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# Toward an efficient sea-rail intermodal transportation system: a systematic literature review

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## Abstract

Effective ground transportation modes linkage with the seaport plays a crucial role in facilitating smooth cargo movement from marine transportation mode to the inland areas and vice versa. Unlike road transportation, rail linkage is a cost-effective and environmentally friendly option. Inadequate sea rail connectivity within the seaport hampers cargo movement speed and impacts overall port capacity. This systematic review places emphasis on sea rail intermodal transportation at the seaport. The review categorizes and analyses previous research contributions to the sea-rail intermodal transportation system, and is organized into five categories: performance evaluation, problem-solving methodologies, planning issues, factors affecting sea rail intermodal transportation, and enhancement strategies within the context of sea rail intermodal transportation. The study discerns current research patterns and identifies gaps within the existing literature while also offering insights into potential future research avenues.

**Keywords:** Sea- rail intermodal, Sea- rail intermodal efficiency, Systematic review, Maritime transportation

## Introduction

Port operations play a significant role in holding the power to impact supply chain efficiency because of their increasing complexity and extensiveness (Lam and Gu 2013). Therefore, ports are looking to improve their connectivity with the hinterland to accelerate cargo flow to and from the inland areas. Many scholars have realized this fact, resulting in an increasing number of studies analysing the hinterland's connectivity using the intermodal transportation system.

In the literature and industry, the words "intermodal" and "multimodal" are commonly used, though perspectives and usage differ. Intermodal transportation refers to a particular form of multimodal transportation in which cargo is transported in the same container between the origin and destination whereas multimodal transportation uses two or more transportation modes to move cargo sequentially, which requires handling and consolidating the cargo at each terminal (SteadieSeifi et al. 2014). Thus, the intermodal transportation system refers to loading unit transfers that carry goods from one mode of transportation to another without handling the commodities during transportation (Lin and Lin 2016). Efficient intermodal terminal operation is crucial in a seaport; proper planning is required for optimal performance. Inefficient terminal operations can slow cargo flow to their destination and increase ship dwell time in the port, leading to higher costs and sustainability concerns.

While intermodal transportation offers cost savings, it can also contribute to congestion and increase emissions, including greenhouse gases (GHGs) and air pollutants. However, an efficient intermodal transportation system can overcome congestion, reduce shipping costs, and keep emissions low.

The primary objective of intermodal transportation is to move goods from their origin to their destination using a unified transport unit, thereby avoiding cargo handling during transport modes transfer (Lee 2015). Intermodal transport system effectiveness depends on interconnectivity and performance in each segment of the transport chain that includes ports, shipping firms, trucking companies, and railways. This in turn affects decision making, operations, and information management. In recent years, numerous publications have examined intermodal transportation matters from various perspectives (Mostert et al. 2017; Yan et al. 2020b).

The European Commission has emphasized the importance of using efficient intermodal transportation instead of relying solely on road transportation, contributing significantly to the rise of $CO_2$ emissions (López-Navarro 2014). Intermodal transportation is acknowledged for mitigating congestion and preventing accidents, which often occur in busy seaports. Owing to its superior environmental performance and avoidance of congestion-related delays, intermodal transportation primarily emphasizes on achieving environmental benefits (Bouchery and Fransoo 2015; Craig et al. 2013; Dekker et al. 2012; Tolga Bektas 2007).

Although below articles present literature reviews of intermodal transportation, this review analyzes the sea-rail intermodal transportation system (SRITS). SRITS offers numerous benefits, including high capacity, enhanced safety, low cost, and reduced emissions (Zheng and Cai 2020). The Agamez-Arias and Moyano-Fuentes (2017) review sheds light on various intermodal options such as road-rail, air-road, sea-rail, and sea-road. The SteadieSeifi et al. (2014) review analysed optimization models that increased system efficiency. However, an in-depth and systematic literature review on sea-rail intermodal is absent and, despite its strategic role for port, this topic has been rarely addressed in the literature. There is thus a noticeable gap in the existing literature on this topic and this study aim to draws researchers' attention to this area, which has ample opportunities for improvement.

The importance of SRITS points to its role in connecting the three most critical nodes in the supply chain. These nodes represent locations where raw materials, industrial facilities, and consumers are located, typically separated by oceans or seas. Of the three locations, SRITS is the sustainable option to establish connectivity, for it plays a significant role in accelerating cargo flow from the ports to the hinterlands and vice versa.

This review places emphasis on SRITS, a particular kind of intermodal transportation. The primary objective of this study is to conduct a systematic literature review (SLR) on sea rail intermodal transportation systems (SRITS) to provide a comprehensive analysis of the existing research landscape, identify gaps, and delineate future research directions.

Therefore, this SLR contributes to the SRITS literature in the following ways:

- By offering a comprehensive overview of the extant literature on SRITS, particularly emphasizing the benefits of sea-rail intermodal transportation and its potential to enhance supply chain efficiency. This review identifies the various benefits associated with SRITS and explores strategies for optimizing system performance.
- By analyzing each identified study, this review sheds light on the methodologies employed and the characteristics of the problems addressed. This includes considerations such as sea-rail dynamics, planning intricacies, and used methods, providing insights into the complexities of SRITS operations.
- By engaging in critical discourse, this review bridges theoretical insights with practical implications, offering valuable insights for researchers and practitioners. The review identifies emerging trends, highlights research gaps, and proposes potential avenues for future investigation, thereby contributing to the advancement of knowledge and practice in the field of intermodal transportation within the maritime sector.

The rest of the paper is organized as follows: Sect. 2 presents the methodology used in this review. Section 3 analyses the literature. In Sect. 4, we answer the research question. Section 5 is a discussion, and in Sect. 6, we conclude the study and shed light on future works.

## Methodology

Researchers' interest in intermodal transportation began to grow in the 1990s (Agamez-Arias and Moyano-Fuentes 2017). A systematic approach is crucial to conducting a rigorous and organized literature review, surpassing the constraints of other narrative review methods to thoroughly understand this field. This approach offers the benefit of improving our understanding of the research subject's methodological facets and facilitates a comprehensive and consistent comparison among research papers. Based on guidelines proposed by Denyer and Tranfield

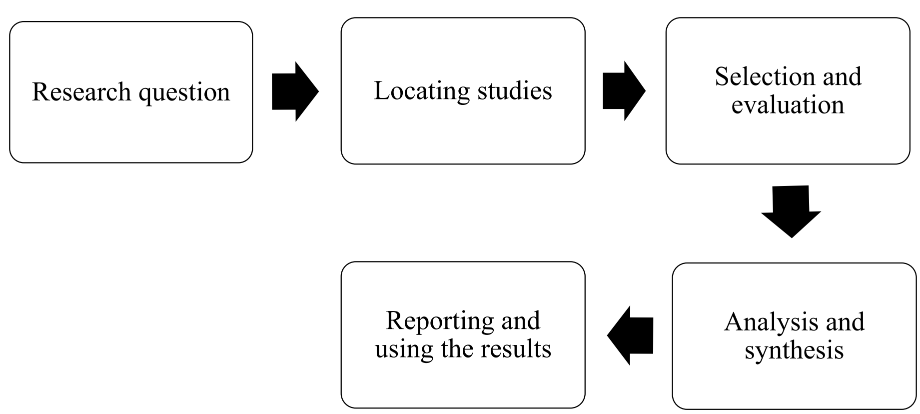


**Fig. 1** Steps in the systematic literature review

(2009), detailed in Fig. 1, a systematic literature review was undertaken to pinpoint pertinent literature. The review outlines the five steps taken in this study.

First step: Following recommendations by Booth et al. (2012) and Rousseau et al. (2008), the initial phase in conducting a systematic review involves establishing the study's scope and preventing ambiguity by defining and formulating the review question: how is SRITS researched, analysed, and implemented effectively to minimize costs and negative environmental effects? Subsequently, this study identified five specific areas of inquiry related to sea-rail intermodal transportation as presented in Sect. 4. Only studies addressing areas within the context of sea-rail intermodal were included in this article.

Second step: This step aims to define articles in line with the research inquiries. The search encompassed three databases such as Scopus, recognized as one of the most extensive peer-reviewed repositories for scientific content, encompassing all pertinent peer-reviewed journals relevant to the research subject (Elbert et al. 2020). ScienceDirect and the Web of Science has also been included as complementary sources.

The search keywords were defined by the following keywords: "maritime intermodal" OR "sea intermodal" OR "sea-rail intermodal" OR "rail-sea intermodal." Journals published in English from 2000 to June 2023 were considered in this research. Table 1 illustrates the number of articles acquired from each search engine, excluding duplicates. These articles specifically pertain to the concept of sea-rail intermodal transportation through their titles and abstracts.

Third step: Selection and evaluation. In this step, a screening process was carried out to assess the relevance of studies addressing the review objective. Figure 2 illustrates the selection and evaluation process. Initially, at the first step of filtration, 31 articles with duplicated titles were removed. The primary emphasis is on intermodal transportation rather than other research domains, such as supply chain management, reverse logistics, and maritime liner shipping.

Consequently, the titles and abstracts of the remaining 234 articles were scrutinized to exclude studies unrelated to SRITS, resulting in 93 relevant articles. The next step involved reading the introduction and conclusion of these 93 articles to further assess their relevance. Of the articles, 22 were excluded: 12 for lack of relevance to the topic and 10 for unavailability of full papers because of access restrictions. During the review process, 10 articles failing to meet quality criteria were excluded; only peer-reviewed published articles, conference papers, and book chapters were selected for the study, while two articles addressing SRITS-related issues were included. The remaining 63 articles were fully read and analysed to address the review objective.

**Table 1** Article numbers by search engine

| Keywords | Databases | Collected articles (%) |
|---|---|---|
| "Maritime intermodal" OR "sea intermodal" OR "sea-rail intermodal" OR "rail-sea intermodal" | Scopus | 139 (59%) |
| | ScienceDirect | 89 (38%) |
| | Web of Science | 6 (3%) |
| Total | | 234 (100%) |

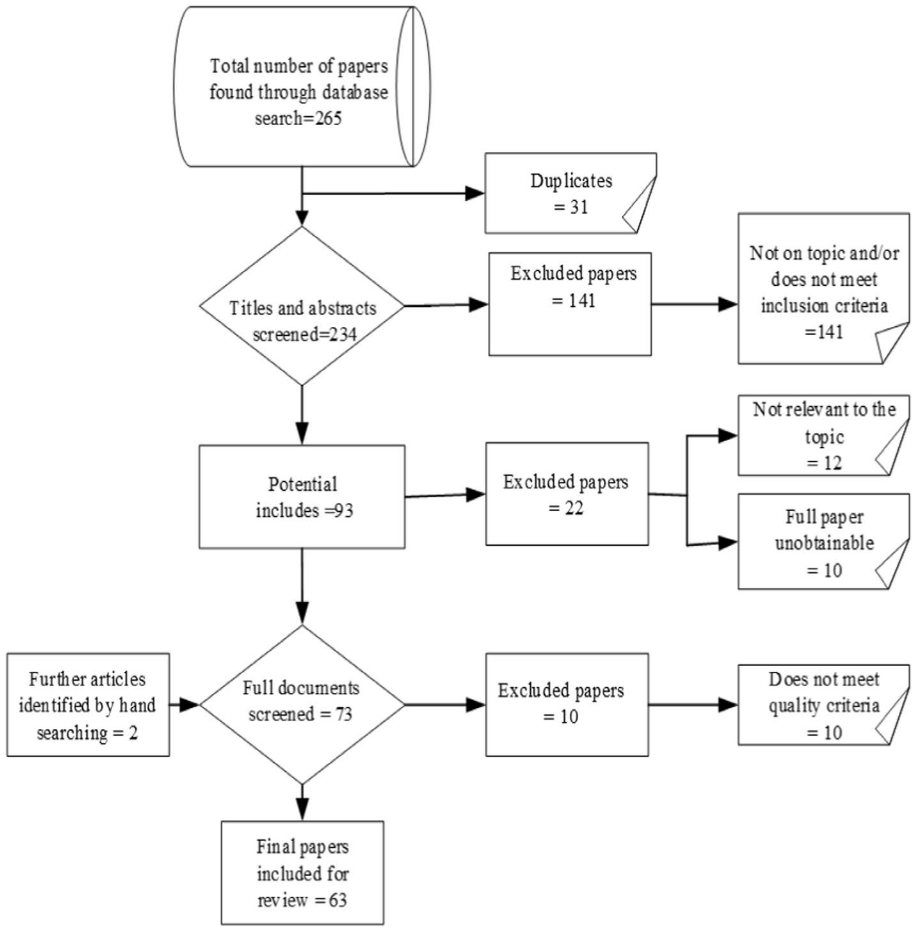


**Fig. 2** Selection and evaluation process

## Analysis of reviewed literature

### Descriptive statistics

Descriptive statistics are essential for summarizing and interpreting the characteristics of the studies included in this systematic review, offering a comprehensive overview of the research landscape. These statistics provide a richer, more nuanced understanding of current research on sea-rail intermodal transportation, highlighting trends, identifying gaps, and informing future research directions. The results will be presented using tables and figures to make interpreting the data summary easier and provide visual cues.

#### *Number of publications by year*

Figure 3 indicates a significant increase in research into SRITS in recent years. Seventy-two percent of the articles were published from 2015 to 2023, while only 28% were published between 2000 and 2014. This trend indicates that researchers' interest in studying SRITS increased after 2014, and it is likely considered an effective solution to seaport challenges. However, researchers are increasingly exploring other related themes of research, such as the role of dry ports within SRITS, which has become an interesting topic in this field over time.

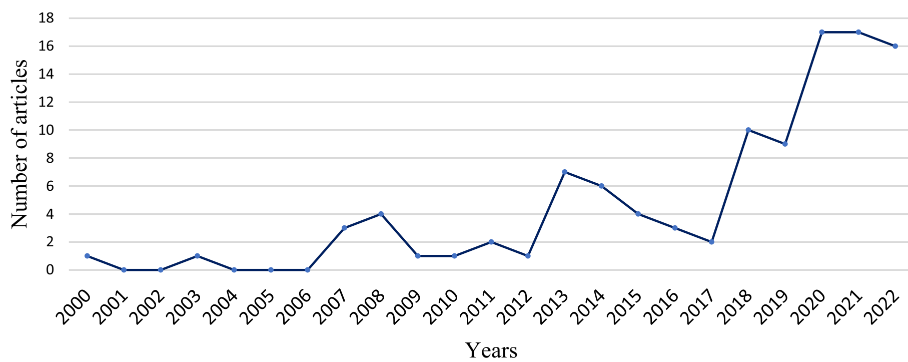


**Fig. 3** Total number of publications by year

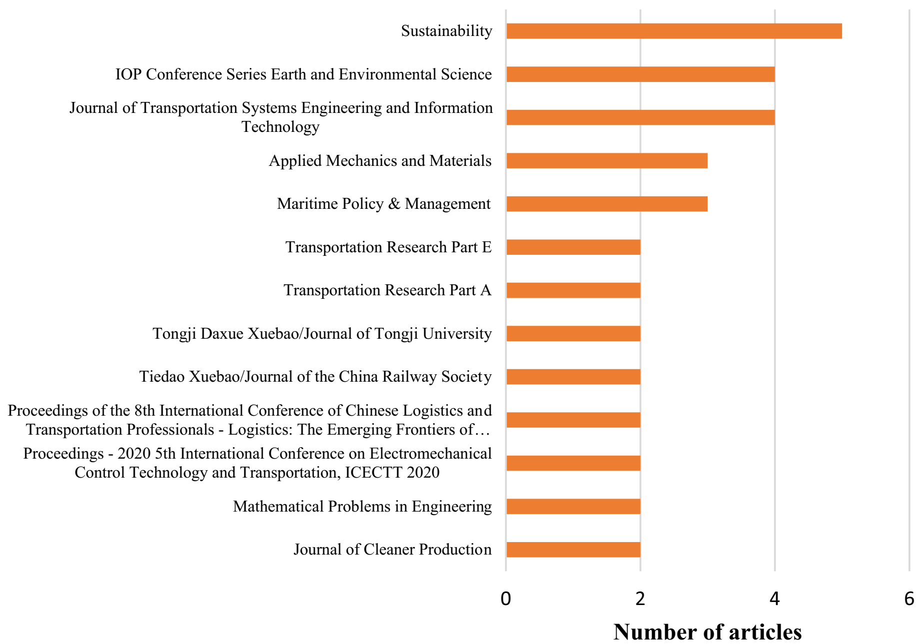


**Fig. 4** Number of published papers by publication

The earliest article in this study that addressed SRITS was by Damachi and Yang (2000) in China. The article discussed the challenges of SRITS in China, summarized by management, infrastructure, capital investment, and information coordination problems.

### *Distribution by journal of publication*

The list of journals where many of the reviewed articles were published is presented in Fig. 4.

These articles have obviously appeared in a select number of relevant journals, including *Sustainability*, *Journal of Transportation Systems Engineering and Information Technology*, *Maritime Policy and Management*, *Applied Mechanics and Materials*, *Journal of Cleaner Production*, and *Mathematical Problems in Engineering*.

Transportation-related journals have a considerable share of this research, while few research studies were published in journals addressing maritime transport, such as *Maritime Policy and Management*. The rest of the articles were distributed across four distinct journals.

## Thematic analysis of reviewed literature

Sixty-three papers placing emphasis on sail-rail intermodal were carefully selected and analysed. The review was categorized into five categories to facilitate the analysis process. This classification includes articles that addressed performance, methodologies used to solve problems, types of planning problems, factors affecting performance, and strategies to improve SRITS. This classification provides insights into the key topics covered in the sea-rail intermodal papers. It is worth noting that certain articles explore multiple themes simultaneously. A comprehensive examination of the papers selected is presented below, aligned with the classification illustrated in Fig. 5 for sea-rail intermodal.

### *Sea-rail intermodal performance*

Recently, the sea-rail intermodal container transportation sector has gained significant attention because of its low cost and environmental benefits. Numerous container ports worldwide have invested in rail terminals within seaports to improve connectivity between railway transportation and shipping areas. This intermodal transportation system provides an opportunity to reduce shipping costs while effectively mitigating congestion and maintaining low GHG emissions. Shifting transportation systems from road to rail can alleviate road congestion and minimize GHG emissions (Abu Aisha et al. 2021). Achieving optimal performance in the intermodal transportation system hinges upon the effectiveness of each component within the chain, encompassing ports, shipping companies, motor carriers, and rail. It is imperative to efficiently integrate these

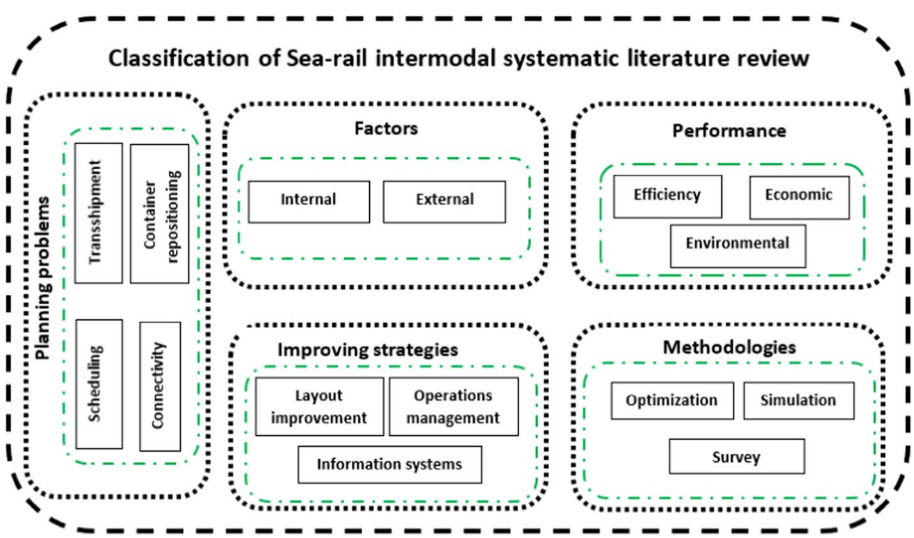


**Fig. 5** Classification of sea-rail intermodal systematic literature review

elements in terms of operations, decision making, and information to ensure the system functions at its best.

### *Sea-rail intermodal efficiency*

Sea and rail transportation system integration, known as sea-rail intermodal transportation, has garnered significant attention in the logistics and supply chain management fields. This mode of transportation offers numerous benefits, including high-volume capacity, energy efficiency, and reduced environmental impact. As the demand for efficient cargo movement continues to grow globally, it becomes paramount to understand and optimize the efficiency of sea-rail intermodal transportation networks.

Many studies have delved into optimizing terminal operations within sea-rail intermodal transportation systems. Yan and Xu (2021) talked about adjusting yard templates and equipment deployment plans to streamline container handling processes and reduce turnaround times, emphasizing operational efficiency and resource optimization. Similarly, Grishin et al. (2022) addressed the challenge of unloading vessels and forming trains, aiming to minimize overall delivery time and reduce costs associated with train formation. These studies underscore the importance of operational efficiency in terminal management and provide insights into practical strategies for optimizing resource use and improving terminal performance.

Efficient transport infrastructure and seamless connectivity between railway and port operations are essential for sea–rail intermodal transportation networks to function smoothly. Zhao et al. (2020) identified key bottlenecks in China's sea-rail intermodal system and emphasized the importance of integrating railway and port operations to optimize cargo flow and reduce transit times. Fang (2016) highlighted challenges arising from insufficient connection conditions between railway container yards and ports, proposing coordinated efforts among stakeholders to address these challenges and enhance infrastructure connectivity. Tadić et al. (2021) placed emphasis on improving port efficiency through dry port terminal development linked to river ports, aiming to reduce congestion and improve overall supply chain efficiency. These studies underscore the significance of transport infrastructure development and multimodal connectivity in enhancing sea-rail intermodal transportation efficiency.

Effective logistics management and innovation play a crucial role in optimizing sea-rail intermodal transportation networks. Zhao et al. (2018a) formulated a model to enhance inbound container distribution efficiency, minimizing the total duration that containers spend in coordination areas through optimal allocation and routing strategies. Meng (2018a) provided a comprehensive analysis of the benefits of sea-rail intermodal transport, highlighting its economic, environmental, and operational benefits over traditional shipping methods. The analysis underscores the multifaceted benefits of integrating sea-rail systems, making a compelling case for their broader adoption. Zhao et al. (2022) used advanced technologies and automation solutions to streamline container handling processes and improve terminal efficiency. The study introduced innovative handling approaches and underscored the importance of innovation in addressing operational challenges and enhancing the competitiveness of sea-rail intermodal transportation networks.

In conclusion, the literature reviewed in this section provides a comprehensive overview of existing research on sea-rail intermodal efficiency. From optimizing terminal operations and improving transport infrastructure to innovative logistics management and technology integration, researchers have proposed diverse solutions to address the complex challenges facing sea-rail intermodal transportation. However, further research is needed to validate and implement these solutions in real-time scenarios, ensuring the continued optimization and sustainability of sea-rail intermodal transportation networks in the evolving global logistics landscape.

#### *Economic efficiency of sea-rail intermodal*

The economic aspect of sustainability plays a pivotal role in the SRITS evaluation and decision-making processes. This aspect encompasses various factors influencing the overall cost-effectiveness and financial viability of transporting cargo between ports and their hinterland. A plethora of literature primarily emphasizes the economic criterion, reflecting its significance in decision making in the sea-rail intermodal transportation system.

Economies of scale are a fundamental principle in SRITS, as they minimize the overall expenses of transporting cargo. Abu Aisha et al. (2021) exemplified this principle by proposing an objective function to minimize the total transportation cost of containers from ports to their destinations. Similarly, Liu (2020) conducted a study to reduce logistics transportation costs while ensuring transportation efficiency to meet customer requirements. Yapegue and Lin (2014) adopted a comprehensive approach by minimizing the total logistics cost associated with container transportation, which included transportation expenses, loading and unloading costs, train formation and sorting costs, container storage costs, and auxiliary costs incurred during train movement. Meng (2018b) provided insights into the operational management model implemented in sea-rail terminals, highlighting its role in enhancing port station economic efficiency while meeting customer integration requirements. This demonstrates the capacity of sustainability to encompass other dimensions through related expenses.

In addition to cost considerations, some studies, such as those by Xie et al. (2022) and Zhang et al. (2021c), explicitly addressed the importance of considering costs alongside environmental criteria. These studies underscored the interconnectedness of economic and environmental sustainability within SRITS, highlighting the need for holistic approaches to decision making that balance financial considerations with environmental impacts.

In the realm of procurement optimization within sea-rail intermodal transportation systems, Liu et al. (2015) delved into the pivotal decision-making process that impacts the operational efficiency and competitive edge of non-vessel operating common carriers. On a similar note, Bo et al. (2013) emphasized the importance of enterprise alliances in fostering railway–waterway intermodal transportation advancement, especially within ports in China. To examine pricing strategies within intermodal transport, Di and Hualong (2012) placed emphasis on the dynamic pricing dilemma in container sea-rail intermodal transportation amidst uncertain conditions.

In summary, the literature reviewed in this section has emphasized the critical role of economic efficiency in sea-rail intermodal transportation systems. By minimizing transportation costs and optimizing operational management models, researchers aim to enhance the SRITS financial viability and sustainability while meeting customer requirements and addressing environmental concerns.

#### *Environmental efficiency of sea-rail intermodal*

Policymakers and researchers alike often emphasize the SRITS superior environmental performance when compared to road transport. The comparative SRITS benefit over road transport in environmental performance is a prominent theme in the literature. This benefit is attributed to the inherent characteristics of sea-rail intermodal container transportation, combining low-carbon emissions with high capacity and alleviating traffic congestion. Although this narrative is compelling, nuanced considerations and challenges merit deeper exploration.

Many studies have investigated the environmental benefits of modal shift towards SRITS. For example, Zhang et al. (2021a) evaluated the environmental benefits of increasing SRITS use in port-connecting freight transportation in Shenzhen, China. By assessing emission reductions and air quality improvements, the study highlighted the potential for SRITS to contribute to sustainable urban development. Similarly, Abu Aisha et al. (2020) and Fan et al. (2019) emphasized reducing greenhouse gas emissions within SRITS by promoting the use of trains for container transportation. These studies acknowledged the importance of optimizing transportation modes and speeds to minimize environmental footprints while maintaining cost-effectiveness.

In addition to modal shift initiatives, infrastructural and technological innovations have emerged as key strategies for enhancing SRITS's environmental efficiency. Wang et al. (2018) explored the integration of automated guided vehicles (AGVs) and railway tracks to improve port connectivity and reduce emissions associated with inland cargo movement. This approach aligned with broader efforts to optimize supply chain logistics and minimize environmental impacts. Despite the growing emphasis on environmental sustainability within SRITS, challenges and trade-offs must be addressed. Winebrake et al. (2008) highlighted the complexities of balancing cost, energy consumption, and emissions within intermodal transportation networks. Though SRITS may offer environmental benefits, there are inherent trade-offs and uncertainties that require careful consideration in policy and planning decisions.

In summary, the literature on SRITS's environmental efficiency reflects a growing recognition of its potential to contribute to sustainable transportation practices. However, achieving meaningful environmental improvements requires a nuanced understanding of the challenges and opportunities inherent in intermodal transportation systems.

#### *Methodologies used in analysing the sea-rail intermodal*

The methodologies used in analysing SRITS reflect a diverse array of approaches that address inherent complexities. This section categorizes and evaluates the methodologies used by various authors, emphasizing the breadth of approaches employed for sea-rail assessment.

Mathematical modelling stands as a cornerstone in SRITS analysis; the use of integer linear programming is dominant across studies. For instance, Yan and Xu (2021) proposed a multi-objective model to plan transfer flow templates within seaport railway terminals, integrating decisions regarding flow volume, yard templates, and equipment deployment. Similarly, Yan et al. (2020b) put emphasis on minimizing container dwell time at sea-rail terminals through an integer programming model, emphasizing the reduction of total dwell time during transhipment activities. Conversely, Zhao et al. (2016) addressed optimal container routing within intermodal transportation networks, treating it as a multimodal multicommodity network flow problem to minimize overall transportation expenses.

Mixed-integer programming emerges as a prevalent methodology in SRITS research. Xie et al. (2022) introduced a bi-objective mixed-integer programming model to optimize logistics cost and time, showcasing the importance of considering multiple objectives in SRITS optimization. Similarly, Yan et al. (2020a) synchronized vessel and train operations using a mixed-integer programming model from a container terminal perspective, accounting for factors such as service time windows and train unloading requirements.

Beyond mathematical models, innovative methodologies such as simulated annealing algorithms and heuristic approaches have been implemented to manage complex operational processes within SRITS. Chang and Zhu (2019) developed a two-phase model to manage storage space allocation, introducing a simulated annealing algorithm and an enhanced heuristic algorithm to achieve balanced workloads and decreased overlap. Similarly, Luo et al. (2018) used a mixed-integer programming model to optimize gantry crane scheduling, placing emphasis on reducing task overflow during loading and unloading operations while optimizing travel distances within the yard.

The identified studies primarily shed light on optimization strategies within SRITS, aiming to address specific challenges and enhance operational efficiency. For instance, Zhao et al. (2020) and Liu (2020) proposed optimization models to reduce transportation expenses, emphasizing environmental sustainability and cost-effectiveness. Similarly, Fan et al. (2019) constructed an energy optimization model to improve the overall SRITS energy efficiency.

In addition to cost optimization, logistical challenges such as empty container movement management were addressed by Zhao et al. (2018c) and Zhao et al. (2018b) who built a nonlinear integer programming model to minimize container relocation and routing costs. The Zhao et al. (2018b) model was validated through two case studies; they showcased its feasibility and assessed how stochastic variables and chance constraints influenced optimal solution and overall cost. Decision-making frameworks proposed by Han et al. (2020) and Wan et al. (2022) offered structured approaches to evaluating system performance and competitiveness, providing a fuzzy multi-attribute decision model to evaluate port hub competitiveness.

Genetic algorithms also emerge as a promising avenue for optimizing container distribution and scheduling within SRITS. Zhao et al. (2018a) and Yang et al. (2023) presented innovative genetic algorithm-based solutions to optimize container organization and collaborative scheduling, respectively. Additionally, Liu and Yang (2013) proposed a two-phase optimization model to address slot control challenges, enhancing operational efficiency within SRITS.

The accurate prediction of SRITS growth plays a pivotal role in new port facility development and the readiness to meet the rising demand for this mode of transportation. In previous years, Tang et al. (2022) constructed a grey forecasting model to predict the sea-rail throughput at the Xiamen port, complemented by the Markov chain application to rectify relative error series. These endeavours improved forecast accuracy and bolstered the credibility of sea-rail throughput data, ensuring reliable predictions for the Xiamen port over the next three years.

Similarly, Li (2013) used a single-variable grey sequence forecast model to anticipate container throughput at Lianyungang Harbour to advance rail-sea intermodal transportation. Tao (2013) devised analytical tools to evaluate potential shifts in transportation modes owing to subsidy initiatives supporting sea-rail intermodal transport between the Port of Ningbo and East Jiangxi province. By using random utility theory and conducting stated preference experiments, Tao formulated detailed models enabling a thorough examination of factors influencing modal choices and shed light on the effectiveness of subsidy policies in promoting SRITS.

Literature on simulation addressing SRITS-related challenges remains relatively sparse. Zhang et al. (2021a) developed a comprehensive model to assess the environmental impacts of multimodal transportation planning in Shenzhen, putting emphasis on enhancing sea-rail intermodal transport use. Feng et al. (2014) pointed out key factors that influence sea-rail intermodal dry bulk transport and constructed a dynamic system model using VENSIM software. The model validated through a case study at Meizhou Bay Port, demonstrating its feasibility and potential for optimizing dry bulk transport.

Other methodologies have also been explored. For instance, Feo-Valero et al. (2011) used the stated preference approach to estimate a modal choice model between road and rail transport for containerized maritime freight shipments in Spain. Wu and Pan (2010) used a support vector machine with game theory to forecast market volume in China's Jinjiang port, extending predictions for the next five years. Ge et al. (2020) conducted a study using questionnaire surveys and content analysis to examine stakeholders involved in China's sea-rail intermodal transport, revealing significant concerns such as institutional and regulatory deficiencies, opposition from the railway sector, and disjointed information systems. Their proposed administrative framework suggests unifying international regulations, reforming the rail sector, and implementing incentive policies for businesses to promote SRITS development instead of direct subsidies. The methodologies used in analysing SRITS encompass a diverse range of approaches, reflecting the multifaceted nature of SRITS problems and challenges. Mathematical modelling, particularly integer linear formulations and mixed-integer programming, emerges as a predominant tool for optimizing various aspects of SRITS, from logistics cost and time to vessel and train operation synchronization. Additionally, methodologies such as genetic algorithms offer promising avenues for addressing complex operational processes within SRITS. These methodologies primarily put emphasis on optimizing strategies to enhance operational efficiency, reduce transportation expenses, and tackle logistical challenges such as empty container movement. Prediction models, such as grey forecasting and Markov chains, help anticipate SRITS growth. Though simulation studies are limited, the literature emphasizes the importance of interdisciplinary approaches and highlights areas for further research. The methodologies discussed underscore the complexity of SRITS and the need for continued investigation to enhance efficiency and address emerging challenges.

#### *Analysing the research problem*

Decision-making processes vary significantly based on the time horizon considered. Time horizon refers to the period over which decisions are made and their impacts are felt. This horizon plays a crucial role in shaping the strategies, goals, and considerations involved in the decision-making process. The planning levels and correlated problems can be summarized as follows: Strategic planning issues revolve around investment decisions regarding existing infrastructure. Tactical planning challenges involve the optimal use of available infrastructure by selecting services and transportation modes, allocating capacities to orders, and planning frequencies. Operational planning problems pertain to real-time decision-making, including order management, responses, and adjustments such as resource allocation based on demand or equipment failures. In this section, we classify the articles into two distinct groups: those centered on transhipment operation problems and those tackling scheduling issues.

#### *Transhipment operations between vessels and trains in seaport rail terminals*

The literature review on transhipment operations between vessels and trains in seaport rail terminals unveils crucial challenges and avenues for improving rail transportation efficiency within maritime logistics. Although rail and road transport modes facilitate goods movement through port areas, rail operations often fall short of road transport in terms of market share. This disparity underscores the urgency of refining rail operations within rail-sea yards to enable more extensive use of rail transportation, thereby mitigating the adverse externalities associated with road transport such as congestion, accidents, and environmental pollution. It is significantly challenging to achieve a balanced modal split between rail and road modes in planning flows through maritime terminals (Iannone 2012). Zhang and Chen (2009) undertook a comparative analysis of evaluating the market share of various transportation modes in Shanghai. Their findings illuminated sea-rail intermodal container transportation expansion from Shanghai Harbour to numerous inland cities. However, this expansion encounters robust competition from established freeway networks in East China and the flourishing Yangtze River waterway, potentially diminishing the share of sea-rail intermodal containers in these regions.

Among the primary activities in the rail-sea supply chain connection, train movement between railway stations and maritime terminals alongside loading, unloading, cargo exchange between the train and ship, and storage of goods assumes paramount importance. However, the literature has largely overlooked the transition between the rail network and maritime terminals, including the processes of train division into wagon groups and subsequent transfer to cargo storage areas. It becomes imperative to shed light on this critical transition and underscore the potential for enhancements in operational efficiency.

Various scholarly endeavours have tackled facets of logistics services complexity at transhipment terminals, aiming to devise decision-making frameworks for effectively assessing service intricacies. For instance, Filina-Dawidowicz and Kostrzewski (2022) delved into the issues of logistics services complexity at transhipment terminals to devise a decision-making method capable of effectively assessing the intricacy of logistics services provided by these terminals. Cost minimization strategies have been explored to optimize overall transportation costs, considering factors such as container storage costs and loading/unloading operation costs. Zhao et al. (2020) conducted a study to minimize overall transportation costs by considering various cost components. This led to considering various types of central rail stations to optimize outbound railway container logistics. The first type involves locating the central railway station adjacent to the dock front, using part of the port yard as a railway yard. The second, exemplified by Dalian Port, positioned the central railway station outside the port gate. The critical difference for outbound railway containers lies in the distance between the train and the ship.

Efficiency in transhipment activities linking ships and trains at seaport railway terminals has also been scrutinized. Studies highlighted the significant impact of handling capacity and storage expenses on the effectiveness of transhipment strategies. Yan et al. (2020a) examined transfer plan efficiency; they found that enhancing storage expenses for imported containers resulted in a more efficient transhipment strategy.

Challenges pertaining to sea-rail transhipment have been thoroughly investigated, including the establishment of train schedules and the formulation of plans for incoming container transhipment. This was what Yan et al. (2020b) highlighted in their study on seaport rail terminals. Their study tackled two significant components within sea-rail intermodal container transport: establishing a train schedule framework and formulating plans for the transhipment of incoming containers.

Allocation problems about handling equipment in container terminals for rail-sea intermodal transportation have also been addressed to optimize the handling of operation efficiency (Naiyu Wang and Wei 2020). Obstacles in constructing sea-rail intermodal transport systems have been elucidated by Zheng and Cai (2020). They outlined the obstacles involved in constructing sea-rail intermodal transport systems in Shanghai, emphasizing the necessity of comprehensive planning and facility integration to foster rail-sea intermodal transport advancement. While extant research has delved into storage space allocation problems in maritime container terminals, limited attention has been given to obstacles in rail–water intermodal container terminals. Chang and Zhu (2019) presented an integrated problem involving storage space allocation, combining considerations related to container block and slot allocation to optimize the efficiency and effectiveness of rail–water intermodal container terminals. Both authors shed light on managing unbalanced distributions and the reallocation of inbound containers within the railway operation area.

#### *Scheduling problems*

Within the sea-rail intermodal container terminal domain, challenges surrounding scheduling problems are multifaceted and require nuanced solutions for operational optimization. Recent studies have contributed valuable insights into various aspects of scheduling complexities and their implications for terminal efficiency.

Yang et al. (2023) conducted an in-depth analysis of the interplay between yard cranes, the automated quay crane (AQC), AGV, and the automated rail mounted gantry (ARMG), putting emphasis on optimizing multi-equipment scheduling in mixed operation modes while minimizing overall energy consumption. Their study emphasized the importance of collaborative scheduling strategies in achieving energy-efficient operations within intermodal terminals. Building upon this foundation, Liu et al. (2023) delved into the integration of scheduling and path planning within sea-rail intermodal container terminals. They proposed a two-level programming model that streamlined horizontal transport machinery, handling equipment and path mapping for AGVs within a novel U-shaped yard configuration. By optimizing yard crane schedules and facilitating precise route planning for AGVs, their approach reduced overall waiting times for AGVs and trucks, further enhancing terminal efficiency. These studies collectively highlight the significance of collaborative scheduling approaches and integrated operational strategies in optimizing scheduling processes and enhancing overall efficiency within sea-rail intermodal container terminals.

Transfer procedures between ships and trains within railway terminals located at seaports were investigated by Yan et al. (2020a), emphasizing the need for synchronized train schedules and container transhipment plans across vessels, yards, and trains. Their study highlighted the intricate logistical challenges involved in achieving seamless transfers between various modes of transport within port terminals.

In addressing the scheduling complexities of gantry cranes within sea-rail intermodal transport yards, Luo et al. (2018) and Li et al. (2022) offered valuable insights. Luo et al. (2018) optimized gantry crane schedules to align with operational requirements, whereas Li et al. (2022) delved into collaborative scheduling problems within multimodal transport harbours, emphasizing the importance of coordination between gantry cranes and trucks to enhance overall terminal efficiency.

Operational challenges such as timeliness, high rates of empty container returns, and cargo density inadequacies were discussed by Liu et al. (2014), highlighting the imperative for operational improvements within sea-rail intermodal terminals. Xie et al. (2017) addressed the coordination and sharing of empty container inventory within intermodal transportation systems, whereas Zhao et al. (2016) optimized container routes within intermodal sea-rail networks across China, underscoring the significance of efficient route planning for cargo movement optimization.

The global issue of empty container shortages examined by Luo and Chang (2019) poses significant challenges to the smooth functioning of intermodal transportation systems. Their study emphasized the need for proactive measures to address container shortages, ensuring uninterrupted industrial activities and a resilient global supply chain.

The repositioning of empty containers and the consequent environmental impacts pose significant challenges for maritime companies operating within sea-rail intermodal transportation systems. Zhao et al. (2018c) undertook a study on the empty container repositioning problem while paying specific heed to $CO_2$ emissions. Their research devised approaches to enhance the efficiency of empty container repositioning while mitigating environmental impacts associated with these operations. Similarly, Pingping et al. (2013) analysed the challenges encountered in combined sea-rail transport in Ningbo, China, especially linking the port to the hinterland and expanding the scope of rail-sea intermodal transportation in Ningbo. In another study echoing emphasis on the

Port of Ningbo, Tao (2013) examined subsidy policies linking the Port of Ningbo with East Jiangxi province, using random utility theory and stated preference experiments to construct two distinct models aimed at assessing the effectiveness of these policies.

#### *Factors affecting the port container sea-rail transportation system*

The efficiency of port container sea-rail transportation systems plays a pivotal role in shaping global trade networks and facilitating economic growth. This discussion elucidates the multifaceted factors influencing these systems and their implications for port operations and competitiveness.

A comprehensive assessment by Damachi and Yang (2000) highlighted various challenges within the sea-rail intermodal transportation sector in China, including inadequate management practices, insufficient terminal infrastructure, lack of modern facilities, coordination inefficiencies, and limited investment capital. Addressing these challenges is imperative for overcoming obstacles and enhancing overall sea-rail intermodal transport performance in China.

Infrastructure emerges as a critical determining point of port throughput and operational efficiency as underscored by Pehlevan and Ricci (2022). Their research emphasized the importance of infrastructure investment and development in enhancing port operations, particularly in ports such as İzmir, Turkey, and Trieste, Italy. The findings highlighted the pivotal role of infrastructure as an enabler of efficient port operations and underscored the need for continued investment in port infrastructure to sustain competitiveness.

Conversely, one of the key findings from some recent studies, as highlighted by the research conducted by Wan et al. (2022), identified a significant shift in the primary factors that affect a multimodal port hub. Traditionally, infrastructure-related factors dominated discussions; however, there has been a discernible shift towards more flexible determining factors such as transportation business efficiency, capacity integration, and service quality. This paradigm shift underscores the industry's imperative to adapt to evolving market dynamics and technological advancements to maintain competitiveness in a rapidly evolving landscape. Chen and Zhang (2021) delineated factors influencing sea-rail intermodal transportation systems into internal and external components. Internal factors directly impact system functionality, including infrastructure and resource scheduling, whereas external factors such as geographical location, economic conditions, and transportation policies exert indirect influences. This comprehensive understanding of internal and external factors is essential for devising strategies to optimize system performance and efficiency.

Operational considerations within sea-rail intermodal transport systems, such as handling capacity and storage costs, are also critical factors influencing system performance, as elucidated by Yan et al. (2020a). Their findings emphasized the importance of integrating these operational factors into system optimization strategies to enhance transhipment operations and overall system efficiency.

Since seaport location impacts port connectivity and other modes of transportation, the Zhang et al. study (2021b) revealed that strategically positioning logistics facilities not only cuts costs by achieving economies of scale but also optimizes transportation effectiveness and service excellence by devising streamlined multimodal networks.

Similarly, the primary research focuses by Han et al. (2021) lay in determining hierarchical hub locations for planning rail-sea container transportation networks, specifically considering the Arctic Route. The study revealed the significant impact of central hubs on total transportation cost and hub locations, while the influence of general hubs remained relatively minor.

Equipment capacity, particularly rail-mounted gantry cranes, emerges as a key determining point of operational efficiency in terminal handling processes, as demonstrated by Yan et al. (2020b). Their findings underscored the pivotal role of crane capacity in shaping transhipment operation performance, highlighting the need to optimize handling equipment capacity to enhance overall efficiency. Naiyu Wang and Wei (2020) outlined guiding principles for configuring handling equipment for rail-sea intermodal transportation, emphasizing the importance of aligning equipment configuration with operational needs to maximize efficiency.

Zhao et al. (2018a) contributed to the field by developing a comprehensive model to optimize container distribution organization within coordination areas. By considering factors such as transhipment capacity and container importance, their model minimizes total container hours, thereby streamlining inbound container movements and improving overall distribution efficiency. This approach significantly advances logistical operation optimization within coordination areas, leading to more efficient container handling and distribution processes. Han et al. (2020) delved into determining factors influencing multimodal transport, specifically concentrating on sea-rail intermodal transportation systems. Their research identified intermodal container transport volume and railway coverage extent as pivotal factors shaping system advancement. By objectively evaluating multimodal transportation development, their study highlighted specific challenges and areas for improvement within selected cities, offering valuable insights for policymakers and stakeholders seeking to enhance system efficiency and effectiveness.

Feng et al. (2014) emphasized critical factors in dry bulk transportation by developing a dynamic system model tailored for sea-rail intermodal transportation. Validated through a case study at Meizhou Bay Port in Fujian, their research demonstrated the model's effectiveness in simulating and assessing transportation systems, thereby advancing transportation planning and optimization in sea-rail intermodal contexts. Huang and Xing (2013) shed light on the factors hindering China's rail-sea intermodal transportation development. Their analysis pinpointed many key challenges, including insufficient trunk line railway transport capacity, inadequate connectivity between seaports and rail tracks, irrational railway tariff mechanisms, limited information sharing between ports and railway stations, and imperfect operational and organizational modes. Addressing these challenges is essential for overcoming barriers to efficient intermodal transportation and fostering system growth.

Li & Ye (2009) and Damachi and Yang (2000) provided complementary insights into rail-sea intermodal transportation system complexities, particularly within the context of China. Li and Ye (2009) concentrated on multifaceted factors influencing these systems at Shanghai Port, emphasizing the importance of geographical positioning, environmental considerations, and operational methodologies. Their study suggested that recognizing and addressing these factors could help stakeholders optimize port operations and enhance system resilience. Damachi and Yang (2000) took a broader view, conducting a comprehensive evaluation of the challenges affecting China's entire intermodal transport landscape. They pinpointed systemic deficiencies such as inadequate management practices and outdated infrastructure, significantly impeding operational efficiency across the intermodal transport network.

Beyond operational hurdles, meteorological factors are critical in rail-sea intermodal transportation. Sun et al. (2022) explored the intricate relationship between meteorological phenomena, glacier melting, and container flow dynamics. Their research highlighted the vulnerability of transportation networks to climate change-induced disruptions, emphasizing the need for adaptive strategies to mitigate risks and ensure system resilience.

#### *Strategies to improve sea-rail intermodal*

The quest to improve SRITS efficiency and sustainability has prompted diverse strategies proposed by researchers and scholars. These strategies range from infrastructure enhancements to policy recommendations and offer valuable insights into fostering a more seamless and integrated intermodal transport landscape.

Abu Aisha et al. (2020) advocated for optimizing SRITS efficiency through strategic changes in container terminal layout and connectivity with dry ports via rail tracks. By reconfiguring terminal infrastructure and bolstering inland connectivity, this approach streamlines cargo handling processes and enhances overall transport efficiency. Similarly, Tadić et al. (2021) proposed the establishment of dry port terminals for Danube River ports, coupled with enhanced rail network connectivity. This strategy envisages transforming existing river terminals into regional logistics hubs, extending their reach and attracting greater freight volumes through enhanced inland waterway transport integration into the European intermodal network. Dry port construction also plays a crucial role in improving port accessibility, as observed in the case of the Port of Ningbo, China, and highlighted by Pingping et al. (2013).

Inward railway container yard construction as proposed by Li and Ye (2009) offers another avenue for optimizing SRITS efficiency. These trans-container handling stations are equipped with custom clearance capabilities and facilitate seamless cargo handling near origin or destination points, enhancing convenience for consignors and fostering the growth of rail-sea intermodal transportation.

Policy recommendations, such as those advocated by Ge et al. (2020), play a pivotal role in shaping the regulatory landscape to foster SRITS development. Their proposed administrative framework emphasized regulatory coherence, sectoral alignment, and incentive-based policies to create an enabling environment conducive to sustained SRITS growth and investment.

Information system integration emerges as a critical enabler for SRITS optimization as highlighted by Jarašūnienė and Čižiūnienė (2021). The establishment of comprehensive logistics information platforms facilitates seamless information exchange among stakeholders, enhancing coordination, efficiency, and operational streamlining within the intermodal transport network.

Embracing the concept of smart ports is a forward-looking strategy to leverage technology for sustainable SRITS development. Fang (2022) discussed the potential of smart port initiatives, integrating automation and advanced information platforms to optimize port operations and connectivity with stakeholders. This approach holds promise for enhancing operational efficiency and sustainability in sea-rail intermodal transportation.

## Discussion

This review underscores the growing importance of sea-rail intermodal transportation in recent years because of its cost-effectiveness and environmental benefits. The review presents a range of studies, each offering distinct perspectives on various facets of sea-rail intermodal transportation system. In this review, we see a growing interest in studying the sea-rail intermodal transportation system, especially in most of the reviewed studies published from 2017 and beyond, as shown in Fig. 3. Yet, this topic still offers many research challenges; planning such a complex system presents intriguing research opportunities.

These studies delve into improving sea-rail intermodal efficiency from various perspectives, such as reducing cargo delivery times, minimizing cost, scheduling operations, repositioning empty containers, reducing emissions, and optimizing terminal layouts. This research underscores the importance of continuous optimization efforts to enhance overall sea-rail terminal performances.

The economic aspect of sustainability has substantial weight because it frequently stands as the foremost consideration in corporate decision making. This assertion is substantiated by the considerable number of articles that emphasize this primary criterion. Studies by Yapegue and Lin (2014), Liu (2020), and Abu Aisha et al. (2021) are cited as examples of research aimed at reducing logistics costs and improving operational efficiency within the sea-rail transport system.

In recent years, there has been a gradual rise in research articles that place emphasis on environmental concerns. However, the quantity of such articles remains relatively constrained, especially those that specifically target environmental aspects and seek to curtail carbon footprint. Environmental considerations are also a key review focus, with many studies highlighting the potential of sea-rail intermodal transportation to reduce carbon emissions and mitigate air pollution. For instance, research by Yan and Xu (2021), Zhang et al. (2021a), and Winebrake et al. (2008) examined the environmental benefits of modal shifts towards sea-rail transport, offering insights into the potential environmental benefits of this mode of transportation. Environmental criteria predominantly revolve around the positive effects of minimizing fuel consumption and reducing emissions at the terminal and within the surrounding city. In most research, emission minimization is the result of minimizing handling container time in the terminal or container delivery at their destination.

Researchers used various methodologies to optimize operational efficiency, minimize costs, and promote sustainable development within the sea-rail intermodal transport sector. A prominent methodology highlighted in the review is the use of mathematical models, particularly integer linear formulations. As demonstrated by studies such as those conducted by Yan and Xu (2021) and Zhao et al. (2016), these models play a crucial role in optimizing various aspects of SRITS operations such as terminal layout planning and container routing. As evidenced in studies such as Xie et al. (2022) and

Yan et al. (2020a), integrating mixed-integer programming further enhances the prescriptive analytical capabilities of these models, which enable simultaneous logistics cost optimization and operational efficiency.

The review discusses the application of optimization models in addressing specific challenges within SRITS, including slot control and container routing. Studies such as Liu and Yang (2013) and Zhao et al. (2018a) exemplified how these models can be tailored to effectively manage container movement, thus improving overall system efficiency. In addition to mathematical modelling, some articles used other SRITS analysis methodologies. For instance, Feo-Valero et al. (2011) used the stated preference approach to evaluate user perceptions and estimate modal choice models, providing valuable insights into user behaviour in the context of SRITS. Similarly, Ge et al. (2020) conducted a questionnaire survey and content analysis to identify key stakeholders and challenges in SRITS development in China, offering practical recommendations for addressing them.

Because of this field's dynamic nature and uncertainty level, some articles highlighted the importance of forecasting and predictive modelling to anticipate future trends and demands within SRITS. Tang et al. (2022) and Li (2013) demonstrated how forecasting models can be applied to predict sea-rail throughput and container throughput to facilitate infrastructure planning and decision making. Given the substantial investment required for sea-rail intermodal infrastructure, it is prudent to use simulation methods to assess investment decisions within terminals. However, only a limited number of studies have used simulation to scrutinize the multifaceted impacts of various factors on system efficiency. This underuse of simulation may stem from a researching tendency to place emphasis on optimizing or examining the effects of a single factor in each problem.

Finding effective solving approaches for large-scale planning problems in complicated systems such as sea-rail intermodal in the terminals is a continual challenge. Despite the computational intricacies of solving complex system issues within the sea-rail intermodal system, solution techniques are often used alongside small theoretical instances. Although these instances offer valuable insights, the applicability of these solution methods to address problems on a more realistic scale remains limited. In practical terms and across most instances, finding an effective solution requires considering all interconnected factors influencing system performance. Currently, existing literature points out that determining the optimal approach for each unique problem remains challenging. However, simulation–optimization techniques have shown promising outcomes when applied to explore complex systems and evaluate proposed scenarios, especially when dealing with the scale and complexity of issues at hand.

The lack of data related to problem-solving forces researchers to consider a different variant in each study instead of considering all interrelated factors. Unlike a more mature field such as vehicle routing problems (VRP), where there is a well-established classification system and a wealth of benchmark problem instances readily available for research purposes, the sea-rail planning field lacks a similar framework. There is no comprehensive classification of sea-rail planning problems, and no standard benchmark instances exist, that researchers can use to compare methods or validate algorithms. This lack of structured data and classification makes it challenging to develop and benchmark solutions for sea-rail planning problems effectively. By explicitly highlighting this gap, we emphasize the need for further development in the sea-rail planning problem domain, similar to the resources available for VRP. So far, there has been a lack of research that uses simulation techniques to analyse and investigate system behaviour and find system bottlenecks that cause system inefficiency and slow cargo flow. This poses a need for further research using simulation techniques to investigate such problems, especially at a strategic level.

The literature review provides a comprehensive analysis of the challenges within SRITS. This review categorizes articles into two main groups: articles addressing transhipment operations between vessels and trains in seaport rail terminals and articles addressing scheduling problems within SRITS. In the realm of transhipment operations, the review emphasizes the importance of improving rail–sea connection efficiency to promote the use of rail transportation over road transport. Studies such as Filina-Dawidowicz and Kostrzewski (2022) and Zhao et al. (2020) delved into the complexities of logistics services at transhipment terminals. Research by Yan et al. (2020a) and Naiyu Wang and Wei (2020) put emphasis on optimizing transhipment activities and handling equipment allocation within seaport rail terminals, highlighting the need for efficient resource use and operational planning to avoid extra investment in new resources until the existing resources are fully used. With respect to scheduling problems, the review discusses studies that explore the coordination and optimization of various equipment and processes within SRITS. Yang et al. (2023) and Liu et al. (2023) investigated collaborative scheduling and path planning to minimize energy consumption and enhance operational efficiency. Challenges related to transfer procedures between ships and trains are addressed, emphasizing the importance of incorporating train schedules and container transhipment plans (Yan et al. 2020a). Furthermore, the review identifies challenges such as gantry crane scheduling, empty container repositioning, and transport capacity procurement, which significantly impact SRITS operational efficiency and competitiveness (Luo et al. 2018; Zhao et al. 2018c), and discusses broader topics such as market competition, pricing strategies, and infrastructure development in the context of SRITS (Zhang and Chen 2009). Interestingly, existing research has primarily shed light on operational-level aspects such as cost and time optimization in logistics. This is understandable, given that application and investments at the strategic level can often come with substantial costs. However, this review reveals a significant gap in research dedicated exclusively to reviewing the sea-rail intermodal within seaports. Addressing this gap through comprehensive literature reviews would contribute to a deeper understanding of the subject and pave the way for further advancements in the field.

The review highlights the importance of understanding and managing internal and external factors to ensure the optimal SRITS performance. Internal factors identified in the literature include infrastructure, equipment, resources scheduling, and transmission service subsystems. These factors directly impact the SRITS port container functioning, as outlined by Chen and Zhang (2021). Studies such as Yan et al. (2020a) and Pehlevan and Ricci (2022) emphasized the significant role infrastructure plays in determining port terminal throughput and performance, highlighting the need for investment in infrastructure to enhance operational efficiency. External factors encompass geographical location, economic conditions, transportation policies, and local weather characteristics. These factors indirectly influence SRITS performance and operation by shaping the broader operating environment in which they operate. Understanding the interplay between internal and external factors is crucial for devising effective strategies to optimize SRITS efficiency, as noted by Wan et al. (2022). Many studies focus on specific factors, such as handling capacity and equipment arrangement on transhipment operations, that directly impact SRITS operational efficiency. Meteorological factors such as glacier melting are pinpointed as important considerations for planning and managing container flow assignments within the sea-rail network, as discussed by Sun et al. (2022).

More than two decades ago, Damachi and Yang (2000) addressed many challenges impacting operational sea-rail intermodal system efficiency in China, such as inadequate management practices, insufficient infrastructure for intermodal transport terminals, outdated technology and facilities, limited coordination of information, and inadequate investment capital. Despite the passage of time, the above challenges are still prevalent in more recently reviewed research on sea-rail intermodal. It thus remains crucial to address these challenges to improve sea-rail intermodal efficiency and effectiveness.

The strategies proposed to enhance SRITS offer valuable insights into improving efficiency, connectivity, and sustainability within the transportation sector through changes in container terminal layouts and the establishment of rail-connected dry ports to enhance SRITS efficiency. This approach seeks to optimize freight transport and logistics operations by integrating terminals into regional logistics centres and expanding hinterland connectivity such as via inland waterways. Ge et al. (2020) advocated for a policy framework promote SRITS in China. This three-step administrative approach unifies international regulations, reforms the rail sector, and implements incentive policies for businesses. By ensuring regulatory coherence, sectoral integration, and providing incentives, this approach creates a conducive environment for SRITS development, encouraging active participation and investment from businesses. SRITS efficiency can also be improved by developing a management information system to enhance operations. This comprehensive logistics information platform supports seamless information exchange among stakeholders, including railways, ports, customs, and intermodal transport companies, thereby improving coordination, efficiency, and streamlining operations within the sea-rail intermodal transportation network (Li and Ye 2009). Lastly, as discussed by Fang (2022), the smart port concept underscores the importance of aligning with new technologies to ensure sustainability. Smart ports leverage automation to better connect ports to stakeholders using automated ships or vehicles. By integrating logistics parks and port and shipping information platforms, smart ports optimize operations, enhance efficiency, and foster sustainable growth within the transportation sector. For further insights into smart ports, readers are encouraged to explore the review by Belmoukari et al. (2023).

The research question at hand explores how SRITS are effectively studied and analysed to minimize costs and mitigate negative environmental impacts. The review underscores that SRITS have been extensively studied and analysed to enhance efficiency while reducing costs and environmental footprints. Scholars have scrutinized sea and rail transportation system integration, putting emphasis on bolstering capacity, improving energy efficiency, and mitigating environmental effects. As discussed in Sect. 3.2, research on SRITS has involved a comprehensive analysis of various dimensions, including infrastructure development, operational challenges, and environmental considerations. Studies have explored the complexities of SRITS operations, such as logistics services, terminal operations, handling capacities, and storage costs, all aimed at optimizing efficiency. Additionally, they have addressed scheduling issues, cost reduction strategies, and operational inefficiencies like empty container repositioning. Key factors influencing SRITS performance, including geographical location, economic conditions, and relevant policies, have been carefully examined. To optimize SRITS, researchers have employed various methodologies, such as mathematical modeling, simulations, and predictive models. Techniques like grey forecasting and Markov chains have been particularly useful for providing accurate growth forecasts and developing optimization strategies for SRITS.

## Conclusion and future research

Sea-rail intermodal transportation has significantly increased over time, establishing itself as a pivotal solution to expanding maritime transport service. The practical importance of this system is also demonstrated by seaport expansion to facilitate the flow of goods towards railway stations within the ports. Consequently, this increasing importance has profound implications for sea-rail intermodal transport operation efficiency and functionality, highlighting the system's far-reaching potential beyond initial expectations.

Research in the sea-rail intermodal domain has notably evolved since the new century. The remarkable economic and environmental benefits of sea-rail intermodal have highlighted the strategic importance of its role in the global supply chain. This paper emphasizes the growing interest among researchers in the sea-rail intermodal system, which is particularly evident by the increasing research in recent years. Despite recognizing the benefits inherent in this mode of transport, the bulk of research has mainly addressed optimization models for the problems at the operational level, resulting in a discernible gap in fully understanding the complex aspects of sea-rail intermodal operations.

This systematic review examined 63 relevant articles across five key themes: performance evaluation, problem-solving methodologies, planning issues, factors affecting sea-rail intermodal, and enhancement strategies within the sea-rail intermodal transportation context. The review revealed increased research interest from 2015 and beyond, underscoring the growing significance of sea-rail intermodal transportation in resolving seaport challenges.

Judging by the presentation of previous articles in this field, we can distinguish the main sea-rail intermodal research aspects. The research initially treated sea-rail intermodal as a benefit in economies of scale; over time, we have noted the development of topics related to other benefits of sea-rail intermodal (for example, environmental benefits). This development can be attributed to the growing pressure from governments and associations to prioritize sustainability in port operations, thereby minimizing negative impacts on the surrounding environment.

By categorizing the existing studies, this review provided a structured understanding of performance assessment metrics, planning methodologies, influential factors, and strategies for optimizing SRITS. Despite the substantial growth in research, opportunities for further exploration and development persist, particularly in emerging themes such as dry ports. Future research avenues should delve deeper into specific geographical contexts, technological advancements, and sustainability measures within SRITS.

This systematic literature review consolidates an understanding of sea-rail intermodal transportation complexities and provides recommendations for future research endeavours. Although the review may not explicitly outline a new theoretical perspective, it lays the groundwork for future studies, guiding exploration into uncharted SRITS dimensions for refining strategies and fostering advancements in sea-rail intermodal connectivity.

Future research endeavours aimed at optimizing intermodal container flow should holistically integrate sustainability concerns, encompassing environmental, economic, and social aspects, aligning with evolving regulatory standards dedicated to safeguarding our planet. Once this emerging paradigm has been acknowledged, port and transport service providers capable of harmonizing profitability with environmental and societal responsibility stand to gain a competitive advantage. Though substantial strides have been achieved in sea-rail intermodal research, notable gaps persist, as detailed in the previous section. Another critical area warranting further exploration is the empirical study of rail intermodal terminal development in various geographic regions and their resilience to climate changes. Given the considerable investment required for sea-rail infrastructure, such a study can tackle specific challenges and facilitate enhancements.

The increase in container traffic and environmental rules in the recent decade have forced involved parties to pay more attention to the negative influence on their operational activities through SRITS. Therefore, container port research in sea-rail intermodal transportation systems is relatively mature. Some kinds of cargo have specific characteristics and need to be carried in general cargo ships or bulk carriers, though. Studying SRITS in general cargo ports and facing these cargo challenges has become necessary to guarantee smooth cargo flow and minimize GHG emissions. This article advocates for heightened research attention from scholars, practitioners, and industry experts toward sea-rail intermodal transportation. This sector offers abundant prospects for future investigations and advancements.

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