transport is deployed more in the field of piece goods as well as bulk goods. Thus, SWL transport proves to be especially suitable for goods that may experience fluctuations in inventory levels (Schäfer & Rabet, 2012).

Since SWL transport is known for the previously mentioned consolidation and shunting movements, it requires long transport times and consequently incurs higher costs for handling and shunting as well as delays (Saeednia, 2020). Conventional SWL freight wagons distinguish

themselves by their indivisible and welded unity of container and flat wagon, which is why there is a wide variety of different freight wagon types to accommodate the specific needs of customers from many industries. This variety however decelerates the shunting process (BNetzA, 2022). Reliability and lead times are the key factors for customers when choosing a form of transport (Wieberneit, 2008), presenting a challenge for SWL.

The fact that it also requires a given infrastructure like a railway siding or a different way of accessing the rail network with available capacities creates a lack of flexibility in this production form. Many private railway sidings have been deactivated over the past decades (Guglielminetti et al., 2014), due to downsizing strategies by railway undertakings to improve their financial situations by eliminating the least profitable business, SWL transport (Guglielminetti et al., 2017). In addition, there are many technical challenges such as the complexity of handling individual wagons and the high organisational effort for the disposition of these numerous individual transport orders with different destinations (Guglielminetti et al., 2014).

The combination of higher costs and lead times, a lack of flexibility, and infrastructure requirements is why a decrease in the modal share of the SWL transport can be observed, while shares of other forms of transport, especially road transport by trucks, are growing (Pittman et al., 2020; Rokicki et al., 2021). To improve the competitiveness of SWL transport, it is useful to look at innovative technologies within this production form.

## 3. Technologies in single wagon load transport

Recent technologies in SWL transport include technologies in the rolling stock, information and communication technologies (ICT), and infrastructure-related technologies. Developments in railway systems usually take a substantial amount of time to implement (Gleser & Elbert, 2024). Harris et al. (2015) mentioned the user, technology, and policy-related barriers to implementing new technologies like ICT. However, innovations in freight transport can improve various operations which can have positive impacts in the field (Baldini et al., 2010). Some of the factors that can experience improvement are productivity, reliability, and time efficiency, as well as safety through a reduction of collisions and accidents (Mutlu et al., 2017) which in return can contribute to accretion in the sector (Kiani Mavi et al., 2022). For this reason, a focused examination of SWL technologies is necessary.

One of the innovations that is expected to be implemented within the next five years and increase efficiency and the railway's green footprint is the digital automatic coupling system (Cantone et al., 2022; DB Cargo, 2024). In European freight transport and consequently, in the German rail freight sector, screw coupling is predominantly used to connect individual freight wagons to form trains. Although this technology is reliable, it is time-consuming, labour-intensive, and costly. As a result, it can be considered a competitive disadvantage in intermodal competition (BNetzA, 2022). The digital automatic coupling technology does not only couple wagons and connect compressed air and power lines but also allows freight wagons to exchange data, allowing for an automatic brake test, that significantly reduces the dispatch process of each train formation (Francisco et al., 2021). As frequent shunting and coupling movements to form new trains are a characteristic part of SWL transport (Islam et al., 2016), this innovation has a lot of potential for SWL transport in particular.

Further innovations include the autonomous shunting, which will facilitate a more efficient train formation and therefore strengthen the competitiveness of SWL transport (ITK Engineering GmbH, 2025). There are already test vehicles in use supporting the development of shunting locomotives equipped with the relevant technology (Reichmann et al., 2025; Samuel, 2022). Furthermore, in collaboration with ITK Engineering and Bosch Engineering, DB Cargo is working to refine automation technology to achieve series maturity. These automated hump locomotives are crucial because shunting operations frequently occur in

areas where personnel are present on the tracks, such as during the loading and unloading of wagons or at industrial sidings with unprotected level crossings (Reichmann et al., 2025). However, in the future, these traditionally manually performed tasks are expected to be taken over by fully automated hump locomotives (ITK Engineering GmbH, 2025).

Additionally, the effects of autonomous trains are being investigated, with many advantages expected from this innovation like improved security, decreased operational costs and emissions, as well as increased capacity and reliability of rail services (Singh et al., 2021).

The focus of this study is on innovative freight wagons. To enhance the competitiveness of rail freight transport and increase its market share, it is essential to construct new wagons and retrofit existing wagon fleets. Some authors argue that retrofitted wagons with specific technological innovations could contribute to greater economic efficiency, improved performance, and significant environmental benefits (Hecht, 2014; McKinsey, 2022). While individual wagons have already been replaced with containers as the transport unit in the intermodal transport system (Ferrari, 2018), freight wagons in SWL transport are often still not containerised. Using innovative freight wagons is expected to reduce lead times and ensure faster loading (Guglielminetti et al., 2014). Examples of these concepts include the InnoWaggon by Innofreight, TransANT by Rail Cargo Group, or the  $m^2$  freight wagon by DB Cargo. While each of these concepts has particular features, they all share one common characteristic: the separability of the container from the flat wagon. This is not possible for conventional SWL freight wagons, which are traditionally characterised by an indivisible and welded unity of container and flat wagon. The lack of rapid adaptability represents a significant weakness of conventional freight wagons, attributed to their long service life and robust vehicle structure. Given the diversity of wagons in SWL transport, driven by the varied requirements of different customers, flexibility is essential to accommodate various cargo types and logistical needs. To achieve greater flexibility various technologies are being explored that focus on the separate treatment of the flat wagon and superstructure (Islam et al., 2016). In the following, exemplary concepts are presented and compared briefly.

InnoWaggon is a modular freight wagon system by the Austrian freight transport and logistics company Innofreight Solutions, consisting of two short-coupled single flat wagons in four sizes,  $2 \times 30$  ft.,  $2 \times 40$  ft.,  $2 \times 45$  ft. and one with a length of 80 ft., allowing different types of superstructures to be attached to them for commodities of all SWL branches. The idea for this type of wagon emerged in 2011 and was realised only three years later. Meanwhile, over 22.000 containers on 3.500 InnoWaggon are being utilised all over Europe (Innofreight, 2026). If market conditions change, the superstructure and flat wagon can be reused separately. Although standard intermodal transport mounting pins are used, the superstructures are dimensioned according to the railway vehicle clearance profiles and are therefore not approved for road transport (Innofreight, 2026).

Another innovative freight wagon is TransANT, a lightweight and flexible platform concept with a payload-optimised design allowing the transportation of more goods per load. It was developed by Rail Cargo Group, an Austrian freight transport company, in collaboration with voestalpine, an Austrian steel and technology corporation. With its standardised platform and modular structure, it offers industry-specific freight transport solutions, especially for SWL industries as well as intermodal wagons (Rail Cargo Group, 2026). For a better understanding, both systems are depicted in Fig. 1.

The latest technology is the  $m^2$  freight wagon.  $M^2$  stands for multi-functional containers and modular flat wagons ( $m \times m = m^2$ ). It is a concept for freight wagon construction and deployment and was developed by DB Cargo in collaboration with VTG, an international railway logistics and wagon leasing company based in Hamburg, Germany, which – with over 84.000 wagons – owns the largest private wagon fleet in Europe (VTG GmbH, 2026).

As displayed in Fig. 2, the  $m^2$  flat wagon is modular, meaning it is adjustable in its length from eleven to twenty-two meters and therefore can match the customers' needs over the freight wagon's life cycle. This adjustment is possible without a renewed authorisation for placing on the market, as the  $m^2$  freight wagon has already been approved by the German Federal Railway Authority to be used for cross-border operations within the European network as of June 2021 (DB Cargo, 2021a; EBA, 2021), which facilitates the operational processes of possible adjustments of the flat wagon. Up to two multifunctional containers or superstructures can be loaded onto it, serving a variety of use cases. Besides, the  $m^2$  freight wagon is fully capable of being operated within the SWL network and riding over shunting humps (DB Cargo, 2021a; DB Cargo, 2021b).

Deutsche Bahn has the largest market share in Europe (BALM, 2023) and around 200 different types of wagons in operation (DB Cargo, 2026b). Therefore, innovative concepts like DB Cargo's  $m^2$  freight wagon, which is targeted to replace 70% of their fleet perspectively (DB Cargo, 2021a; DB Cargo, 2021b) could provide the necessary technology to realise SWL transport's potential. This context forms a key rationale for conducting a case study and interviews with DB Cargo. As the largest railway undertaking in Europe, DB Cargo offers invaluable insight into the workings, historical evolution, current state, and potential future directions of SWL transport.

Across manufacturers, the principal potentials of innovative freight wagons can be summarised into four key factors:

#### Potential A: increased flexibility for customer-specific requirements

According to the websites of Innowaggon, TransANT as well as DB Cargo, all three providers of innovative freight wagons promise their users a variety of detachable and interchangeable industry-specific superstructures that are compatible with partly adjustable modular flat wagons in different lengths. This will ensure a rapid adaptation of



Fig. 1. InnoWaggon RockTainer SAND by Innofreight (left) (Innofreight, 2026) and TransANT hopper wagon (right) (TransANT, 2026)



Fig. 2. The  $m^2$  freight wagon by DB Cargo (Author's work, photo by DB Cargo).

equipment to customer needs, even in case of a change in logistical needs.

*Potential B: enhanced vehicle load capacity*

Particularly, TransANT and Innowaggon promote the lightweight construction and high durability of their freight wagons, which allow an increased transport capacity. DB Cargo also advertises a higher availability of loading space. The goal of the wagon providers is to achieve a higher vehicle load capacity, enabling more goods to be transported per load and consequently reducing the number of trains needed, which in turn saves resources.

*Potential C: reduced downtimes*

By using detachable containers and flat wagons, the components can be used individually and therefore more efficiently, which reduces downtime (TransANT, 2026).

*Potential D: enhanced flexibility in maintenance processes*

Another area that benefits from the separability of flat wagons and containers is maintenance. This is mentioned by TransANT, who states that container and flat wagons can be maintained in workshops separately, which facilitates and speeds up the organisational process of maintenance.

These four potentials shall be analysed and finally compared against the seven identified impacts through the interview study to determine whether the interviewees concur, disagree or identify additional, previously unrecognised potentials for improvement.

**4. Methodology**

*4.1. Case study design*

The aim is to analyse how innovative freight wagon concepts allowing the separation of flat wagon and container in SWL transport can influence the competitiveness of this production form and help increase the modal share development of rail freight transport. To achieve this, the authors decided to adopt an exploratory single-case case study design.

This approach is particularly well-suited for this research because it allows for a deep, contextual and detailed analysis of a unique phenomenon that cannot be adequately captured through other methodologies (Yin, 2018). A single-case study is the best way to explore the complexities of SWL transport and innovative freight wagon concepts in a real-world setting.

The rationale for using a single case design, as outlined by Yin (2018), is that it can provide insights that extend beyond the specific case itself. In this study, the focus is on DB Cargo and their  $m^2$  freight

wagon concept, which represents a significant innovation within the rail freight sector (DB Cargo, 2021a; DB Cargo, 2021b). DB Cargo, being the largest railway operator in Europe, along with their collaboration with VTG as the leading railway logistics and wagon leasing company (VTG GmbH, 2026), offers a unique opportunity to understand the broader implications of this innovation for the SWL market and its operational processes. By concentrating on this single case, the impact of the  $m^2$  freight wagon concept on key factors such as cost, lead times, and infrastructure requirements can be thoroughly assessed. This focused approach enables us to generate insights that are not only specific to DB Cargo but also potentially applicable to the rest of the rail freight sector, aligning with Yin (2018) recommendation for using single-case studies to gain broader perspectives from in-depth analysis.

To collect data, professionals at DB Cargo working in the field of SWL and the market introduction of the  $m^2$  freight wagon, with eight to over 36 years of experience in the transport industry, were interviewed between August and October 2023. Their diverse expertise provides valuable insights into the future development of SWL in Germany and Europe. The interviewees' job descriptions and years of experience are listed in Table 1.

A semi-structured flexible interview protocol was conducted based on existing literature, company reports and statistics to allow different insights into the professionals' perspectives and domain knowledge. The

**Table 1**  
Interviewees' Job Descriptions and Years of Experience (Author's work).

Interviewees	Job Descriptions	Years of experience in the industry	Years of experience in the company
Interviewee A (I-A)	Head of Processes and Quality at the operational control unit	>34 years	>34 years
Interviewee B (I-B)	Consultant focusing on the steel fleet	>30 years	>12 years
Interviewee C (I-C)	Project Manager at the industrial sales division of product management	>12 years	>12 years
Interviewee D (I-D)	Freight wagon management, key figure calculations and development (turnaround time of freight wagons)	>8 years	>8 years
Interviewee E (I-E)	Senior project consultant for freight wagon control, expert in empty wagon management, damaged wagon management and stabling management	>27 years	>27 years
Interviewee F (I-F)	Freight wagon management, additional commercial agreements with partner rail freight undertakings, head of the national division	>16 years	>36 years

interview protocol is available in the Appendix.

Since the goal is to discover new rationales, open-ended questions related to the research questions were formulated (Dubois & Gadde, 2002). The interviews were designed to explore the impact of the  $m^2$  concept on its future competitiveness. Conducted with professionals from the same field and company, no contradictory statements were observed, but rather a quick saturation of viewpoints. To challenge these unified findings, a group interview was conducted with three professionals. Each professional was interviewed individually and simultaneously, providing an opportunity for in-depth responses and additional insights. While not strictly a focus group interview as per Krueger & Casey (2014), this approach allowed for dynamic interaction, fostering comprehensive discussions, and potentially generating new ideas and findings. Additionally, it proved to be efficient, collecting diverse perspectives within a relatively short timeframe. Using this method for data collection allowed triangulation of the literature and market research with the interview findings, providing a more in-depth understanding of the case. The consistent saturation of viewpoints, even following the group interview, was identified as the termination criterion for data collection, as no new insights were uncovered. The analysis identified impacts of containerisation on SWL, which have been categorised into specific subcategories to facilitate a more detailed examination of the data.

To avoid the risk of bias associated with exclusive interviews within one company and to improve the robustness of findings, five additional interviews were conducted to validate and cross-check the results. These interviewees, selected based on their professional roles within SWL transport or in competing transport modes, such as combined rail-road transport, and thereby ensuring a diversity of perspectives relevant to the study, consist of a regional manager overseeing several container terminals at a company engaged in intermodal transport operations (M-A in Table 2), a business development manager from a rail freight company also active in the field of combined transport (M-B in Table 2), a senior logistics network manager possessing extensive knowledge of the logistics and transport sector, as well as a wide professional network (M-C in Table 2), and the general manager and logistics manager of a railport facility (M-D and M-E in Table 2). Including perspectives from both terminal operators and service providers allowed us to ground the validation process in the practical knowledge of individuals with direct experience in the transshipment of intermodal loading units, which is an essential focus of the analysis. A summary of the interviewees' job descriptions and years of professional experience is provided in Table 2. The validation interview protocol is available in the Appendix.

#### 4.2. Interview design and process

To set up the interviews, the interviewees were contacted via e-mail and informed about the topic and background of the study, enabling them to prepare in advance. Three individual interviews of approximately 30 min each and one group interview with three participants lasting approximately 45 min were conducted. All interviews were

**Table 2**  
Logistics Managers' Job Descriptions and Years of Experience (Author's work).

Managers	Job Descriptions	Years of experience in the industry
Manager A (M-A)	Regional Manager of multiple Container Terminals	>23 years
Manager B (M-B)	Business Development Manager of a Rail Freight Transport Company	>10 years
Manager C (M-C)	Senior Logistics Network Manager	>15 years
Manager D (M-D)	Manager of a Railport	>10 years
Manager E (M-E)	Logistics Manager of a Railport	>10 years

carried out via Microsoft Teams.

To be able to analyse the interview data, the interviews were recorded with the permission of the interviewees and later transcribed using the transcription tool Sonix as well as proofread for any transcription errors. After that, the transcriptions have been imported into MAXQDA, a software for qualitative data analysis. Within this software, the interviews were read again and coded using the fundamental types of open, axial and selective coding from grounded theory (Corbin & Strauss, 2014) to form categories.

To illustrate the analysis process, exemplary text segments were categorised, and these categories were consolidated into a cohesive framework in Fig. 3.

To ensure the quality of the case study, a rigorous research design was pursued (see Table 3) following the four criteria of construct validity, internal validity, external validity and reliability (Gibbert et al., 2008; Yin, 2018).

To validate the findings, managers from related but competing fields, such as combined transport, as well as those with a specific focus on SWL transport, including managers operating a railport, were selected. This approach ensured diverse yet industry-relevant perspectives. Validation sessions were conducted via video or phone calls, with meetings lasting 15 to 30 min. During these sessions, managers were presented with the study's findings and asked for their feedback, including whether they agreed or disagreed with the results and any critiques of the findings or methodology. The interview responses were summarised as key points and subsequently categorised into thematic areas, including agreement with findings, specific experiences with SWL transport and innovative freight wagons, as well as suggestions for improving the production form. This systematic analysis provided insights into recurring patterns and key critiques, which were then integrated into the conclusions. A detailed summary of this feedback is presented in Chapter 6 of this paper.

### 5. Findings: impacts of innovative freight wagons on SWL transport

This section discusses the impacts of the  $m^2$  freight wagon on SWL transport. As facilitated by this technology, features such as the separability of the container and flat wagons, lead to the transformation of operational processes and key figures for both customers and railway undertakings.

#### 5.1. Impact 1: reduced turnaround times and costs

A freight wagon is a critical asset, incurring expenses whether in use or idle. These expenses, including taxes, insurance, maintenance, and inspections, contribute significantly to SWL operational costs (I-B, I-C).

While a conventional freight wagon needs to be transported to a customer and left there overnight to load, with the  $m^2$  freight wagons, a pre-loaded container can be transhipped onto the flat wagon and leave the customer's site immediately after, reducing downtimes due to waiting or loading significantly. This leads to shorter turnaround times and in return allows to serve more transport requests in the same period (I-C, I-E). This means that by separating flat wagon and container it is possible to maximise wagon utilisation.

#### 5.2. Impact 2: increased efficiency of processes at customers' sidings

The  $m^2$  concept is especially viable for industries that are already using the SWL transport (I-C). Compared to conventional SWL freight wagons, which are a welded unity of container and flat wagon, with the  $m^2$  freight wagons customers can take off the containers, use them as a buffer or storage space at their siding, stack them next to or on top of each other, and save time by pre-loading containers before the arrival of the "pick-up" flat wagon (I-A, I-B, I-C). This allows an optimisation of intra-logistics by allowing not only rail but also truck transport of the

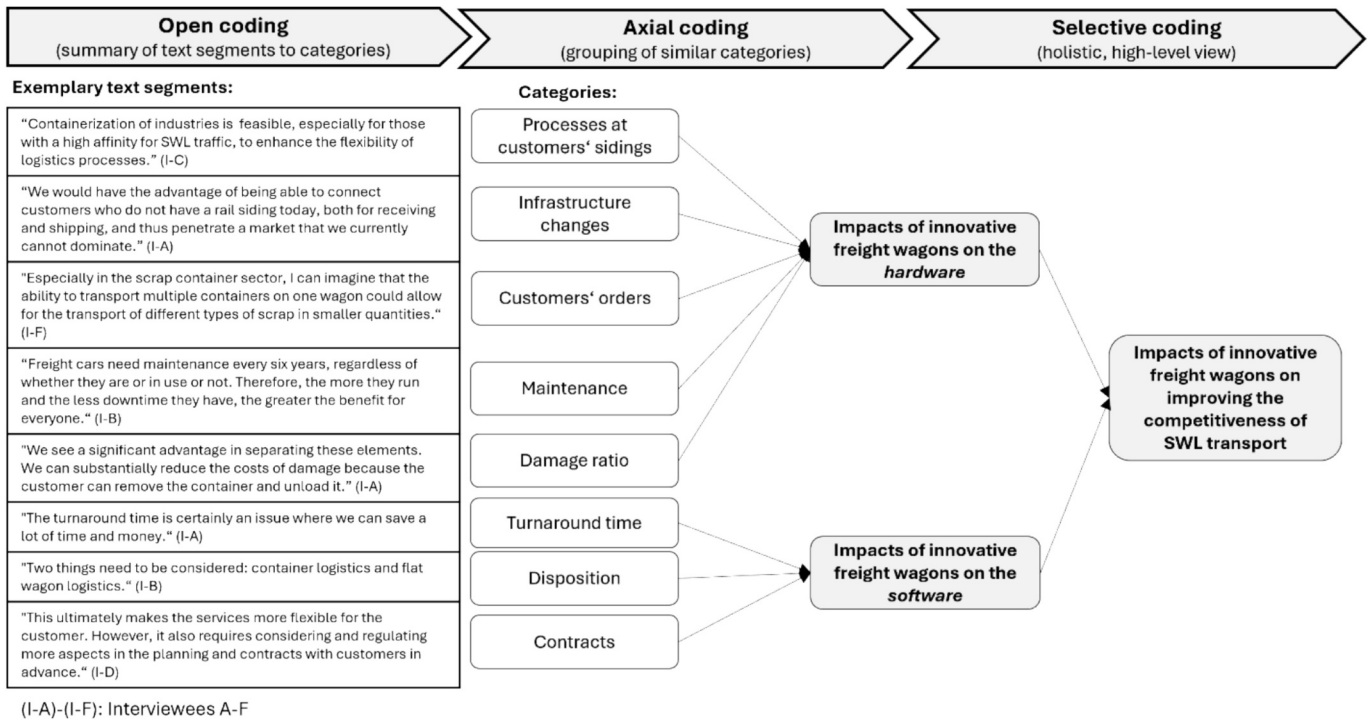


Fig. 3. Illustrated Process of the Interview Analysis (Author's work, inspired by Friedrich et al. (2024)).

Table 3  
Quality measures of the case study.

Design Tests	Fulfilment of test	Measures implemented in this study
Construct validity	Identifying correct operational measures for the studied case to ensure data collection leads to the precise observation of reality (Denzin & Lincoln, 2017; Yin, 2018)	Review of interview recordings and transcripts; coding of transcripts in software MAXQDA to build categories; triangulation of interview data with data from literature and internet search.
Internal validity	Establishing a causal relationship to defend research conclusions (Gibbert et al., 2008; Yin, 2018)	Not for exploratory studies (Yin, 2018).
External validity	Analytical generalisation of the case study's findings (Gibbert et al., 2008; Yin, 2018) as well as a rationale for the case study selection (Cook & Campbell, 1979; Gibbert et al., 2008)	Using "how" and "why" research questions, to arrive at an analytical generalisation more easily. Provision of detailed case study context, allowing the reader to comprehend the case selection: lack of previous work on potentials of innovative freight wagons on the competitiveness of the SWL transport; a need for exploration on this specific topic by collecting data from professionals within the rail freight industry.
Reliability	Repetition of research design will lead to the same result (Yin, 2018)	Documented interview protocol for data collection as well as usage of software MAXQDA for data analysis and storage, ensuring a transparent research process.

containers on the company's premises' infrastructure, which creates unmatched flexibility. In the foreseeable future, this would also enable the handling of containers using autonomous reach stackers, capable of autonomously transporting standardised containers to a designated unloading point (I-C).

Next to (pre-)loading, this innovative technology also allows more efficient and flexible unloading. By being able to take off the container from the flat wagon, unloading can be done by tilting and turning the container, rather than by cranes or dredging, which represents a far more time-consuming process. Unloading by tilting and turning also requires less staff for shunting movements (I-A, I-C).

An additional security measure provided by m<sup>2</sup> freight wagon design enables them to withstand shunting movements without the risk of containers falling off. Freight wagons of the combined transport lack this ability, due to the G-forces that emerge when pushed over the shunting hump resulting in containers falling off (I-B).

### 5.3. Impact 3: enhanced infrastructure accessibility

A critical requirement for industrial customers considering traditional SWL transport is access to a rail siding, which is essential for ensuring seamless transportation from origin to destination. Access to rail siding serves as a requirement difficult to fulfil due to the rail network's rigidity compared to the extensive reach and accessibility of the road network (Islam et al., 2016). Establishing a rail siding entails meeting a series of requirements, including the appointment of a rail operations manager, expertise in rail freight operations and freight transport, and adherence to industry-specific logistics standards. However, for a railway infrastructure company, constructing a rail siding for a customer with minimal weekly freight volume, say three or four wagons, proves cost-inefficient (I-C, I-F). Economic viability necessitates a certain scale of shipments, making rail siding accessibility a persistent challenge for many customers seeking rail transport solutions (I-A, I-F). While transshipping loading units at a so called railport presents an alternative for customers without access to rail sidings that still wish to transport goods by rail (DB Cargo, 2020), this additional step may deter them from opting for rail transport, leading them to favour road transport for the primary leg, especially if it's already required for pre- and possibly post-haulage.

An important contribution of deploying separable containers and flat wagons in SWL transport is extending the access points, which are currently limited to customers with own rail sidings. For customers

without a rail siding, a transport of goods per rail in the SWL system would involve the delivery of the commodities per truck to a railport, where they can be loaded onto a freight wagon, which is very time-consuming. However, utilising the separable wagon technology eliminates the need for unloading and loading the commodities at the railport. The commodities can be loaded into the containers at the customers' sites', just like in combined transport, and transported to railports, terminals, or other transshipment points, and still make use of the SWL system after being transhipped onto flat wagons.

Increased accessibility to the SWL network would contribute to re-establishing SWL in new markets, not available to it initially due to a lack of rail sidings and high costs for handling goods at transshipment points (I-A, I-C, I-F). This increased accessibility and flexibility would improve the competitiveness of SWL compared to road transport.

#### 5.4. Impact 4: increased flexibility for customers' ordering options

A containerisation of SWL transport would significantly impact processes at customers' sites. One factor is the altered size of containers, while another is the modular design of  $m^2$  flat wagons, allowing for the placement of up to two containers. Compared to traditional SWL, customers need to provide more detailed specifications when ordering freight wagons. They can choose to order containers exclusively, specifying the container type, or flat wagons only, to tranship pre-loaded containers, or a combination of flat wagons and containers (I-A).

The SWL primarily serves industries like steel and scrap, where the latter encompasses a wide array of scrap types. In the scrap industry, the ability to load two multifunctional containers on one flat wagon can revolutionise loading processes. These containers can accommodate smaller quantities of various pre-sorted scrap types, facilitating homogeneous transport. This proves advantageous for scrap dealers, enabling them to adjust their scrap offerings based on demand for specific types, and for steel manufacturers, who save time on sorting scrap (I-A, I-F).

#### 5.5. Impact 5: enhanced flexibility in maintenance processes

Freight wagons need to be maintained regularly, either to be repaired when a defect is detected or after a certain period as preventative maintenance (Bigi et al., 2024). According to the interviewees, maintenance capacities in the European market are relatively limited due to constraints on components like wheelsets, which are expensive to manufacture due to their specific requirements. There are only a few companies capable of producing these wheelsets, which results in bottlenecks. The combination of insufficient maintenance capacities and these bottlenecks lead to wagon fleets waiting outside workshops for repairs, incurring both time and costs (I-A). The separation of the flat wagon and container consequently enables individual treatment of damages. If either is damaged the other part can resume service ensuring continuous utilisation and again minimising the downtime of the non-damaged part.

Another aspect to consider is that the flat wagon as a vehicle, and the containers as loading units, are subject to different maintenance regulations. Traditional freight wagons are considered vehicles and are subject to vehicle maintenance regulations, which are more expensive than the maintenance of loading units. By separating these two components, the maintenance of the container attachments can be carried out more flexibly at container maintenance workshops which are certified according to different principles and therefore naturally have different, more affordable cost blocks. Similar to the trucking industry, this prevents the need for the whole freight wagon to visit expensive, highly qualified, audited vehicle maintenance workshops. This would disburden the vehicle maintenance workshops, leading to fewer spare parts needed to be kept in stock, which in turn would reduce the operational costs of these workshops (I-A).

Conversely, one interviewee implies that the separability of the flat wagon and container may result in additional maintenance

requirements, primarily at the interface between the two components of the  $m^2$  freight wagon. Compared to conventional SWL freight wagons, which do not involve separation, this interface could experience increased wear and tear over time. However, since the interface is less exposed than that of a container wagon in combined transport, and assuming that the separation frequency is similar, the associated maintenance needs are likely to remain within a manageable range and not exceed what is typically encountered in combined transport operations (I-E).

#### 5.6. Impact 6: lower damage rate of freight wagons

Freight wagons utilised in rugged industries like steel and scrap are particularly susceptible to extensive damage. To maximise volume capacity, scrap material is tightly packed into containers using large magnets, compressing the material and exacerbating wear and tear on the wagons. These forces not only cause damage during loading but also during unloading at steel producers, leading to significant wear on both the wagons and peripheral devices. This is especially inconvenient when it impacts critical components like brake changeover devices, which, if damaged, entail expensive repairs. This leads to an increased damage rate in this industry compared to e.g. steel coils. Often, identifying the responsible party proves challenging, resulting in these financial losses being absorbed into general costs, leading to an increase in the average price in the scrap market (I-A).

By using separable flat wagons and containers, damage costs may be reduced. Customers can take off the container and compress the material in it without damaging the flat wagon or unload the container with qualified tilting equipment, where the contents of the container are unloaded by gravitational force after turning (I-A). This will decrease the damage rate on the containers and especially on the flat wagons, which will be less likely to be damaged by these transshipment and unloading processes. This reduction of costs positively impacts the economic outcome of railway companies offering transport services and assets and in return allows a reduction of costs for customers.

#### 5.7. Impact 7: more flexible, but complex disposition of flat wagons and containers

Currently, logistics operations in the SWL follow a specific pattern. Typically, freight wagons are shunted to the customer in the morning. After loading or unloading at the customer, they are retrieved by the railway undertaking in the afternoon or the following day. This results in the freight wagons remaining at the customer's location for approximately 24 h (I-B).

Switching to separable containers changes this pattern. Depending on the order, flat wagons with or without containers are being shunted to the customer. If containers are delivered, they can either remain at the customer if they are needed on-site, dispatching the flat wagon back to the shunting station without containers, or if the customer has pre-loaded and ready-to-ship containers, they can simply transfer them onto the flat wagon, ideally allowing the departure of the train with the same shunting trip, which would reduce turnaround times by two days for pick-up and delivery, for example. Hence, transshipping containers proves to be significantly less time-consuming than loading and shunting, provided the customer possesses the necessary handling equipment (I-D, I-E).

The utilisation of both assets separately introduces an intriguing dimension. Presently, the smallest unit size is represented by the "freight wagon number" or "vehicle number." Under the current system, the IT of the railway undertaking has complete control over the freight wagon.

However, in the future, the smallest unit size becomes the container, each with an individual "container number", proclaiming a new control parameter and fundamentally changing the conventional "freight wagon" to a "carrying vehicle" or flat wagon. While the flat wagon will stay on the rail, the container can be taken off and is therefore only

controllable to a certain extent. The detachment from the flat wagon implies a loss of determinability over its subsequent disposition (I-E, I-F). The challenge is going to be the management of the containers beyond the rails. To help with this challenge, the containers will be equipped with GPS sensors. This way, they can be traced and tracked within the system. Not only will the containers be separated from the flat wagon in reality, but also operationally within the system. This also constitutes a challenge, since establishing a new core data logic with container numbers as well as flat wagon numbers within a company's software is not easily done (I-D, I-E, I-F).

Furthermore, it is essential to ensure the compatibility between flat wagons and containers, considering factors such as the length of the flat wagon, its current condition, and other pertinent parameters. For the customer, receiving the ordered flat wagon-container combination is primary. Adherence to agreed-upon terms, such as refraining from unilaterally retaining a container without prior coordination with the railway undertaking due to perceived necessity, underscores the critical importance of communication between the customer and the railway undertaking (I-E, I-F).

## 6. Conclusion

### 6.1. Discussion of findings and implications for managerial practice

This paper presents the results of studying the potentials of innovative freight wagons, identifying four main ones, including more flexibility for customer-specific requirements, enhanced vehicle loading capacity, reduction of downtimes as well as more flexible maintenance processes.

Through the conducted interviews, it was found that the identified potentials correspond to the interviewees' expected impacts of innovative freight wagons, particularly the m<sup>2</sup> freight wagon, on processes of SWL transport. One of the potentials that was not mentioned by the interviewees is the enhanced vehicle load capacity. The authors suggest that the focus of the interview study was more on the technology and its impacts on processes, rather than on the change in parameters such as load capacity, which could be why it has not been mentioned. Additional impacts that were identified are the increased efficiency of processes at customers' sidings, enhanced infrastructure availability, lowered damage rates of freight wagons, as well as the more flexible but complex disposition of flat wagons and containers, despite the apparent nature of the latter. Based on the interview study, impacts of innovative freight wagons in SWL transport could be found that had not been apparent through prior literature and market research. To summarise and compare the potentials found through this prior research and the impacts found through the interview study, the results have been illustrated in Fig. 4.

This study addresses various challenges and opportunities for managerial practice in the transport industry. Understanding these implications is essential for developing strategies to enhance the efficiency

and competitiveness of SWL transport. The findings highlight critical challenges of SWL transport, including higher costs and lead times, intense competition from road freight, and limited infrastructure accessibility. To address these challenges and enhance managerial practices in the transport industry, stakeholders should adopt measures to improve the competitiveness of SWL transport. Using technologies such as the m<sup>2</sup> freight wagon, which allows a containerisation of SWL transport, could improve key processes within this production form, including those at the customers' sidings, maintenance, and damage rates of freight wagons. Measures for improvement in this area could include establishing information and communication systems that provide data about each order, container, and flat wagon. This will optimise operational processes such as disposition and maintenance planning, and in return decrease turnaround times as well as maintenance costs, which will lead to competitive pricing for SWL services. This will benefit not only the customers but also railway undertakings providing these services. However, the findings do not consider the comparatively high empty weight of the m<sup>2</sup> container, which is attributable to the robust construction required to endure the demands of the steel scrap industry (DB Cargo, 2021a). This design results in higher production costs compared to competing solutions. For this innovation to be successfully introduced to the market and achieve long-term adoption, these factors must be addressed. This, in combination with the key strategies mentioned in the findings, will enhance the competitiveness and sustainability of SWL transport in the future.

### 6.2. Validation and critical review of SWL and innovative freight wagons

As outlined in Chapter 4, validation interviews were conducted with five logistics managers to corroborate the study's findings, elicit constructive feedback, and identify potential critiques. During each interview, the core results, specifically, the four identified potentials and seven key impacts of innovative freight wagons, were presented. Interviewees were asked whether these findings aligned with their own professional experiences and assessments, and were explicitly encouraged to return any critiques or disagreements to ensure open and unbiased responses.

All interviewees confirmed that the presented findings were plausible and consistent with their understanding of the current state of SWL transport. No participant expressed disagreement or questioned the validity of the identified potentials and impacts. The discussions revealed broad consensus regarding the relevance of the findings and the important role that innovative freight wagons may play in enhancing SWL transport.

Nevertheless, while the potential of innovative freight wagons was widely acknowledged, interviewees consistently emphasised that the future success of SWL transport is contingent upon addressing significant organisational and infrastructural barriers. Drawing on their operational experience, participants offered valuable practical insights into existing limitations and reflected on how innovation in wagon

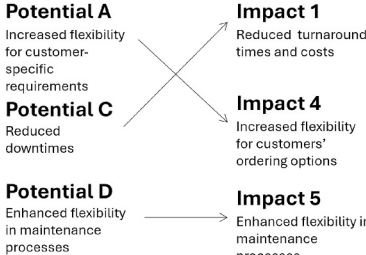
Matching potentials and impacts	Potentials from market search, not mentioned by interviewees	Impacts stated by interviewees, not recognized in prior market search
<p><b>Potential A</b> Increased flexibility for customer-specific requirements</p> <p><b>Potential C</b> Reduced downtimes</p> <p><b>Potential D</b> Enhanced flexibility in maintenance processes</p> <p><b>Impact 1</b> Reduced turnaround times and costs</p> <p><b>Impact 4</b> Increased flexibility for customers' ordering options</p> <p><b>Impact 5</b> Enhanced flexibility in maintenance processes</p> 	<p><b>Potential B</b> Enhanced vehicle load capacity</p>	<p><b>Impact 2</b> Increased efficiency of processes at customers' sidings</p> <p><b>Impact 3</b> Enhanced infrastructure accessibility</p> <p><b>Impact 6</b> Lower damage rates of freight wagons</p> <p><b>Impact 7</b> More flexible, but complex disposition of flat wagon and containers</p>

Fig. 4. Results of the comparison of potentials and impacts of innovative freight wagons (Author's work).

technology could contribute to overcoming them. Despite critical observations, there was shared agreement that SWL transport offers substantial potential, provided it is effectively organised and supported by an enabling operational framework. The following section details the individual perspectives and contributions of each interviewee.

One of the interviewees (M-A in Table 2) explained that despite their primary focus on combined transport, SWL services are occasionally handled at their facilities. In those cases, the feeder train operations from the shunting hub to their terminal are typically managed by railway undertakings that already oversee combined transport train services to the terminal, ensuring a relatively smooth process for both types of transport. However, challenges occur when single wagons occupy tracks needed for the arrival and transshipment of large combined transport trains, underscoring the importance of well-coordinated feeder train services for last-mile operations. According to the terminal manager M-A, organising SWL traffic is particularly complex, requiring coordination across multiple stakeholders, which makes it less appealing to terminal operators. If not properly managed, SWL operations can disrupt terminal efficiency by blocking critical infrastructure. Additionally, containers of SWL transport can involve diverse types, some requiring specialised handling methods prone to errors, such as attachment of chains for transshipment. While SWL is acknowledged as important and manager M-A generally agrees with the study's findings, effective organisation is essential to avoid operational disruptions. To minimise interference with combined transport terminal activities, M-A recommends that SWL traffic be managed through dedicated facilities such as railports.

Following this proposition, follow-up interviews were conducted (M-D and M-E in Table 2). At their railport, SWL transport primarily involves the handling of food products and palletised goods, which are typically unloaded from sliding wall wagons upon arrival and subsequently transferred to trucks for final delivery. Despite unfamiliarity with the  $m^2$  freight wagon technology attributed to their lack of involvement in scrap metal transport, they expressed strong interest in the concept of containerised SWL transport. The ability to transship only the container, without the need to reload goods between different transport units, was seen as a significant improvement in operational efficiency. They emphasised the potential benefits of developing innovative freight wagons tailored specifically to palletised goods within SWL operations.

Additional critical perspectives emerged in two follow-up interviews (M-B and M-C in Table 2). While acknowledging the development of innovative freight wagons for SWL transport as a positive advancement, particularly in enhancing the attractiveness of loading processes, they emphasised further improvements beyond such innovations to maintain the long-term competitiveness of SWL, especially when compared to road transport. A primary challenge SWL is facing is the extended lead times caused by frequent delays, which stem from complex organisational processes such as consolidations at shunting hubs and smaller railway stations. While the introduction of innovative wagons is a valuable step, it does not sufficiently address the fundamental inefficiencies in the current organisational structure of SWL. For instance, scepticisms were expressed regarding the widespread and spatially comprehensive adoption of digital automatic coupling technology (M-B). Moreover, although railports are used for SWL, it was noted that their utilisation remains limited, and bottlenecks at shunting hubs persist, which were contributed to delays (M-C). It was emphasised that SWL requires a fundamental transformation beyond technological innovation to include a comprehensive rethink of its operational organisation. Containerisation, for instance, would reduce differences from combined transport and could facilitate improvements. Ultimately, a thorough analysis of market demand is essential to guide the evolution of SWL into a more competitive and efficient transport system.

## 7. Limitations and contribution to scholarly knowledge

The methodological choice of a single case study results in findings being based on the insights shared by employees of the company working on the  $m^2$  freight wagon technology. Viewpoints of professionals with different functions and levels of experience in the rail freight transport sector were presented, however only a limited number of interviewees were included. To address this limitation and enhance the robustness of the findings, validation interviews with five additional logistics managers from different organisations were conducted. These interviews provided constructive feedback and critical perspectives, helping to corroborate and contextualise the initial insights.

While the exploration of innovative solutions, such as the  $m^2$  freight wagon technology, offers a practical framework for enhancing SWL transport efficiency and competitiveness, this research lays the groundwork for future studies to delve deeper into the operational processes such as the disposition of the containers and flat wagons of separable SWL freight wagons of not only the  $m^2$  technology, but also different innovative freight wagon providers, and investigate their impacts on the competitiveness of SWL transport.

Moreover, examining the long-term impacts of implementing these technologies on the transport chain, as well as freight demand patterns, is an important direction which impacts the planning of SWL transport as an integral part of rail freight transport. Scholars may also investigate the potential for integrating advanced information systems, digitalisation and data analytics to further optimise operational efficiencies and reduce costs.

Another promising area for future research is the exploration of infrastructure enhancement strategies to improve accessibility to rail transport, examining how targeted investments and policy measures can support the availability and capacity of railports, terminals and shunting yards. Exploring customer perceptions and satisfaction with SWL transport innovations could help tailor future advancements to meet market demands effectively. Lastly, it is crucial to emphasise the need for further research focused on the fundamental transformation of SWL transport beyond technological innovations, including a comprehensive re-evaluation of the operational organisation.

### CRedit authorship contribution statement

**Aylin Altun:** Writing – original draft, Methodology, Investigation, Data curation, Conceptualization. **Ralf Elbert:** Writing – review & editing, Supervision. **Mahnam Saeednia:** Writing – review & editing.

### Funding

None.

### Declaration of competing interest

None.

### Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.rtbm.2026.101611>.

### Data availability

No data was used for the research described in the article.

### References

- Baldini, G., et al. (2010). An early warning system for detecting GSM-R wireless interference in the high-speed railway infrastructure. *International Journal of Critical Infrastructure Protection*, 3, 140–156. <https://doi.org/10.1016/j.ijcip.2010.10.003>

- Bigi, F., Bosi, T., Pineda-Jaramillo, J., Viti, F., & D'Ariano, A. (2024). Long-term fleet management for freight trains: Assessing the impact of wagon maintenance through simulation of shunting policies. *Journal of Rail Transport Planning and Management*, 29, Article 100430.
- Bundesamt für Logistik und Mobilität (BALM) (Federal Agency for Logistics and Mobility). (2023). Anteil der DB Cargo und der Wettbewerber (NE-Bahnen) an der Verkehrsleistung im deutschen Schienengüterverkehr in den Jahren 2013 bis 2022. Accessed on June 10<sup>th</sup>, 2024 <https://de.statista.com/statistik/daten/studie/738594/umfrage/anteil-an-verkehrsleistung-im-deutschen-schienengueterverkehr-nach-akteuren/#:~:text=Der%20Anteil%20am%20Verkehrsaufkommen%20im,be%20rund%2067%20Prozent%20gelegen.>
- Bundesamt für Logistik und Mobilität (BALM) (Federal Agency for Logistics and Mobility). (2024). Anteil der Eisenbahn an der Transportleistung im Güterverkehr in Deutschland in den Jahren von 2013 bis 2027 und das Ziel der aktuellen Bundesregierung für das Jahr 2030 (laut Modal-Split). Statista Accessed on June 17<sup>th</sup>, 2024 <https://de.statista.com/statistik/daten/studie/12200/umfrage/anteil-der-eisenbahn-am-gueterverkehr-in-deutschland/>.
- Bundesministerium für Digitales und Verkehr (BMDV) (Federal Ministry for Digital and Transport). (2020). Masterplan Schienenverkehr, Berlin. <https://www.bmdv.bund.de/SharedDocs/DE/Anlage/E/masterplan-schienenverkehr.pdf>.
- Bundesnetzagentur (BNetzA) (Federal Network Agency). (2022). Sondererhebung Einzelwagenverkehr – Marktstrukturen und Wirtschaftlichkeit. [https://data.bundesnetzagentur.de/Bundesnetzagentur/SharedDocs/Downloads/DE/Sachgebiete/Eisenbahn/Unternehmen\\_Institutionen/Veroeffentlichungen/Marktuntersuchungen/Sondererhebung/ewv\\_bericht.pdf](https://data.bundesnetzagentur.de/Bundesnetzagentur/SharedDocs/Downloads/DE/Sachgebiete/Eisenbahn/Unternehmen_Institutionen/Veroeffentlichungen/Marktuntersuchungen/Sondererhebung/ewv_bericht.pdf).
- Cantone, L., Durand, T., Ottati, A., Russo, G., & Tione, R. (2022). The digital automatic coupler (DAC): An effective way to sustainably increase the efficiency of freight transport in Europe. *Sustainability*, 14(23), Article 15671. <https://doi.org/10.3390/su142315671>
- Cook, T. D., & Campbell, D. T. (1979). *Quasi-experimentation. Design & analysis issues for field settings*. Rand McNally.
- Corbin, J., & Strauss, A. (2014). *Basics of qualitative research: Techniques and procedures for developing grounded theory*. Sage publications.
- DB Cargo. (2020). A railport for (almost) everything Accessed on June 17<sup>th</sup>, 2024. URL: <https://www.dbcargo.com/rail-de-en/logistics-news/railport-fichtl-5149812>.
- DB Cargo. (2021a). Der Güterwagen der Zukunft: multifunktional und modular Accessed on June 17<sup>th</sup>, 2024. URL: <https://www.dbcargo.com/rail-de-de/gruen-und-innovativ/innovationen/m2-wagen>.
- DB Cargo. (2021b). So sieht der Güterwagen der Zukunft aus Accessed on June 17<sup>th</sup>, 2024. URL: <https://www.dbcargo.com/rail-de-de/logistik-news/so-sieht-der-gueterverkehr-der-zukunft-aus-6166412>.
- DB Cargo. (2024). DACFIT: Ein Meilenstein für die Digitale Automatische Kupplung Accessed on August 15<sup>th</sup>, 2024. URL: <https://www.dbcargo.com/rail-de-de/logistik-news/dacfit-ein-meilenstein-fuer-die-dak-12822814>.
- DB Cargo. (2026a). Single wagonload transport: flexible and all-encompassing. URL <http://www.dbcargo.com/rail-de-en/services/Rail-transport-services/Single-wagon-load-transport#:~:text=What%20is%20single%20wagonload%20transport,to%20form%20a%20complete%20train.>
- DB Cargo. (2026b). Freight wagon catalogue Accessed on June 17<sup>th</sup>, 2024. URL <https://gueterverkehr.katalog.dbcargo.com/catalogue>.
- Denzin, N. K., & Lincoln, Y. S. (2017). *The SAGE handbook of qualitative research* (5th ed.). Sage Publications.
- Dubois, A., & Gadde, L.-E. (2002). Systematic combining: An abductive approach to case research. *Journal of Business Research*, 55(7), 553–560. [https://doi.org/10.1016/S0148-2963\(00\)00195-8](https://doi.org/10.1016/S0148-2963(00)00195-8)
- Eisenbahn-Bundesamt (EBA) (German Federal Railway Authority). (2021). Markteinführung des innovativen modularen Güterwagens m<sup>2</sup>. URL [https://www.eba.bund.de/Z-SGV/Projekte/laufende\\_Projekte/m2/m2\\_node.html](https://www.eba.bund.de/Z-SGV/Projekte/laufende_Projekte/m2/m2_node.html).
- European Commission. (2011). *Transport WHITE PAPER roadmap to a single European transport area – Towards a competitive and resource efficient transport system*. Brussels.
- European Commission. (2022). Railway freight transport statistics Accessed on May 9<sup>th</sup>, 2024. [https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Railway\\_freight\\_transport\\_statistics#Germany\\_recorded\\_the\\_highest\\_rail\\_freight\\_transport\\_performance\\_in\\_the\\_EU](https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Railway_freight_transport_statistics#Germany_recorded_the_highest_rail_freight_transport_performance_in_the_EU)
- Ferrari, P. (2018). Some necessary conditions for the success of innovations in rail freight transport. *Transportation Research Part A: Policy and Practice*, 118, 747–758. <https://doi.org/10.1016/j.tra.2018.10.020>
- Francisco, F., et al. (2021). Is large technological investment really a solution for a major shift to rail? A discussion based on a Mediterranean freight corridor case study. *Journal of Rail Transport Planning and Management*, 19. <https://doi.org/10.1016/j.jrtpm.2021.100271>
- Friedrich, A., Lange, A., & Elbert, R. (2024). Business models for logistics service providers in industrial additive manufacturing supply chains. *The International Journal of Logistics Management*, 35(2), 364–394. <https://doi.org/10.1108/IJLM-04-2022-0165>
- Gibbert, M., Ruigrok, W., & Wicki, B. (2008). What passes as a rigorous case study? *Strategic Management Journal*, 29(13), 1465–1474. <https://doi.org/10.1002/smj.722>
- Gleser, M., & Elbert, R. (2024). Combined rail-road transport in Europe—a practice-oriented research agenda. *Research in Transportation Business & Management*, 53, Article 101101. <https://doi.org/10.1016/j.rtbm.2024.101101>
- Guglielminetti, P., et al. (2014). *Study on single wagonload traffic in Europe-challenges prospects and policy options*. European Commission.
- Guglielminetti, P., et al. (2017). Rail freight network in Europe: Opportunities provided by re-launching the single wagonload system. *Transportation Research Procedia*, 25, 5185–5204.
- Harris, I., Wang, Y., & Wang, H. (2015). ICT in multimodal transport and technological trends: Unleashing potential for the future. *International Journal of Production Economics*, 159, 88–103.
- Hecht, M. (2014). Innovative rail freight wagons – A precondition to increase the market-share of rail freight. *Archives of Transport*, 29(1), 17–26.
- Innofreight. (2026). Company website. URL <https://www.innofreight.com/logistik/innowaggon/>.
- Islam, D. M. Z., Ricci, S., & Nelldal, B. L. (2016). How to make modal shift from road to rail possible in the European transport market, as aspired to in the EU transport White paper 2011. *European Transport Research Review*, 8, 18. <https://doi.org/10.1007/s12544-016-0204-x>
- ITK Engineering GmbH. (2025). ITK Engineering and DB Cargo develop fully automated shunting locomotive for series production Accessed on April 29<sup>th</sup>, 2025. URL: [https://www.itk-engineering.de/wp-content/uploads/2025/04/2025-04-11\\_press\\_release\\_DB\\_Cargo.pdf](https://www.itk-engineering.de/wp-content/uploads/2025/04/2025-04-11_press_release_DB_Cargo.pdf).
- Kiani Mavi, R., Kiani Mavi, N., Oлару, D., Biermann, S., & Chi, S. (2022). Innovations in freight transport: A systematic literature evaluation and COVID implications. *The International Journal of Logistics Management*, 33(4), 1157–1195. <https://doi.org/10.1108/IJLM-07-2021-0360>
- Krauth, M., & Haalboom, D. (2022). An economic view on rerouting railway wagons in a single wagonload network to avoid congestion. *European Transport Research Review*, 14, 48. <https://doi.org/10.1186/s12544-022-00573-y>
- Krueger, R. A., & Casey, M. A. (2014). *Focus groups: A practical guide for applied research* (5th ed.). Sage publications.
- Marinov, M., Woroniuk, C., & Zunder, T. H. (2012). *Recent developments with Single Wagon Load services, policy and practice in Europe. 2012 federated conference on computer science and information systems (FedCSIS)*. IEEE.
- Marton, P., & Koháni, M. (2007). Methods and techniques for design of effective and competitive single wagon load transportation. *A Security Model for an Operating System for Security-Critical Applications in Small Office and Home Environment*, 3 (2009), 63.
- McKinsey. (2022). Bold moves to boost European rail freight Accessed on August 15<sup>th</sup>. URL: <https://www.mckinsey.com/industries/travel-logistics-and-infrastructure/our-insights/bold-moves-to-boost-european-rail-freight>.
- Mutlu, A., Kayikci, Y., & Çatay, B. (2017). Planning multimodal freight transport operations: A literature review. In *22nd international symposium on logistics, Ljubljana, Slovenia* (pp. 553–560).
- Pittman, R., Jandová, M., Król, M., Nekrasenko, L., & Paleta, T. (2020). The effectiveness of EC policies to move freight from road to rail: Evidence from CEE grain markets. *Research in Transportation Business & Management*, 37, Article 100482. <https://doi.org/10.1016/j.rtbm.2020.100482>
- Rail Cargo Group. (2026). Company website Accessed on May 8<sup>th</sup>, 2024. URL: <https://www.railcargo.com/de/leistungen/wagenladungen/equipment/gueterverkehr/transant>.
- Reichmann, M., et al. (2025). Introducing the concept of grades of automation for shunting operations. *Journal of Rail Transport Planning and Management*, 33(2025), Article 100500. <https://doi.org/10.1016/j.jrtpm.2024.100500>
- Rokicki, T., et al. (2021). Development of intermodal transport in the EU countries. *European Research Studies Journal*, 24(4), 300–308.
- Roland Berger. (2021). im Auftrag des VDV: Gutachten zum Schienengüterverkehr in Deutschland bis 2030 Accessed on April 24<sup>th</sup>, 2024. URL: <https://www.vdv.de/rb-pu-b-21-021-cop-adv-gutachtenschienengueterverkehr-210921-online-es.pdf>.
- Saeednia, M. (2020). A framework for managing resources at hump shunting yards. In *IEEE 23rd international conference on intelligent transportation systems (ITSC)* (pp. 1–6).
- Saeednia, M., Bruckmann, D., & Weidmann, U. (2015). Event-based model for optimizing shunting yard operations. *Transportation Research Record*, 2475(1), 90–94. <https://doi.org/10.3141/2475-11>
- Samuel, M. (2022). Alstom demonstrates fully autonomous driving of a shunting locomotive in the Netherlands Accessed on April 29<sup>th</sup>, 2025. URL: <https://www.alstom.com/press-releases-news/2022/11/alstom-demonstrates-fully-autonomous-driving-shunting-locomotive-netherlands>.
- Schäfer, H., & Rabet, S. (2012). How Xrail and capacity management will redesign Single Wagonload rail services to raise efficiency and competitiveness. In W. Stölzle, & T. Lieb (Eds.), *Business Innovation in der Logistik*. Wiesbaden: Business Innovation Universität St. Gallen. Springer Gabler. [https://doi.org/10.1007/978-3-658-00644-0\\_10](https://doi.org/10.1007/978-3-658-00644-0_10).
- Singh, P., et al. (2021). Deployment of autonomous trains in rail transportation: Current trends and existing challenges. *IEEE Access*, 9, 91427–91461. <https://doi.org/10.1109/ACCESS.2021.3091550>
- TransANT. (2026). Company website Accessed on May 7<sup>th</sup>, 2024. URL: <https://www.transant.com/Unternehmen>.
- VTG GmbH. (2026). Company website Accessed on April 17<sup>th</sup>, 2024. URL: <https://www.vtg.de/>.
- Wieberniet, N. (2008). Service network design for freight transportation: A review. *OR Spectrum*, 30(1), 77–112. <https://doi.org/10.1007/s00291-007-0079-2>
- Yin, R. K. (2018). *Case study research and applications: Design and methods* (6th ed.). Sage Publications, Inc.