The Role of Digital Twins on Rail Operations at EU Container Terminals: Crucial or Negligible?

LINUS BRÜLL, University of Twente, The Netherlands

Fig. 1. Reachstacker loading a cargo train at a German hinterland terminal, 2023

In the course of the past decade climate change has become an increasingly urgent and popular topic. Making up a significant portion of the EU's gas emissions, the EU logistics sector is pushed to make a drastic modal shift from truck transport to the more efficient rail transport in order to achieve the EU's climate goal of net zero greenhouse gas emissions by 2050. This paper found, that the implementation of a digital twin is effective enough to catalyse a hinterland terminal's rail performance to meet current climate target such as a 28,57% increase of transport until 2025. However, its impact is overshadowed by infrastructural and political issues persistent in the EU i.e. the invasion of Ukraine or the lackluster railway infrastructure, which make up the greatest bottlenecks, hindering rail from reaching the popularity of truck and inland waterways transport. Furthermore, digital twins are found useful as long as they can ameliorating significant processes such as wagon planning and container handling, but have many more future use cases, that are currently still too expensive or complex to implement. For instance, seamless geotracking through an open data exchange across the entire supply chain and the full automation of container planning via a digital twin simulation.

Additional Key Words and Phrases: Digital Twins, Rail Freight, Container Terminal, Green Logistics, Digitisation, Modal Shift

1 INTRODUCTION

In the year 2015, the Netherlands together with other EU nations committed to achieve climate neutrality by 2050 under the Paris Agreement [UNITED NATIONS 2015]. To achieve such a goal the European Commission recommends a 90% net greenhouse gas emission reduction by 2040 [Directorate-General for Communication 2024]. In addition, "ambitious" member states also committed to a 55% emission reduction by the year 2030 under the 2021 EU Climate Law [European Union 2021].

To assess how EU nations are adapting to the ever approaching deadline, one has to turn to the Netherlands, which has consistently had one of the top logistics industries within the EU[Hadžikadunić et al. 2023]. Regarded as the "gateway to Europe" for freight transport [Ministerie van Infrastructuur en Waterstaat 2019], it is crucial that the Dutch logistics system timely adjusts to EU requirements by adapting its operational workflow. As one of the largest industries in the country, the Dutch logistics sector makes up roughly 12% of the nation's total greenhouse gas emissions [CBS Statistics Netherlands 2022]. Moreover, the Netherlands stands at the risk of being affected disproportionately to its neighboring countries by the consequences of climate change i.e. since the country is located below sea level, a further rise of three meters would force the port of Rotterdam to move locations thus causing it to lose its biggest advantage of having fast transport routes to the hinterland and severely decrease the amount of operational areas for inland terminals [De Iongh 2020].

For the Dutch ministry for Infrastructure and Water Management this means, amongst other goals, nearly doubling its transport via rail by 2040, since the transport sector is heavily reliant on truck and inland shipping transport [Eurostat 2024]; both of which are less environmentally friendly as they make up twice as much greenhouse emissions as rail transport within the EU [European Environment Agency 2023]. In addition, the ministry promotes a strong focus on digital transformation within the logistics supply chain in order to standardize the wide usage of digital transportation allowing

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for legal, paperless and universal data sharing [Ministerie van Infrastructuur en Waterstaat 2019]. Subsequently, these measures aim to maximize operational efficiency thus minimizing emissions and retaining the Netherlands' key position in the Trans-European transport networks.

As a means to combat transparency-related issues within rail freight to allow for an increase in volume transported by trains, Pool in 2021 conducted research identifying requirements of a good digital twin design for rail freight in the Netherlands [Pool 2021]. This paper serves to validate and extend the design set forth by Pool through an analysis of the impact, limitations and deficiencies an implemented digital twin proof-of-concept has on operations at container terminals.

2 BACKGROUND

2.1 Research Context

The research in this study is conducted in the context of the software company Cofano Software Solutions, in short, Cofano. Based in the Netherlands, the mid-sized company, founded in 2012, supplies software solutions and systems to the logistic industry inside Europe.

Cofano's customers are operating in all parts of the freight transport supply chain, however, their most popular product by the name of Stack helps inland container terminals, often called hinterland terminals, plan, oversee and manage operations. Supporting all three means of transportation, systems like Stack are referred to as tri-modal terminal operating systems, or abbreviated as TOS.

Part of the customer-base using Stack are using the application to monitor and organise their container depot via a yard management module. The map layout not only allows for the tracking of container positions and the overview of vehicle operations on the yard, but also includes a live display of trains currently stationed at the terminal.

The University of Sheffield defines a digital twin as "a live digital coupling of the state of a physical asset or process to a virtual representation with a functional output" [Catapult 2020]. Under its definition of digital twins, which has been acknowledged to be a universally acceptable definition [Boyes and Watson 2022], Cofano's digital representation of incoming trains can be considered to be a digital twin. Although only used in the context of container terminals, the 2D depiction of trains and their goods potentially covers all requirements for an adequate digital twin for rail freight as defined by Pool [Pool 2021] and might thus be an appropriate proof-of-concept to validate and identify the need of further amendments to such artifact.

2.2 Related Work

However popular the subject of logistical transport may be for research purposes, studies addressing issues of rail freight transport, and moreover its challenges at hinterland terminal, remain sparse and is rarely particularly focused on the European logistics sector, if at all. Thus, the research review in the following section shall be taken with a grain of salt as some paper sources stem from times prior to events such as the corona pandemic or the war in Ukraine and include case studies that were done in a diverse set of EU countries that may differ in their infrastructure and digitisation.

<u>Low-Density High Value goods</u>

When a shipper gets an order to transport coal, ore, sand, etc., there is no question that she will pick rail as her choice of transport. Low value high density goods are primarily transported via train [Islam et al. 2015]. Nevertheless, containerized goods, which are low-density high value cargo, are the dominant and growing types of goods [Islam and Zunder 2018] and require faster as well as more reliable 'door-to-door' transportation, which is currently only provided by truck transport. The reasons why rail transport is nonviable for such transport vary.

As a vital challenge, for instance, it is most profitable for rail freight carriers to do transport with a fully loaded train. To have the bundling of cargo is, however, commonly infeasible for a single shipper, leading them to opt for truck shipment instead. This issue could be alleviated by a 3PL that facilitates "horizontal collaboration" [Cruijssen et al. 2007], which refers to the collaboration of two or more non-competing partners, who aggregate their goods on the same rail freight vehicle to guarantee a fully loaded train; though, due to difficulties in finding strategic or operational alignment and discrepancies in technological infrastructure many logistical firms choose against collaborations. A potential method to strengthen such collaboration is the additional facilitation of cargo and cargo unit tracing by the 3PL to allow for better monitoring of rail voyages for all parties and thus an easier alignment process [Islam and Zunder 2018].

<u>Attitude Towards Innovation</u>

Furthermore, some papers suggest the rail industry is still too heavily reliant on long-standing titans [Islam and Zunder 2018]. The persistent dynamic within the sector does not allow for a free and fair competition among incumbents and new entrants [Islam and NewRail Centre for Railway Research 2014]. Besides, opportunities for untapped market demand, such as the rising demand for transport of perishable goods in reefer containers, are commonly ignored due to the fear of undertaking a major shift in business strategy. This phenomenon lead to the phrase "no modal shift without mental shift" [Islam and Zunder 2018].

2.3 Problem Statement

Despite great environmental benefits and lower unit costs when compared to road shipping [Daramola 2022], many shipping companies refrain from rail transportation due to a lack of a 'door-to-door' service and unreliable transport [Halse et al. 2019; Islam and NewRail Centre for Railway Research 2014]. Complex as well as complicated processes at container terminals, that commonly lead to prolonged layovers of trains and container demurrage (surcharge for containers staying on the depot for a prolonged period of time) bring uncertainties for both the shipper and the customer, which could be avoided by truck transportation [Schaar et al. 2023].

For shipping companies, the decision on a mode of transport is not solely dependent on the climate efficiency and is commonly based on other environment dependent factors e.g. the structure of the loading units [Stinga and Olteanu 2019]; however, the majority of issues and disadvantages of rail transport are not only present, but also amplified on container terminals. A more detailed layout of these issues will be assessed later on in the study.

Since data-driven applications could potentially eliminate transparency related issues [Schaar et al. 2023], Pool conducted research to identify an adequate digital twin design for rail freight and thus introduce a universal default for the industry. However, the proposed design was never implemented and therefore lacks validation [Pool 2021]. Therefore, the design's application must still be assessed throughout all steps of the rail supply chain to be considered universally applicable.

2.4 Research Questions

The problem statement presented combined with the consideration that Cofano's proof-of-concept is used exclusively in the context of container terminals leads to the following research question. In order to answer the question at hand systematically and improve measurability of the research, it is then further broken down into sub research questions.

> **RQ:** "How effective is the implementation of digital twins for rail freight on EU hinterland container terminals to comply with the EU 2050 climate goals?"

Firstly, to get an overview of the industry's current status quo and the overall attitude of the rail logistics sector towards digitisation, it should be assessed how important digital innovations are for the future of the market.

> **SRQ1:** "What role does digitisation play in the current development of rail transport?"

Secondly, the focus will shift on the role of digital twins specifically; therefore, it shall be assessed how the usage of digital twins is perceived in the context of rail terminals.

> **SRQ2:** "How great is the impact of a digital twin implementation on the operations of a rail container terminal?"

Thirdly, Pool's digital twin design will have to be evaluated based on possible expansions. Thus, limitations and flaws have to be identified to determine necessary amendments and additions of the MVP design for a beneficial usage in production.

> **SRQ3:** "Which elements from Pool's initial design need to be amended or added for the successful application at container terminals?"

Lastly, to determine if the availability of a digital twin at a terminal is a negligible artifact in the development of the logistics sector, a further analysis of how beneficial the addition of a digital twin is to the performance of a terminal.

> **SRQ4:** "Do rail hinterland terminals see an improvement in their economic performance and sustainability once they start utilizing digital twins?"

By answering these sub-research questions, there will be enough ground to evaluate if the impact of a train's digital twin on terminal operations is great enough for them to comply with set climate goals as mentioned in the Dutch ministry's climate suggestions [Ministerie van Infrastructuur en Waterstaat 2019] and if the further extension of the twin design could sway this conclusion in a meaningful manner.

3 RESEARCH METHODOLOGY

The subsequent section presents the methodologies used to verify that the rail depiction within Cofano's yard management module can be considered an appropriate proof-of-concept of the digital twin proposed by Pool [Pool 2021], validate the implemented digital twin and assess the need for further amendment or extension of the artifact.

3.1 Validation of proof-of-concept

For his digital twin design, Pool created a list of requirements a proof-of-concept prototype would have to fulfill [Pool 2021]. Please find the detailed requirement list under Figure 5 in the appendix. Therefore, the satisfaction of the following requirements must first be established to guarantee that the results found in this study can be used to verify the design proposed by Pool:

R1 The system shall support a 6-layered, modular architecture.
R2 The system shall support a relational database scheme.
R3 The system shall support an event-driven architecture.
R4 The system shall implement a GUI.

This assessment is crucial to allow for future digital twin implementations using this proposed design standard. Even if the use cases of the digital twin design change in the context of hinterland terminals in comparison to the freight transport, it should be assessed as well as amended upon its application at each step of the rail supply chain.

3.2 On answering SRQ1

Judging the state of an industry without professional insights can be quite challenging and inconvenient. Therefore, multiple experts working in either rail transport or terminal operations related to rail, are consulted via interviews. The list of experts participating in the interviews includes:

Dutch Transport Coordinator: By coordinating transport orders for customers across Europe, they can adjoin to this research via their unique industry-wide perspective that reaches beyond the terminal yard.

COO and Head of Train Monitoring at a prominent German Terminal Network: They have worked in German logistics for more than six years and are coordinating a team overseeing the rail planning process, whilst utilizing Cofano's digital twin. Hence, their experiences add value to the research, for they understand what impact digitisation and digital twins has, both in the past and in the future.

CEO of a German Hinterland Terminal: The expert has coordinated and managed as CEO or expediter at multiple container terminals in Austria and Germany for almost 20 years. Thus, their insights can help to understand the current needs of rail transport at terminals located in the heart of Europe.

Managing Director at a London-based logistics consultancy firm: Having worked for over 25 years in logistics Europe-wide, they bring experience from positions such as general management at PSA Cargo Turkey and Gemport. Training logistics experts internationally allows them to bring a less EU-centric perspective to these EU specific issues for the purpose of this study.

These participants were chosen due to their ongoing engagement in the European rail shipping sector, their diverse roles within the supply chain and their independent perspectives as both brand-new and long-established corporations.

Within the expert interviews, these inquiries will be made to answer SRQ1:

(1) What, in your opinion, are the main challenges for the rail industry, that hinder it from achieving transport volume similar to truck and barge transport?
(2) One paper states "no modal shift without mental shift", since the rail industry shows a general lack of initiative and engagement with persistent issues and untapped market demands. Do you recognize such an attitude towards modern innovations and do you think it is a considerable barrier to making the modal switch?
(3) Some papers blame the persistent dominance of the market by long-standing industry titans. Is the rail transport market actually not liberalized enough to let new incumbent competitors join a free and fair competition?

3.3 On answering SRQ2

Continuing with the expert interviews, the interviewees will also be asked the following questions regarding the impact of digital twins on container terminals (SRQ2):

(4) How did the implementation of digital twins impact the wagon planning and container handling processes on the terminal?
(5) Does the implementation of a digital twin increase satisfaction with customers and shippers enough to entice a switch from truck/barge?

3.4 On answering SRQ3

To conclude the interviews, the experts are inquired about the required features digital twin for rail freight should have for the beneficial application at container terminals and which aspects are still missing from Cofano's TOS system:

(6) Which amendments could improve the terminal's workflow regarding rail operations?
(7) Is a digital twin train composition of locomotive and wagons sufficient?

Though, the formulation of the listed questions might differ when asked to a rail shipping expert, for they are unfamiliar with exact terminal operations and will instead be asked for the requirements a digital twin must have for the usage in the context of a general train trip.

3.5 On answering SRQ4

In order to objectively evaluate the performance of the terminals working with Cofano's TOS system, a data analysis on the total volume of TEUs, which were transported via rail over the terminals, will be performed. Moreover, the combined average of all terminals will then be compared to the target line suggested by the Dutch government. Based on this comparison it will be possible to verify whether the availability of a digital twin has helped the terminals to succeed the government-set milestones or if the affect is blurred by the impact of other environmental factors.

4 ESTABLISHING THE PROOF-OF-CONCEPT

4.1 Introduction Cofano's Yard Management

Fig. 2. Yard management overview in Cofano Stack

In Figure 2 one can see the current yard management overview available in Cofano Stack. The user is able to interact with the individual wagons by selecting it on the screen. Once the wagon is selected, all available details are displayed and the wagon can be removed, moved or another wagon can be added to the train. Corresponding to the wagons, the containers are shown on the map and their location is updated whenever a handling move has been carried out for them.

The train layout is shown in different forms within a handful of modules in Stack that are used for diverse sets of functions i.e. the booking planner will see an overview of the train in a 2D side-view to ameliorate arranging the order of the individual containers on the wagons; in contrast to the reachstacker driver, who will see the wagon location on the yard map as shown in Figure 2.

4.2 Fit/Gap Research Methodology

First introduced by Gulledge [Gulledge 2006] and closer defined by Pajk et al. [Pajk and Kovačič 2013] the Fit-Gap Analysis methodology is commonly used for managing requirements of enterprise resource planning (ERP) software systems. By identifying how well each business requirement is covered by the software system, IT vendors and product owners can get a better grasp on the status quo system capabilities and any outstanding work needed to make the system sufficient.

In order to assess how sufficiently a requirement is covered by a given system, one of the four following fit levels is assigned:

Perfect Fit The system completely supports the business process without any modifications.

Acceptable Fit The system supports the business process with minor modifications or adjustments.

Marginal Fit The system supports the business process, but significant customization or workaround solutions are required.

No Fit The system does not support the business process, and extensive customization is needed, or an alternative solution must be found.

4.3 Evaluation R1

The first requirement can be considered an acceptable fit, for the Stack software is built on a framework utilizing RESTful services allowing for standardized communication between different modules that enables it to scale continuously. In addition, the application implements a MVC framework connecting the user's input via API requests with the database and subsequently displays it through the front-end. Notwithstanding, Stack does not cohere to the MVC principle in a strict fashion throughout the back- and front-end, though, the overall framework distinguishes enough between the different functions of classes to have R1.3 recognized as an acceptable fit.

Lastly, no data is currently reliant on carriers' compliance or available GPS trackers on wagons as all rail and rail cargo information may be inputted either manually by the user (terminal operator/train inspector) or automatically by a pre-gate system. Note, that the effectiveness of an automatic asset health detection for railways is negligible in the context of container terminals.

4.4 Evaluation R2

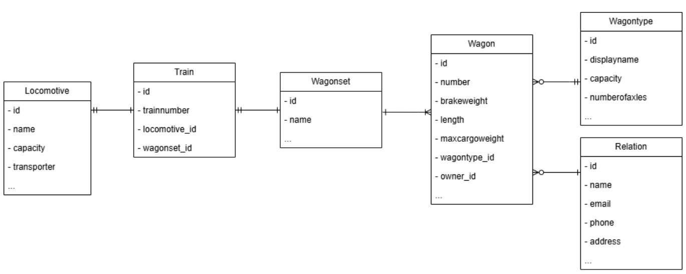

Fig. 3. Relational Database Diagram

All data that is used for the functioning of the rail digital twin is stored in Stack's pgAdmin relational database. As seen in Figure 3, a composition, here called train, is made up of a locomotive and a wagonset, which in-turn holds multiple units of wagons. Despite not having so-called "units", which are either wagons or a locomotive, in this scheme each train has one and only one locomotive and wagonset; yet, one is able to add an unbounded amount of individual wagons to the assigned wagonset. Additionally, the TOS-system logs any handlings and updates made to a booking, which means that any events are stored and can retroactively be tracked.

All in all, the system covers a sufficient amount of sub-requirements making it an acceptable fit.

4.5 Evaluation R3

Even though Stack stores the history of all actions performed on the train, the system is not set up to showcase the full history of train movements and updates. For the operators on the terminal, it is foremost and solely important to have a digital representation of the current train status, which allows them to make better informed decisions; for instance, monitoring the order of the wagons to determine the sequence of containers that ought to be loaded or unloaded.

Because the event-driven architecture is only covered to a minimal extend within the current system, R3 is just a marginal fit. However, as mentioned above, this requirement is also not as relevant to the application on container terminals.

4.6 Evaluation R4

Throughout the TOS-system there are multiple screens on which the train might be displayed with its cargo. Prior introduced in 3.1, the planner requires a side-view layout of the container arrangement, whilst the terminal operator might want to have a top-down view on the railways. Thus, a 2D geographically correct map is provided in the software. Furthermore, the map also includes the individual wagons with their respective details i.e. train service, wagon number and the location on the train.

However, due to the lack of train movement, any animations as well as playbacks are not of particular interest to the terminal and are thus not incorporated in the integrated map. Given that there are many sub-requirements dedicated to this aspect, the fourth requirement is by and large merely a marginal fit.

4.7 Evaluation Conclusion

After having all requirements considered and assessed on their individual fit to Cofano's current TOS-system, it can be said that the digital train representation of Stack covers the majority of relevant requirements set forth by Pool.

Specifically requirement one and two are an acceptable fit with the software's status quo, which is sufficient, for the need of features such as an event-driven architecture and a playback system for train movements is negligible in the setting of a container terminal. Besides, the necessity of having a fully implemented GUI were largely invalidated during expert interviews; therefore, even a marginal fit of R4 shall suffice for the purpose of this study.

5 THE ROLE OF DIGITISATION

5.1 Underlying Bottlenecks

As outlined in the related work section, there are fundamental bottlenecks that have prominently hindered the development of the rail transport sector. These aforementioned issues are critical to rail carriers and hinterland terminals alike, which was prevalent in the interviews.

Unsurprisingly, given its widespread presence in literature [cf. Related Work], all experts were in consensus, that the overarching problem was the inability of rail shipping to provide customers a 'door-to-door' service and is instead still too reliant on truck transport for the last mile delivery. Furthermore, this issue is caused by the general lacklusterness of reliability in train deliveries and the protract handling times for which the interviewees gave multiple underlying reasons.

On the one hand, all experts emphasized that further expansion of the rail infrastructure in a timely and efficient manner is a vital step to facilitate quicker deliveries with less downtime i.e. delays or cancellations. The third interviewee bewailed about the fact that the German rail infrastructure had not only ceased to expand in recent years, but had instead deteriorated in quantity as well as quality [DB InfraGO AG 2023], much to their chagrin [cf. interview III]. Although less problematic, the progression of the Dutch railways expansion is, nevertheless, slow too, according to the first interviewee [cf. interview I].

On the other hand, the phrase "no modal shift without mental shift" seemed exaggerated to most of the experts, though, they agreed that even minor changes in operations and especially in business strategy are dependent on substantial amounts of investments. To be the first company in the industry to implement brand new technologies or strategies is usually too risky and not worth the investment, said the rail expert from the Netherlands [cf. interview I]. Besides, this roadblock is not limited to the established companies either. New players, such as the interviewed hinterland terminal, can still compete properly " by staying agile" [cf. interview III], but commonly fail due to overly aggressive business tactics or the inability to adapt to the market [cf. interview II].

Though, the general manager at the London consulting firm furthermore remarked, that rail is commonly the least profitable mode of transport for intermodal terminals, which leads to even greater hesitancy when it comes to making major investments into rail innovations [cf. interview IV]. Rail does not have the same amount of profit margins as truck, since customers are more willing to pay a mark-up for the convenience of a 'door-to-door' service and because the rail industry has seen an increase in competition in the past few years [Directorate-General for Internal Policies 2015; Halbesma et al. 2022].

5.2 Role of digitisation in rail logistics (SRQ1)

Subsequently, the role of digital innovation in the field seems ambiguous and its impact, relative to the above listed challenges, nearly irrelevant to the sector's future growth due to its impotence to directly address these systematic and infrastructural problems. Whilst most of the industries in the EU are still struggling with digitisation, the rail industry has not shied away from investments and was digitally adept early on [Scordamaglia and Service 2019]. Thus, notwithstanding of an exemplary effort to digitize, the challenges around protract transit times and the inability to undergo major changes in strategy still remain difficult to maneuver.

6 DIGITAL TWIN IMPACT ASSESSMENT

6.1 Application of a Digital Twin

Once again, experts were in agreement that utilizing a digital twin does enhance logistical processes. On the whole, there were a few significant benefits as well as challenges that stood out during the interview and were universally shared by the interviewees.

So, for instance, having the assistance of a digital twin whilst performing or planning terminal operations does in-fact ameliorate the process and "makes it more tangible" [interview II]; especially, for employees that have yet to grasp workflow processes in its entirety i.e. younger employees. An ageing workforce is a substantial threat to the sector and is believed to cause acute labor shortage and a decline in overall firm productivity in the near future [Gekara et al. 2019] and having the opportunity to provide new professionals with a detailed overview of the terminal's or train's layout in real-time, is therefore valuable.

Furthermore, having the knowledge of a container's location on the yard and understand complications forthwith, enables the terminal to take needed precautions ahead of time such as notifying rail carriers about delays or readjusting the wagon planning to ensure a fully loaded outgoing train. Thereby, the digital twin improves the terminal's risk management capabilities [cf. interview II].

Besides, the location tracking of rail freight is a feature commonly inquired about and requested by leading shipping companies such as Maersk [cf. interview I]. Knowing the detailed status of the cargo on its voyage not only allows these companies to accurately update the customer about their goods' whereabouts and the time of arrival, but also continuously analyse bottlenecks of the train trip, which appears to be a double edged sword.

On the one hand, figuring out the exact causes of pivotal failures in the rail supply chain could lead to the tackling of bottlenecks and, therefore, subsequently to an improvement in the reliability of train transport, addressing a crucial issue as identified in the previous section.

On the other hand, however, this process requires the mutual agreement of all parties to have a complete coverage through extensive data exchange and to take full accountability for the mistakes of their actions, which is something that is welcomed by all in principle, but not in practice [Du et al. 2012; Schrampf et al. 2022]; a common issue found in logistics and evident to all interviewees [cf. interviews].

6.2 Impact of Digital Twins on Rail Terminals (SRQ2)

In general, a digital twin in the context of rail container terminal operations brings advantages, be it by supporting a novice labor force or through enhanced risk management. Nevertheless, the system is limited by environmental factors like the previously discussed complexity of an industry-wide data exchange and the limiting scope of solely yard operations, which will be covered in the upcoming section.

6.3 Strong suits and potential additions to Cofano's Digital Twin

During the interviews most key features of Cofano's digital twin were discussed and even though it is satisfactory for the usage on the terminal, a few additions were mentioned, that could significantly increase the scope of usage and might become the future norm.

Above all, Pool's design framework as it is implemented through the Cofano Stack system was sufficient for the tracking of container positions on the yard and the process of planning containers on the individual wagons, according to the expert from German terminal network [cf. interview II]. These are the two main use cases of a digital twin on the container terminal and the interviewee, who has been using the digital twin for multiple years, was also satisfied with the current capabilities of the system [cf. interview III].

In order to have an even more significant benefit from the digital twin, however, the TOS should additionally feature the location of wagons and containers outside of the terminal, said interviewee II [cf. interview II]. Such a transparent connection to the rail carrier would allow the terminal to have an even greater lead time for adjustments and share frictionless geotracking of the freight with shippers and customers.

Moreover, although all interviewees saw the datafied train units outlined in Pool's design and present in Cofano's TOS i.e. locomotives, wagons and train compositions [cf. Figure 3] as sufficient, they unanimously acknowledged the potential gravity the tracking of individual containers could have on their operations. Evidently, the realisation of such requires major investments into an array of tracking devices for the terminal, yet, as the expert working in German terminal logistics highlights [cf. interview III], the costs of Internet of Things (IoT) devices are steadily dropping [365 2019], whilst the spectrum of different sensorics is continuously growing. For example, one interviewee mentioned smart twist locks or seals that have IoT sensors integrated [Red Flag Cargo Security Systems 2022], which showcases a growing number of IoT applications at every step of the transport whether it be the locking of the container or the gate-in of the train [cf. interview III]. According to the terminal operators, the workflow automation that follows the integration of container tracking could further reduce the potential of human error.

Lastly, the Londoner expert was in agreement stating that not only having a operational digital twin was sufficient for rail terminals, but even having just a TOS-system would be beneficial as most terminals in Europe still operate without one [cf. interview IV]. Research of the market is still underdeveloped, however, and no official study exists, which shows what percentage of terminals have yet to implement a TOS. In addition, the expert mentioned that the next meaningful appendment to the system would be the full automation of container planning using simulations of the digital twins, which has been proven effective [Gambardella et al. 1998; Kemme et al. 2017], though, is still too expensive to be implemented by EU hinterland terminals, since the implementation of automated cargo handling can cost up to a billion dollar [Ameliakling 2023].

6.4 Revision to Pool's digital twin design (SRQ3)

All in all, it was found that Pool's digital twin design framework is applicable to container terminals supporting rail transport in its MVP form. The two main use cases i.e. wagon planning and container handling are sufficiently supported to justify its implementation. Notwithstanding, to achieve a system that allows the frictionless geotracking of the cargo, rail carriers shall also support a digital twin and a data exchange between all involved parties shall be warranted.

Furthermore, for the sake of workflow automation, the rail experts saw great potential in the addition of container units to the relational database as soon as reliable IoT sensors become affordable enough to be widely implemented. This concept also applies to making a fully automated port that allows for operational optimization through simulations, which is, however, still too expensive for hinterland terminals to implement.

7 ABILITY TO REACH DUTCH CLIMATE GOALS

7.1 Climate Goals set-forth by the Dutch Ministry

With the deadline for climate neutrality in the year 2050 approaching, the Netherlands as one of the ambitious EU nations, aims to nearly double its transport via rail by 2040 [Ministerie van Infrastructuur en Waterstaat 2019] with an "increase in freight transport by rail from 42 million tons to 54-61 million tons by 2025". To merely reach the conservative goal of 54 million tons, this effectively means a 28,57% increase in performance within six years or 0,397% per month from 2019 until 2025.

7.2 Data Analysis Setup

Cofano's customers vary within factors such as their size, their network of connections and their location. Thus, there is no one standard that could fit all. In addition to that, the increase in transport volume suggested by the government is regarding the entire rail supply chain and not just container terminals alone. As highlighted in previous sub research questions, there are numerous systematic and infrastructural issues that pose a bigger challenge to the sector's growth than the operations and digitisation of a container terminal.

Nevertheless, by combining the average performance in rail transport of an array including many different Cofano customers, a clear index is formed. Next, a target line is set, that stems from the performance of the average terminal of 320 TEUs per month, when it first started using Cofano's TOS, and then linearly increases by the 0,397% per month, so around one TEU per month, required to meet the conservative goal of an increase by 28,57% until 2025. This, of course, assumes that the throughput of the container terminal matches the industry's course of delivery and that the same goals apply to hinterland container terminals, which is likely setting the bar considerably higher than actually expected.

7.3 Data Analysis Findings

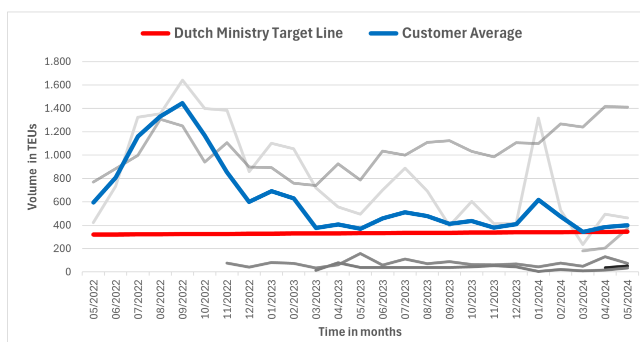

Fig. 4. Overview of Terminals' Performance

In the above shown Figure 4, one can find the collective rail performance of all terminals that use Cofano's TOS for their rail freight transport indicated by the blue line. Moreover, another red line shows the linearly increasing target line, which should continuously be met if the terminals want to meet the 2025 Dutch climate targets. The terminals' average makes a sharp and sudden drops at the end of 2023, which is due to the new addition of smaller terminals, that contribute to the average. However, their performance is also taken into account for the target line.

All in all, the terminals are able to showcase minor, but gradual growth after the TOS implementation, leading them to keep up with the 0,397% monthly benchmark. Notwithstanding, one can see from the drastically increasing performance in the beginning of 2022 due to the end of the coronavirus pandemic [Cargo 2021; Goodman 2022; United States International Trade Commission 2021] and the decreasing transport volumes at the larger terminals starting at the end of 2022, caused by Russia's invasion into Ukraine [BBC News 2024; Jacobs and Service 2022; Swanson 2022], that large political and infrastructural changes influence the rail freight performance far great than the implementation of a TOS or a digital twin. Besides, terminals already utilizing a TOS with a digital twin are also unable to withstand the effects of such events.

7.4 Impacted Performance of Digital Twin Users (SRQ4)

The findings of the data analysis conducted on the rail performance of hinterland terminals using Cofano's TOS and its digital twin, both highlight that continuous growth, which is sufficient to keep up with the Dutch climate targets by 2025, is achievable using a TOS and underline that political and infrastructural changes affect terminals too greatly, so that the benefits of a digital twin implementation cannot outweigh or counteract major events such as the coronavirus pandemic or the invasion of Ukraine.

8 CONCLUSION

This research paper set out to conduct three individual assessments based on pre-existing literature, expert interviews with logistic professionals either operating in rail shipping or at container terminals, and the data analysis of the statistical performance of terminals, which have already worked multiple years with a digital twin for rail freight. Covered topics include: The role digital twins play in the current development of the EU rail industry, the system requirements of a digital twin when integrated at container terminals supporting rail modality and the impact of the digital twin implementation on the performance of container terminals in comparison to the 2040 climate goals set forth by the Dutch government. Making such assessment aimed to subsequently answer the main research question: "How effective is the implementation of digital twins for rail freight on EU hinterland container terminals to comply with the EU 2050 climate goals?"

It was clearly established that related literature, expert interviews and the all analysis of terminals' rail performance all share two main findings. First, the implementation of digital twins of rail freight on hinterland container terminals in the EU has great operational advantages and has proven to catalyse the rail performance of a terminal enough to meet the Dutch climate targets of 2025 and hence likely the EU 2050 climate goals. Secondly, however, the most important bottlenecks of the rail industry lay outside of the terminals operational scope and thus, whilst the implementation of a digital twin is effective, its impact is overshadowed by infrastructural and political issues persistent in the EU.

Both the experts as well as the related literature made clear that the greatest bottlenecks the rail industry is facing today are the expansion of public railway infrastructure and an inability to perform strategic adjustments to either market demands or issues, which are mostly unrelated to digital twins as well as digitisation in general; rendering its importance to making rail transport competitive to other modes of transport i.e. vessel or truck as negligible. Despite not being able to address these persistent issues, digital twins are still a beneficial addition to rail container terminals. The primary two use cases of using a train layout to assist in the wagon planning process and tracking container handlings on the yard can ameliorate the workflow by visualising complex processes to a novel labor force and preventing user errors through automated detection of mistakes.

Furthermore, the design framework for digital twins of rail freight as defined by Pool [Pool 2021] proves sufficient for the application at container terminals supporting rail transport. However, the desired ability to have frictionless geotracking of the rail freight over the entire voyage requires a wider collaboration of all involved parties through a free data exchange, which has not yet reached unanimous consensus in the industry due to conflicting interests. Besides, the ultimate goal of operational optimization using a fully automated planning process via digital twin simulation is still too expensive to implement.

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A APPENDIX

A.1 Usage of AI Disclaimer

During the preparation of this work the author utilized ChatGPT and Google in order to perform research and review sentences for grammatical or structural mistakes. ChatGPT was solely utilized for linguistic and coherence purposes; thus, the present paper does not feature any sentences, that were generated by AI. After using these services, the author reviewed the content as needed and takes full responsibility for the content of the work.

A.2 Figures

Requirement	Requirement Level	Fit Level
R1. The system shall support a 6-layered, modular architecture.	Domain	Acceptable Fit
R1.1. The system shall allow gradual innovation through the low-effort extension of • The number of sensors connected • The number of RESTful sources	Product	Perfect Fit
R1.2. The system shall incorporate the REST and OPC principles	Product	Perfect Fit
R1.3. The system shall incorporate the MVC principle	Product	Acceptable Fit
R1.4. The system shall implement an independent, automated wagon tracking and identification	Product	Acceptable Fit
R1.5. The system shall implement an independent, automated asset health detection	Product	No Fit
R1.6. The system shall have a log-in function	Product	Perfect Fit
R2. The system shall support a relational database scheme.	Domain	Acceptable Fit
R2.1. The system shall incorporate compositions composed of one or more units	Product	Perfect Fit
R2.2. The system shall incorporate wagons and locomotives as units	Product	Perfect Fit
R2.3. The system shall have the option to transform a composition into a train	Product	Acceptable Fit
R2.4. The system shall support the storing of events	Product	Acceptable Fit
R2.5. The system shall never incorporate commercially sensitive data	Product	No Fit
R2.6. The system shall incorporate the specific fields as given in Figure 7.2	Design	Marginal Fit
R3. The system shall support an event-driven architecture.	Domain	Marginal Fit
R3.1. The system shall check the memory for new sensor-data	Product	Acceptable Fit
R3.2. The system shall generate events from incoming sensor data	Product	Acceptable Fit
R3.3. The system shall incorporate a snapshot system for the database	Product	Fit
R3.4. The system shall apply events to the snapshot nearest to a user given time-interval	Product	Marginal Fit
R4. The system shall implement a GUI.	Product	Marginal Fit
R4.1. The system shall have a 2D geographically correct map of the rail network	Design	Perfect Fit
R4.2. The system shall have a button for a real-time mode	Design	No Fit
R4.3. The system shall have a button for a historical mode with a time-interval selection	Design	No Fit
R4.4. The system shall display individual wagons on the rails	Design	Acceptable Fit
R4.5. The system shall display multiple wagons as one composition/train on the rails	Design	Perfect Fit
R4.6. The system shall display the movement of wagons and compositions on the rails	Design	No Fit
R4.7. The system shall have an option to play or pause a certain timeframe	Design	No Fit
R4.8. The system shall display asset health of the individual wagons	Design	No Fit
R4.9. The system shall display warnings for risks and hazardous materials	Design	Acceptable Fit
R4.10. The system should display wagon information of a selected wagon	Design	Perfect Fit
R4.11. The system should display train/composition information of a selected composition	Design	Perfect Fit

Fig. 5. Fit/Gap Analysis on Pool's Requirement List

A.3 Interviews

The interview with the Dutch transport coordinator can be accessed here
The interview with the German COO and head of train monitoring can be accessed here
The interview with the CEO of the German hinterland terminal can be accessed here The interview with the London-based consultant can be accessed here