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Analysis of the barriers to multimodal freight transport and their mitigation strategies

Ahmed Karam[1,2,3*], Anders Julius Klejs Jensen[1] and Mohamed Hussein[4]

Abstract
Multimodal Freight Transport (MFT) has been introduced as a solution for reducing the external costs of freight transport while achieving cost improvements. Despite the MFT benefits, its share has been low in practice, and transport by trucks remains the most preferred transport mode. A few works have recently investigated this issue by discussing various barriers to MFT. However, little conceptual work comprehensively examines the barriers that organizations may face during MFT applications. To address this gap, this paper has reviewed 104 studies and identified 31 barriers and possible strategies for overcoming them. To clarify the nature of these barriers, we developed a conceptual barrier framework that positions the identified barriers within the overall MFT chain. This framework categorizes the barriers into six categories: MFT terminal, MFT network, management, regulations and subsidies, delivery characteristics, and interoperability. The findings provide decision-makers and practitioners with theoretical and practical insights into the barriers to transition toward MFT and will assist them in implementing MFT successfully.

Keywords Multimodal, Freight, Barriers, Transport, Modal shift, Solution strategies

1 Introduction

The transport sector considerably impacts global warming because it accounts for over a quarter of all greenhouse gas (GHG) and a third of all final energy consumption [1]. These circumstances, combined with a growing demand for green solutions, have led to increasing interest in multimodal freight transport (MFT), which combines two or more transport modes and is considered a strategy for increasing the proportion of more environmentally friendly transport modes such as rail and inland waterways [2].

Despite the MFT benefits (e.g., cost and emission improvements) shown by modelling studies and the several European policies to promote MFT [3–7], Europe still has a low percentage of MFT. According to European statistics, the market shares of inland freight transport by road, rail, and inland waterways in 2020 are 77.4,16.8, and 5.8%, rspectively. Taking the average across European nations from 2010 to 2020, rail market share has declined by roughly 1.2% compared to 2010, while water market share has decreased by 1.6% [8]. This indicates that the modal split has remained roughly stable for many years, and road transport by trucks remains the favoured choice due to its superior flexibility and reliability [9]. This low share of MFT solutions is due to the many barriers facing MFT implementation [10–14]. Establishing an MFT system requires analyzing its barriers in several dimensions such as economic, technological, environmental, social,

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*Correspondence:
Ahmed Karam
akam@build.aau.dk; ahmed.mustafa@feng.bu.edu.eg
[1] Department of the Built Environment, Aalborg University, Thomas Manns Vej 23, Building: 1-352, Aalborg Øst 9220, Denmark
[2] Mechanical Engineering Department, Faculty of Engineering at Shoubra, Benha University, Cairo, Egypt
[3] Department of Technology, Management and Economics, Technical University of Denmark, Akademivej, Building 358, Lyngby 2800, Denmark
[4] Civil Engineering Department, Faculty of Engineering, Assiut University, Assiut, Egypt

and policy [13]. For instance, MFT between Europe and Asia is hampered by various technological, political, economic, social, and legal challenges [15]. These challenges increased travel time, freight losses, delivery reliability, and underutilization of transportation modalities [15].

To date, there exists no comprehensive review of MFT barriers. Existing studies focused on specific MFT solutions in a local context [14] or identified barriers through surveys rather than using a systematic review methodology [10, 11]. The present work contributes to the literature by developing a conceptual barrier framework, based on a systematic literature review, to identify all potential barriers to MFT growth. Besides the identified barriers, we also provide illustrative examples from the literature and propose potential solutions for these barriers. Furthermore, the current work has important theoretical and practical contributions. Theoretically, it expands the previous barrier categorization into a conceptual barrier framework consisting of six categories: MFT terminal, MFT network, management, regulations and subsidies, delivery characteristics, and interoperability. This is an improved framework than discussing the barriers separately, as most previous research did. The current work conducted a thorough literature analysis and found 31 barriers. Practically, the developed framework enriches the material database for scholars and serves as a valuable reference and guide for transport service providers, IT developers, academics, decision-makers, funding organizations, and entrepreneurs in implementing MFT [16]. Moreover, this research might be used as a benchmark by transport officials to analyze the barrier factors in various nations and gives suggestions for accelerating MFT growth.

2 An overview of the MFT

Different terminologies related to MFT have been defined by the European Union (EU) [17]. In the literature, multimodal transport has other terminologies, i.e., intermodal, co-modal, and synchromodal transport. However, there exist a few differences among these terminologies. MFT is defined as using at least two different transport modes, whereas intermodal transport refers to MFT that utilizes the same loading unit (e.g., a TEU container). Co-modal transport increases the utilization of different modes, while synchromodal transport emphasizes the real-time operations of MFT transport [5]. In this work, the term "multimodal" is used broadly.

Figure 1 shows the MFT chain through which commodities are transported from shippers to freight receivers. The freight flow in MFT might be domestic or international, including extra operations such as customs clearance if it is an international MFT. The major activities of MFT include pre-haulage operations for pick-up, transhipment operations at MFT terminals, long-haul transport, and post-haulage operations for delivery. Road trucks are mostly used in pre- and post-haul transport, but for long-haul links, MFT may utilize road, rail, air, and water modes. Long-haul transport often mixes multiple modes, while in some cases, pre- and post-haul transport might also use a mixture of trucks and bicycles in city logistics. Consolidation of goods in long-haul transport vehicles allows for economies of scale and cost

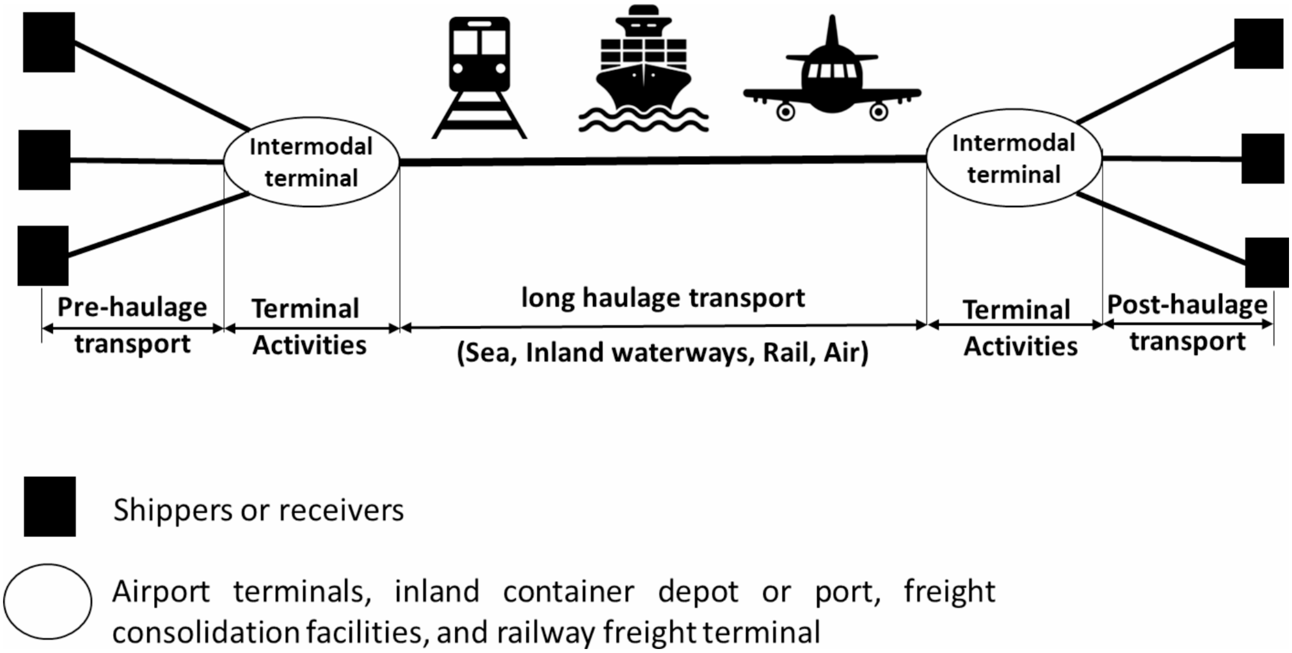

Fig. 1 A typical representation of MFT

and emission savings. Setting up an MFT system successfully necessitates some factors that can be divided into six basic elements. First, MFT terminals are necessary handling facilities where freight transshipments may occur between the start, finish, or intermediate points of the transport chain [18–21]. Second, an MFT transport network combines different mode networks into a single transport network and defines routes and services for the efficient freight flow between the shipper's and receiver's warehouses [20, 22]. Third, MFT policies are also necessary to promote modal shifts [13, 14, 23–26]. Fourth, effective management of services at various players, including freight forwarders, LSPs, and carriers of various modes, is also necessary for MFT [27]. Fifth, the MFT is also influenced by the delivery characteristics of companies, such as the freight weight, its dimensions, location, and the customers' needs [28–31]. Finally, the national transportation networks of neighbouring nations should be highly interoperable to establish MFT on a global scale [32]. The present work identifies all potential MFT barriers related to the previously listed elements of MFT.

3 Search strategy and results

In this work, relevant works were identified using three steps. Firstly, we conducted a title, keyword, and abstract search of previous studies using WoS and Scopus databases. These databases were selected because they cover a wider portion of the literature. These databases have been searched using the following keywords:

- "Intermodal" with "Freight", "Goods", or "Cargo".
- "Multimodal" with "Freight" "Goods", or "Cargo".
- "Modal shift" with "Freight" "Goods", or "Cargo".

This search obtained 1,030 and 1,734 studies in WoS and Scopus, respectively. Secondly, the studies underwent a screening process and were considered if they satisfy the following two criteria:

- Journal articles that analyze the MFT applications qualitatively or quantitatively.
- Articles that deal with short-haul or long-haul transhipment and multi-actor coordination, schedule synchronization, or using standardized load units in MFT.

Additionally, articles that focus primarily on mathematical models and algorithms were excluded. Moreover, a Google search was made to obtain reports on MFT applications. Consequently, 77 studies were initially identified. Finally, backward snowballing was applied to find more related studies by cross-referencing the identified studies from the previous step. 26 additional studies were obtained by backward snowballing, resulting in a final set of 104 studies covering the period from 1996 to 2022. The analyzed studies included 69 research papers, six review papers, three conference papers, 17 industry reports, one book, one master thesis, and two PhD theses. The journal papers represent 72% of the 104 works. Figure 2 shows that MFT research has paid increasing attention, specifically from 2007 to 2022. This is due to several research and development projects funded by EU countries.

4 The conceptual barrier framework

To identify and categorize barriers from the 104 works, this study used a systematic approach, known as meta-synthesis, which can help find qualitative evidence that responds to a particular research question [33]. Recent review studies have successfully used the meta-synthesis

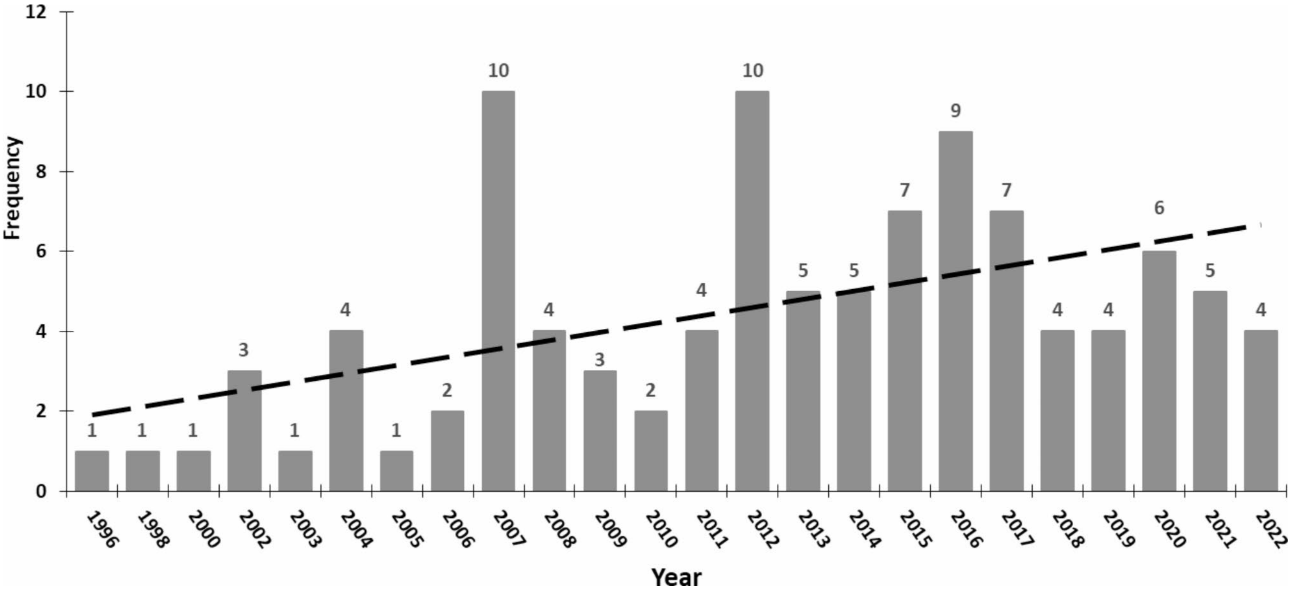

Fig. 2 Number of publications per year

to pinpoint barriers to adopting sustainable practices; see, for instance [34]. Three main stages comprise the meta-synthesis: the initial stage involves coding each section of each work freely line by line. In the coding process, text that discusses potential barriers is summarized. The coding process was made manually. Particularly, we define a barrier as a physical, technical, or functional obstacle that affects the continuity of long-distance or cross-border flows and can impede the diffusion, implementation, and continuity of multimodal transport. Consequently, descriptive barriers that capture the data meaning in each work were identified. Next, if we could not code subsequent works into previously defined barriers, a new barrier was defined. Out of the 104 works, the initial stage obtained a preliminary collection of 55 barriers. In the second stage, similar barriers were grouped into one representative barrier by identifying the barriers that explain the same problems but have different wording. Next, these barriers were united into one or more broad barriers. A final set of 31 distinct barriers were found after multiple repetitions of the second step and listed in "Appendix 1" along with the relevant references. The third stage divided the 31 barriers into classifications that better reflect the nature of the identified barriers. Based on the literature analysis and the discussion in Sect. 2, the authors clustered the identified barriers into six categories: MFT terminal, MFT network, management, regulations and subsidies, delivery characteristics, and interoperability.

Figure 3 illustrates the conceptual barrier framework for the MFT. As shown in Fig. 3, the 31 barriers serve as the "black box" of MFT transition and resist the MFT benefits. The following sections clarify more this "black box" by offering concrete examples and potential solutions for the identified barriers.

4.1 MFT terminal-related barriers

MFT terminals are often located in the main cities along the freight transport corridors and might be container terminals, dry ports, river ports, seaports, and rail terminals. MFT terminals mainly include high productivity handling equipment and providing other services, such as warehousing and customs-related functions. The efficiency of MFT services is highly correlated to the

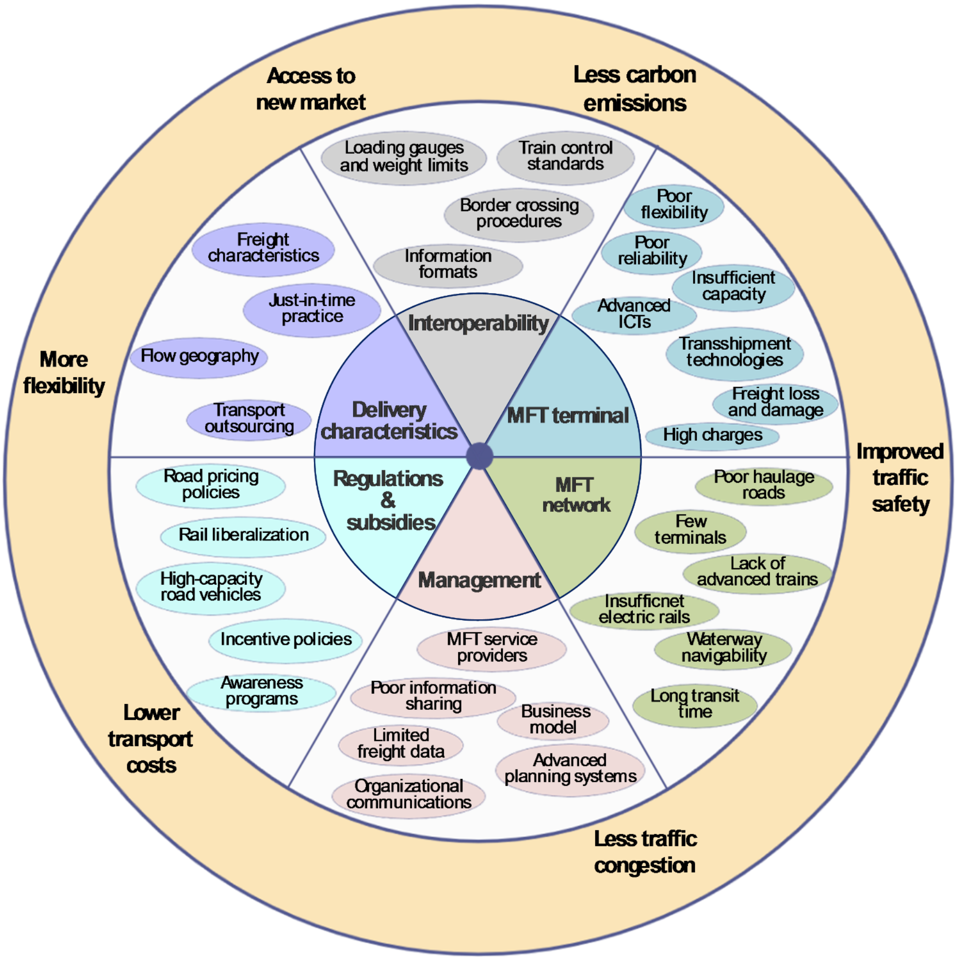

Fig. 3 Potential benefits, barriers to MFT (black box), and main barrier categories of MFT, (ordered from outer to inner circles)

performance and characteristics of MFT terminals [19, 20]. Seven barriers related to the MFT terminal could be identified from the literature as follows.

4.1.1 Poor service flexibility

Shippers have been continually moving towards a just-in-time operation, which requires a transport system of high service frequency (the weekly departures) and availability on a 24/7 basis [10, 35]. Several scholars reported that the low frequency of freight trains and port calls daily or weekly and the limited opening times of terminals impair the flexibility of MFT solutions [19, 36–39]. Additionally, the low frequency of freight trains is a major barrier to shippers whose shipments cannot fill a train [15]. The limited-service frequency also increases the planning efforts and administrative costs of intermodal rail transport diminishing the decrease in transport costs and emissions compared to road transport [40].

4.1.2 Poor service reliability

Reliable transport is essential for satisfying the requirements of just-in-time practice, hub-and-spoke operations, and port deadlines [41]. Thus, many shippers consider high reliability the most important determinant for mode choice and shifting from road to sea or rail [19, 36, 42]. MFT transport has less reliability because of the need for changing modes at terminals where several unexpected events might occur, e.g., resource shortage, accidents, extreme weather, and mismanagement [18, 35]. For instance, Combinant (Combined Terminal Antwerp) and Novatrans (rail freight operator) reported that, on average, a freight train has a reliability of 50%, which means 50% of al shipments arrived at the promised delivery times if the delay limit is set to 30 min (UIRR, 2014). Such low reliability can induce a shift back to the road due to the high ability of road trucks to respond to unexpected events, e.g., by taking alternative routes to avoid congestion [35].

4.1.3 Insufficient terminal capacity

A case study showed that inefficiencies in ten European intermodal freight transport chains are caused by the lack of capacity inside the terminal environment, which is an important barrier [43]. In Australia, the port terminals suffered from limited rail capacity, e.g., limited sidings and insufficient lifting productivity [44]. This would cause lower productivity rates, long turn-around time, and cost increases [45]. Also, a large and sufficient cargo-handling capacity is important for achieving a modal shift [46]. Behrends [47] showed that increasing the capacity of intermodal rail terminals is necessary to absorb the expected growth of intermodal rail transport while providing good quality and service. In Europe, existing rail terminals are located near urban areas, and therefore, spatial constraints restrict capacity extension [48]. Moreover, insufficient capacities of terminal gates might increase the cost of pre-and post-haulage operations because of the congestion and waiting times at the gates.

4.1.4 Lack of horizontal transshipment technologies

In most terminals, transshipment operations use vertical transshipment equipment, such as reach stackers and gantry cranes, which take longer and pose a greater risk of cargo loss or damage. Moreover, 80% of European trailers cannot be lifted vertically, restricting a large modal shift from road to rail [19]. Instead of vertical transshipment equipment, Woxenius [49] suggested various horizontal transshipment technologies that require less space, staff, and handling times. Horizontal transshipment technologies also provide less cost for transferring cargo between trucks and can produce a remarkable shift from road to rail [50–52]. Recently, several technology providers developed horizontal transshipment solutions for non-liftable semi-trailers; see, for example, Modalohr, CargoBeamer®. The key problem is that the high investment costs of horizontal transshipment technologies make the modal shift decisions more difficult, especially if the benefits of intermodal transport remain uncertain [53, 54].

4.1.5 Lack of advanced ICTs

When shipments change transport mode at MFT terminals, this requires fast information flows and efficient collaboration among railway operators, port authorities, road hauliers, cargo handling companies, and customs [55]. Tsiulin et al. [56] showed that the lack of advanced IT applications causes several operational problems, such as inefficient document management and cargo picking-up error or cargo theft. Therefore, ICTs enable efficient interfaces at MFT terminals for achieving smooth freight transfer among different modes [31, 57]. Besides improving information sharing, using ICT-based planning solutions, e.g., yard and berth planning algorithms, can improve the distribution of capacity and space for freight shipments in yards and at berth [58]. Harris et al. [59] noted that ICTs can also improve handling time, operation costs, and customer service and satisfaction at MFT terminals.

4.1.6 Risk of freight loss and damage

In MFT, freight might have a higher risk of freight damage or loss because of multiple levels of transshipment at terminals [14, 40]. In recent decades, there has been a notable increase in goods requiring temperature control during transportation, like perfumes, medicines, packaged food, and other products sensitive to temperature. Railway rolling stock has not adapted to this demand due to a lack of modern features such as onboard electricity in wagons. Thus, freight damage might also happen if there is a lack of temperature-controlled trailers/containers and continuous temperature monitoring in refrigerated containers stored at MFT terminals [40, 60]. According to Rich et al. [61], the risk of freight damage is very important in the case of high-value goods, which are generally more sensitive towards poor, multiple transshipment operations. In addition, theft of cargo might happen while trains wait at borders or sidings. For example, many sidings of the Europe-Asia road-rail link are in remote areas where train security is not high. This increases the transport cost due to the need for cargo protection and insurance [15, 19].

4.1.7 High terminal charges

Several scholars agree that transshipment costs at MFT terminals are one of the largest cost components of intermodal solution transport, representing an important barrier [18, 62]. According to Paixão and Marlow [45], port charges represent 70% of total short-sea shipping costs. Port of Esbjerg et al. [63] suggested that building the MFT terminal within the port environments might reduce its handling costs on the condition that the port staff or the stevedoring companies can fit the MFT operations into the ongoing port operations. This way enables avoiding the non-productive time and purchasing extra equipment.

4.2 MFT network-related barriers

The MFT network involves all routes and intermodal terminals which transport services can use. Among other factors, the characteristics of the transport vehicles, corridor layout (number of terminals along the corridors), road access to the terminals, and long-haul characteristics affect the efficiency of intermodal operations along the corridors and influence the ability to attract cargoes to MFT. Six intermodal network-related barriers could be identified as follows:

4.2.1 Poor haulage roads

Pre-, and post-haulage (PPH) trips account for a large share of the MFT's externalities and costs, for instance, around 50% [23]. This is because PPH trips are mostly performed during commuting peak hours and, consequently, road congestion impairs terminal accessibility [47, 48]. This increases the operating costs, environmental impacts, and transport time of the PPH operations. This also risks the road trucks missing their appointments with the terminals [64]. Hasan et al. [42] reported that trucks might not be allowed to cross the city during the daytime to reach the terminal, so trucks must wait, increasing the trucking time and the total logistics cost. Santos et al. [23] reported that the large distance between the MFT terminal and the main infrastructure network leads to longer drayage distances or times, which might impair the competitiveness of intermodal solutions. To ensure the right prerequisites for modal shift, the government can increase the capacity of the terminals' access roads [23] or build an elevated expressway to bypass the city, hence reducing trucking times [42].

4.2.2 Few MFT terminals

Establishing many terminals along the transport corridor cause short PPH trips from or to the terminal, which is important for urban logistics to intermodal transport [20, 22]. Small towns along the transport corridor often lack MFT terminals, making freight transport customers of small towns dependent on road transport [26, 65–67]. Therefore, a denser network of small-scale terminals is needed to realize the MFT benefits [68]. Furthermore, a denser network of small-scale terminals provides flexibility to react to disruptions such as blockage of the main rail route by diverting traffic to an alternative terminal. However, such a denser network might increase the high fixed costs and transport network overheads [20]. With horizontal transshipment technologies, it is possible to develop a network of small terminals, at a comparatively lower cost, along the corridor where train operators can pick up or transport fewer containers at each terminal [50].

4.2.3 Lack of advanced trains

Faster and longer freight trains can improve the economic performance, wagon turnaround time, operating cost, and productivity of intermodal rail transport [10, 51, 63, 69–72]. Truschkin and Elbert [51] suggested that introducing long trains can be more important than providing subsidies to intermodal operators. For instance, increasing train length by four more Megaswing wagons would make the intermodal cost equal to road transport cost, given that 79% of train loading space is utilized [70]. However, faster and longer freight trains might face some infrastructural and operational constraints. For example, emergency braking on switches could lead to the risk of derailment while loss of grip can happen when restarting from a standstill on steep railway lines [73, 74] and another constraint is the inadequate length of many existing passing sidings [75]. While freight trains are faster, the average speed would be between 50 and 60 km/hr because of the relatively long dwell times at terminals and weak cooperation among the national infrastructure operators [69, 70]. As noted in the work of Gurri et al. [76], a train with electric current along the trainset and power distributed along the wagons could solve these technical problems.

4.2.4 Lack of electrified rail network

Electric trains use energy less than diesel trains, and therefore, they can improve operational costs and emissions of intermodal rail transport [19]. For instance, Merchan et al. [77] reported that electric trains in Belgium reduced 26% of their environmental impact. Furthermore, electric locomotives enabled the transport of heavier loads, which provided an opportunity for the cost-environment-energy performances of the MFT system. In Europe, around 55% of th rail network is electrified, requiring train operators to run a train with two locomotives (electric and diesel) or change from electric to diesel [78]. This increases capital costs and lead times, making operations more expensive [15]. Smith et al. [57] showed that using electrified rail services leads to important cost advantages if oil prices increase over time because of international events and limited oil reserves.

4.2.5 Poor navigability of waterways

The limited navigational capacity is an important challenge for the competitiveness of MFT using inland waterways. According to Walker et al. [37], poor navigability of waterways is caused by several reasons, including narrow sections, shallow sections, and low bridges on waterways. Hasan et al. [42] reported that the shallow sections of the waterways at Dhaka–Chittagong in Bangladesh require ships to wait for high tide to cross these shallow sections. In addition, some portions of the channels have sharp bends, disallowing the use of mega-ships and high sailing speed. They noted that improving the channel navigation through infrastructure development can reduce 6 h in the average transit time for IWT vessels.

4.2.6 Long transit times

Transit time represents the total time from origin to destination and is an important determinant for promoting MFT solutions since they are competitive with road [19, 41]. Winebrake et al. [79] indicated that rail transport is often cost-competitive, but it always has a longer transit time than other transport modes. Loading and unloading operations at terminals increase transit time and thus reduce intermodal transport preference [11, 80]. Moreover, the yard dwell time of freight trains ranges between 10 and 50% of the total tranit time in Europe [4]. The high variability in the yard dwell times impairs the overall service reliability of intermodal rail transport. Beškovnik and Golnar [46] also reported that most cargo delays occur at ports, which in turn increases the transport cost and time in the maritime supply chain.

4.3 Management-related barriers

Managing MFT is complex because of the participation of different stakeholders, who might be competitors. There are management-related factors influencing the ability of MFT solutions to compete with road freight transport. Intermodal transport management is faced with six barriers as follows.

4.3.1 Lack of MFT service provider

MFT chain is sometimes managed by different operators, e.g., rail operators and freight forwarders [81]. However, shippers and consignees typically prefer purchasing transport services from a single operator, i.e., MFT service provider, who will take the liability for delay, loss, or damage of the cargo [10] and select the best combination of modes and carriers to achieve the needs of shippers or consignees [14, 40, 82]. MFT service provider also enables efficient cooperation among all stakeholders along the transport chain, e.g., combining freight from different shippers to improve the train's capacity utilization and PHP operations [83]. For example, an MFT network was implemented between Rotterdam, Moerdijk, and Tilburg and could achieve a stable modal split of 19% truck transport, 46% ship transport, and 35% rail transport, exceeding the port's overall goals for 2033 [84].

4.3.2 Poor information sharing

On the operational level, information sharing among different MFT actors is necessary for the efficient execution of the scheduled transport services of different transport modes [14, 82] and rapid response in real-time to any disturbances (such as accidents, weather changes, or equipment failures) [5, 85]. If one or more actors in the transport chain do not share their logistics information, this might create "black holes" in the freight information along the supply chain, which in turn hurts the competitiveness of intermodal solution transport [40, 57]. For example, inefficient information sharing between terminal operators and truck drivers make it difficult for truck drivers to pick up their containers without long waiting times and high empty running, increasing the costs of drayage operations (Jun, 2020). Compared to unimodal transport, information sharing among trading partners of MFT is very complicated due to the cost associated with information sharing, different IT interfaces, and the risk that their competitors will use the information [3, 34, 57].

4.3.3 Limited freight data

From a policy perspective, infrastructure planners cannot efficiently conduct policy analysis and make long-term decisions about the best sites and capacities of MFT terminals due to the limited data available on freight movements and their aggregate static nature [3, 86]. In addition, the lack of high-quality freight data leads to an inaccurate representation of external costs in transport costs, affecting the cost competitiveness of MFT solutions [87]. In Australia, for instance, strategic intermodal rail freight decisions were always challenged by lacking complete, up-to-date, and reliable freight data and the high cost incurred to collect and use those data. With the rail deregulation process, the number of private rail operators increased, reducing the availability of rail freight data due to severe competition among rail operators [86].

4.3.4 Lack of organizational communications

The promotion of MFT highly depends on the quality of communication and interactions among the different stakeholders in the freight transport chain [86]. The lack of organizational communications among potential intermodal transport stakeholders is an important barrier to promoting intermodal rail transport [14]. Empirical evidence showed that direct transport users, i.e., shippers and final customers, might not be aware of the possibilities of MFT solutions, and they do not know who to contact to identify the best MFT option for them. In most cases, this is due to a lack of organizational communications among the port or rail operators and direct users [63].

4.3.5 Lack of a business model

The business model defines how to improve intermodal freight services regarding reliability, lead time, costs, and flexibility [88]. In North America, Spychalski and Thomchick [88] reported that the business model could ensure reliable trains schedules among major terminals, competitive service prices, and integrated planning of all intermodal operations using ICT tools. Several studies agree that business models should consider vertical and horizontal cooperation schemes among different actors for achieving service improvements, cost reduction, and economies of scale [63, 70, 89, 90]. Lehtinen and Bask [81] classified the existing business models for intermodal rail transport into four types based on who takes the responsibilities for MFT: the rail freight operator and the 3PL logistics service provider, a large shipper, the rail freight operator, and several 3PLs.

4.3.6 Advanced planning systems

Advanced MFT planning systems are necessary for private stakeholders, such as MFT operators, and public actors, such as policymakers and port authorities, to achieve effective operational and strategic planning [3]. Without advanced planning systems, it is hard for shippers to evaluate the cost-effectiveness of MFT solutions because of the increased complexity of MFT planning compared to road transport [91]. Advanced MFT planning systems can be implemented as one integrated 'Internet' platform connecting all actors in the MFT chain by using different tracking and Internet-based technologies. These platforms enable different actors to collaborate and share real-time information seamlessly and securely on all operations from dispatch to arrival [59]. See, for example, the GIFTS Platform [92]. Advanced MFT planning systems also involve computational algorithms for operational and real-time planning of transport orders and reactions to any disturbance [5]. For more details, see the literature survey in [3].

4.4 Regulations and subsidies -related barriers

Promoting intermodal transport also depends on the extent of the governmental support, which could be regulations and subsidies, e.g., more stringent environmental regulations, road pricing policies, investment for MFT infrastructure, and higher fuel and energy prices. The lack of government support can hinder the modal shift towards intermodal transport. The following discusses five barriers to regulations and subsidies.

4.4.1 Inadequate pricing policies for road transport

Road pricing policies can increase road haulage costs and put external pressure on road freight transport companies to change their overall business strategy by considering intermodal rail transport in the future [40]. Vehicle and fuel taxes and stricter environmental legislation are the most used policies to internalize external transport costs [93–95]. Moreover, direct road user charges, e.g., tolls for heavy-duty vehicles, could effectively produce a shift to rail or water in some EU countries such as Switzerland, Germany, and Austria [31]. However, Woodburn [39] found that some companies might improve their road transport efficiency in response to increasing road haulage costs rather than shifting to other transport modes. Other companies might formulate contracts in a way that enables passing the increases in fuel prices to their customers. Rich et al. [61] stated that efficient rail and inland waterway networks should be in place before increasing road charges, so a modal shift is most likely to happen.

4.4.2 Lack of full rail liberalization

Rail market liberalization aims to stimulate the entry of new rail freight operators into the rail market and prevent the track company (the infrastructure owner) from distinguishing its trains from those of other operators. This creates fair and free competition among new entrants and incumbent operators, improving the costs and efficiency of rail freight services [96]. Regardless of the liberalization initiatives and reform packages suggested by the European Commission [16], full rail market liberalization is not achieved yet, impairing the competition in the rail freight transport market [10, 97]. In some European countries, e.g., Ireland, Greece, Croatia, Lithuania, Luxembourg, and Finland, the incumbent freight operator has 100% of the marketshare [98]. This may reduce the growth of intermodal rail freight transport [31, 97].

4.4.3 Allowing high-capacity road vehicles

Many countries, e.g., Canada, Australia, Brazil, and Scandinavia, permit larger and heavier vehicles (LHVs) with lengths and weights up to 32.5 m and 76 tons, respectively. This is unacceptable from the point of view of policies to encourage intermodal transport. This is because allowing LHVs can reduce road freight costs and, consequently, induce a shift from rail and water to road transport [31, 99]. For example, Liimatainen et al. [100] found that sharing rail freight transport decreased by 4% due to allowing LHVs. In Sweden, Pålsson et al. [101] showed that the shift from rail to road would reach 8.7% due to permitting LHVs (74 tonnes/34 m vehicles). In Belgium, Meers et al. [102] showed that a 5% price reduction in road transport due to allowing LHVs could reduce the market share of intermodal transport by 15%. Pålsson and Sternberg [101] suggested that such a modal shift can be avoided if a kilometre-based charge for the LHVs is implemented. It is worth noting that adjustments to road infrastructures, including turning points, guardrails, and jersey barriers, originally designed for lower loads and smaller vehicles, must be considered to allow for safe operations of the LHVs.

4.4.4 Lack of incentive policies

Governments might implement some incentive policies to improve intermodal service share [11]. Several studies suggested a variety of legal and fiscal incentives for intermodal transport services [13, 14, 23–26, 103]. Table 1 summarizes the policy incentives identified from the existing literature.

4.4.5 Lack of awareness programs

Customers historically view the MFT as a time-consuming and inefficient transport mode. Consequently, logistics managers perceive that a shift from road to rail and waterways transport might significantly affect the flexibility of their supply chain in terms of delivery frequency and quantity [14, 83]. Freight forwarders and shippers might lack knowledge of recent MFT solutions advances [63]. The economic and delivery quality criteria are often prioritized over saving the environment since freight shippers are not interested in or are less conscious about environmental sustainability [11, 36]. Therefore, governments should increase the awareness of freight transport sectors by clarifying incorrect claims regarding intermodal solutions and providing educational training for freight forwarders on how to operate multimodal transport efficiently [40, 104, 105].

4.5 Delivery characteristics-related barriers

Freight delivery characteristics include flow geography (e.g., shippers' locations and customers), delivery frequency, transport management (e.g., the use of own or external transport modes), and the types and volumes of goods transported. Freight delivery characteristics affect the extent to which the transport quality would reduce with a change in transport modes. Four barriers related to freight delivery characteristics are discussed as follows.

4.5.1 Inadequate freight characteristics

Freight characteristics can be divided into market-related characteristics (e.g., value and demand of freight) and physical characteristics (e.g., the value-to-weight ratio and the perishability of the freight) [11]. Only certain freight characteristics are suitable for intermodal transport. Some cargo might have physical characteristics that necessitate special handling requirements or lead to a higher risk of damage and theft in intermodal transport solutions. Also, this issue might be due to the outdated rolling stocks that have not been upgraded for decades and capture a significant market share. Low-weight and high-value goods are often transported by road or air to reduce the capital in-transit inventory, while low-value and heavy bulk commodities, e.g., coal and grain, are frequently shipped by rail or water [30, 31].

Table 1 Policy Incentives for Promoting MFT

Incentive policies	Description
Grants for MFT infrastructure and equipment	Grants for companies to buy intermodal handling equipment, construct new terminals, or expand existing terminals. For example, funding transport infrastructure (TEN-T projects) in Europe.
Exemption from road vehicle tax.	Exempting liftable semi-trailers used in MFT from the road vehicle tax.
Exemption from cabotage restrictions.	To promote MFT, governments can exempt the initial and final road trips of MFT made by foreign haulers (i.e., cabotage) from traffic restrictions.
Increasing max gross weight of road vehicle for MFT transport	Governments may allow more cargo weight on semi-trailers within MFT than those in road transport.
Partnership programs	Public private-partnership programs for co-financing the construction of new terminals. For example, the public entity owns the land while the private company constructs the terminals and ensures enough demand for the MFT services in the future.
Subsidies to freight operators.	Financial aids can be introduced in the form of a reduction of track access charges as well as custom costs during MFT operations and a waiver of road toll charges. For example, The Marco Polo Program in Europe compensated projects with €1–2 per 500 tkm shifted.

4.5.2 Just-in-time practice

Ooperational preferences of customers/shippers regarding just-in-time deliveries have greatly increased and affect the carriers' decision on the mode choice [106]. Just-in-time practice necessitates fast, frequent, and reliable freight transport. Thus, several studies consider just-in-time practice as a disadvantage for intermodal rail and inland water transport solutions [10, 11, 31, 39]. Some studies suggest that this barrier might be overcome by collaborative logistics in different just-in-time supply chains, which can be incentivized by new legislation to enable modal shifts [107].

4.5.3 Unfavourable flow geography

The freight flow's geographical characteristics include the transport's total distance to be covered and the availability of intermodal links as an alternative to road trucks. Intermodal rail and waterways modes only become cost-competitive when transporting a large amount of freight over long distances [28, 29] because of the additional cost of pre and post-haulage operations [91, 108]. The break-even distance of intermodal rail transport ranges between 600 and 900 km [29]. In small countries, e.g., Denmark, transport distances are short, and with increasing terminal charges, this makes the MFT solutions more expensive than road transport [63]. Short sea shipping has a cost-competitive advantage over a transport distance between 1100 and 2500 km [109].

4.5.4 Transport outsourcing

Shippers often outsource their freight transport to freight forwarders, who typically decide on the transport modes and are often restricted to specific transport modes. Therefore, transport outsourcing can be a barrier to shifting from road to intermodal solutions [110, 111]. In addition, freight forwarders might have semi-trailers that are non-cranable and less suitable for intermodal rail solutions. Therefore, the success of the intermodal solution depends on the performance of the contracted freight forwarders [40].

4.6 Interoperability-related barriers

Globally, MFT might be challenged by the lack of interoperability across national rail networks, if neighbouring countries have differences in rail infrastructure standards [32]. The following discusses four interoperability-related barriers.

4.6.1 Loading gauges and weight limits

In rail transport, the loading gauge represents the maximum height and width of rail vehicles when loaded. Therefore, if countries use different loading gauges and weight limits, operating freight trains across their railway networks is hindered by the inability of trains to pass safely through bridges and tunnels [19, 32, 112]. Compared to the Americas, Asia and Europe are linked by railway networks that use different railway systems, lacking common railway standards [15]. Due to different loading gauges, European intermodal rail freight operators could not achieve economies of scale in train operation, similar to North America [113]. To promote the shift from road to rail, many European ports started adapting their rail facilities to the standard rail gauge, such as the Port of Barcelona [112].

4.6.2 National Train control standards

Train control systems are the hardware and software equipment that track the positions and motions of trains to ensure that they run safely, over the intended route, and according to schedule. Across Europe, there exist more than 20 different train control systems, obstructing cross-border traffic due to the need to stop the train for changing locomotives. For example, there are seven types of train control systems on the Paris-Brussels-Cologne and Amsterdam routes [114]. European Commission had several initiatives to create the European Railway Traffic Management System (ERTMS), which is standardized rail communication and signalling system that allows for efficient border crossing of trains, with investments of over €770 million [112]. The vast deployment of ETRMs will create a seamless European railway system and improve the railway's competitiveness. In the future, ERTMS could be integrated into an efficient multimodal digital freight system for supporting the smooth cross-border operations of intermodal railway transport [59]. It is important to note that many trains today do not access the high-speed or high-capacity networks where ERTMS is mostly applied. What is needed, then, is poly-current and poly-voltage freight rolling stock suitable for running on the ERTMS network. *Border crossing procedures.*

The inconsistent or time-consuming cross-border procedures between countries within the same region, represent a challenge for increasing the use of intermodal rail freight transportation [12, 115]. In the early years of short-sea shipping, customs-related operations at borders were identified as a challenge in Europe [116]. If customs services are unavailable in terminals on a 24-hour basis, this would lead to significant delays in MFT. Thus, simplifying and unifying the border control processes can improve the effectiveness of MFT. Europe addressed this barrier by using ICTs such as electronic authorization and the application of electronic data interchange for customs procedures so that cargo does not require a check every time it passes a border. Moreover, policy initiatives suggested making guidelines for customs procedures and identifying and eliminating obstacles delaying the border-crossing processes.

4.6.3 Different information formats

Actors in the intermodal transport chain have different information technology, interfaces, and formats. Adopting these technologies is hampered by a lack of standards for data exchange and technologies, hindering information sharing and processing, and resulting in "black holes" in shipment information [57]. Through the COMCIS project, this problem was addressed by standardizing data systems and sharing [117].

5 Solution strategies to the identified barriers

Herein, we discuss various solutions to the identified barriers, such as infrastructure expansion, and adoption of new technologies and regulations.

For MFT terminals-related barriers improving service reliability requires implementing a system resilience for assessing and mitigating the negative effects of disruptions and identifying ways to recover quickly from disruptions [118]. Synchromodal transport concepts can change modal combinations and operational timetables after the shipment has departed in response to new information or a disruption [119], and it can increase service flexibility and reliability. Building dry ports, a concept called extended gateway, may increase the terminal capacity by locating extra terminals near the consumption point [120]. Moreover, this may reduce port congestion and logistical challenges for shippers using inland waterways [121]. According to existing studies [50, 51], horizontal transshipment technology can reduce cargo damage while increasing the effectiveness and cost of transshipment operations. ICTs can streamline terminal operations, secure data exchange, increase cargo security, and prevent freight delays, loss, or damage [59]. Furthermore, terminal operators can improve the efficiency of drayage operations by better planning truck arrivals and operations with truck appointment systems [122]. Building the MFT terminals within the port's boundaries may allow using the seaports personnel or stevedoring firms in the MFT operations. This way can reduce terminal operating costs, allow the port crew to work more efficiently, and allow purchasing of additional handling equipment [63].

For the MFT network-related barriers infrastructure investments in new or dual rail lines, waterways, MFT terminals, and inland ports are mostly required to effectively address network barriers. However, these investments are frequently lacking. To improve terminal accessibility, the government may build an elevated expressway to bypass the city [42]. Also, it could build a network of small terminals along the corridor using horizontal transshipment technologies at a lower cost so that train operators can pick up or deliver fewer containers at each terminal [50]. Introducing modern trains is key to attracting freight traffic. These advanced trains feature improved aerodynamics and technologies ideal for longer, faster, and heavier wagons. Incorporating real-time monitoring and predictive maintenance ensures optimal efficiency. Despite their initial high cost, these trains offer long-term benefits like energy efficiency and enhanced capacity, resulting in significant cost savings. Along with introducing electric, faster, and longer freight trains, reduced long terminal dwell times and insufficient cooperation among national infrastructure operators are also important [69, 70].

For management-related barriers MFT service providers are needed to assist shippers in selecting the optimal mode and carrier combinations to achieve the required cost, speed, and degree of environmental impact that satisfy the shipper's objectives. MFT service providers help coordinate efforts among various shippers to lower costs, travel times, and GHG emissions and implement effective synchromodal transportation by encouraging collaboration among all parties of the logistics chain [82, 123]. Furthermore, the business model must be based on vertical and horizontal collaboration forms. In reality, if appropriate incentives are in place, containers and vehicles [124, 125], facilities [126], and even transport orders [127] may be shared in MFT systems. MFT routing models must also incorporate ICT advancements to support and coordinate intermodal operations as new data becomes available in real-time [3, 85]. According to recent research, blockchain technology may be used in MFT management to overcome obstacles to exchanging information in shipping businesses and data confidentiality problems [56]. To establish commercial relations with road carriers, port, and railroad operators may collaborate with trucking companies in a last-mile solution [12].

For regulations and subsidies-related barriers internalizing all the transport external costs is a good policy to encourage a modal shift to MFT solutions [128]. Additionally, high taxes may be required [93–95]. Taxes may be more effective when combined with other decarbonization measures. For example, heavy-duty vehicle tolls applied in most EU countries have successfully encouraged rail or inland waterways transport in Switzerland, Germany, and Austria. Some measures could also restrict heavy-duty vehicles on corridors where rail or water, are available [129]. Because labour expenses account for a significant portion of transportation costs, reducing the permitted hours of operation may encourage a shift from road to rail [35]. Governments must accelerate rail liberalization by establishing clear regulations [10, 97]. MFT may receive direct government support. For example, the EU's Marco Polo Program paid projects €1–2 for every 500 tkm of shifts (equivalent to €25-€50 for each tCO_2 avoided). Furthermore, the government should promote awareness of the MFT benefits through educational and training initiatives [11, 57]. Marketing campaigns may be an excellent way for businesses to disseminate current information on MFT and encourage modal shifts [130].

For delivery characteristics-related barriers with shifting from "push" logistics services to "pull" services, transport systems must provide frequent, fast, and reliable delivery of small shipment sizes. The question is whether MFT, which includes rail and water, can support the pull logistics chain. Collaborative logistics may allow many shippers' freight to be combined, resulting in the massive quantities required for MFT to be practical [131]. New regulations encouraging cooperative logistics, increased inventory, and shipping may enable modal change [107]. It is critical to select a transport service provider with sufficient expertise to provide high-quality intermodal transportation and meet pull logistics systems' needs [40].

For interoperability-related barriers Countries must upgrade rail infrastructure to a uniform standard rail gauge to facilitate train travel between neighbouring countries. ICT improves train system cross-border interoperability. For example, the ERTMS is a cutting-edge train management system used in many countries outside of Europe. Similarly, the EU promoted developing the River Information System, an ICT system for inland rivers [132]. ICT systems may expedite border crossings. The use of technological advancements, such as electronic data exchange for customs operations, can also improve interoperability. Policy measures unifies the rules for customs procedures by establishing "one-stop" offices for administrative and customs requirements across countries.

6 Conclusions

Though several scholars have shown the MFT benefits and the several governmental policies to promote MFT, a very small percentage of transport uses MFT. Thus, the present work contributes to the literature by conducting a systematic review of relevant studies to identify all potential barriers to MFT growth, proposing a conceptual barrier framework, and discussing solution strategies for these barriers. Based on the literature analysis, 104 works were identified and studied, and 31 barriers were obtained. To better understand these barriers, a six-categories framework was developed to conceptualize the identified barriers. These categories include MFT terminal, MFT network, management, regulations and subsidies, delivery characteristics, and interoperability. One key advantage of the developed framework is the barriers categorization according to the basic aspects of MFT. This helps decision-makers and practitioners understand where and when barriers might arise in the MFT chain and accordingly make informed decisions. Of the 31 barriers, seven are related to the MFT terminal; six are MFT network-related; six are management-related; five are related to regulations and subsidies; four are associated with delivery characteristics, and four are interoperability-related.

This work also presented solution strategies for overcoming the identified barriers. Some of these strategies are implementing a system resilience in MFT terminals and along the MFT networks, synchromodal transport concepts, extended gateway concepts, horizontal transshipment technology, the use of ICTs, introducing electric, faster, and longer freight trains, adopting collaborative business models among stakeholders along the MFT chain, raising awareness of MFT advances, and encouraging cooperative logistics, and focusing on waste-prevention initiatives. Additionally, this paper identified proof examples and the best practices for each barrier. Moreover, it contributed theoretically and practically to the literature. Theoretically, it expands the previous barrier categorization into a conceptual barrier framework consisting of six categories. Practically, the developed framework enriches the material database for scholars and serves as a valuable reference and guide for decision-makers and practitioners in making decisions to implement MFT. Moreover, this research might offer a benchmark for assessing the success of MFT applications by analyzing the potential barriers to MFT developments and giving suggestions for accelerating MFT growth.

Despite the provided valuable insights, the study has its limitations. Firstly, the identified barriers were not ranked in relative importance. Although citation frequency can be used to rank them, this approach is inaccurate as the literature's emphasis on particular barriers changes over time. Secondly, the study overlooked the interlinkages between these barriers. To address these limitations, future research can utilize ranking and pairwise comparison techniques, e.g., Delphi and Analytical Hierarchy Process (AHP), to determine the relative importance of identified barriers and develop better mitigation strategies. It would also be valuable to quantify the influences of different barriers on MFT using multi-agent simulation and modelling methods.

7 Appendix 1: the identified barriers to MFT

Categories	Specific barrier	References
MFT terminal-related barriers	Poor service flexibility	[10, 15, 19, 35–40]
	Poor service reliability	[18, 19, 35, 36, 41, 42]
	Insufficient terminal capacity	[43–48]
	Lack of horizontal transshipment technologies	[19, 49–51, 53, 54]
	Lack of advanced ICTs	[31, 55–59]
	Risk of freight loss and damage	[14, 40, 60, 61]
	High terminal charges	[18, 62]
MFT network-related barriers	Poor road haulage	[23, 42, 47, 48]
	Few MFT terminals	[20, 22, 26, 50, 65–67] [68]
	Lack of advanced trains	[10, 51, 63, 69, 70]
	Lack of electrified rail network	[15, 19, 57, 77, 78]
	Poor navigability of waterways	[37] [42]
	Long transit times	[11, 19, 41, 46, 79] [80]
Management-related barriers	Lack of MFT service providers	[10, 14, 40, 81–84]
	Poor information sharing	[3, 5, 14, 34, 40, 57, 82, 85]
	Limited freight data	[3, 86, 87]
	Lack of organizational communications	[14, 63, 86]
	Lack of a business model	[14, 63, 70, 81, 88–90]
	Advanced planning systems	[3, 59, 91]
Regulations and subsidies -related barriers	Inadequate pricing policies for road transport	[31, 39, 40, 93–95]
	Lack of full rail liberalization	[10, 16, 31, 69, 96–98]
	Allowing high-capacity vehicles	[31, 99–102, 133]
	Lack of incentive policies	[11, 13, 14, 23–26, 103]
	Lack of awareness programs	[11, 14, 36, 40, 57, 63, 83] [104] [105]
Delivery characteristics-related barriers	Inadequate freight characteristics	[11, 30, 31]
	Just-in-time practice	[10, 11, 31, 39, 107]
	Unfavorable flow geography	[28, 29, 63, 91, 108, 109, 131]
	Transport outsourcing	[40, 110, 111]
Interoperability -related barriers	Different Loading gauges and weight limits	[15, 19, 32, 86, 112, 113]
	Different national train control standards	[59, 112, 114]
	Different border crossing procedures	[12, 115, 116]
	Different information formats	[57]

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Author' contributions
Ahmed Karam conceptualized the research and created a suitable methodology. Ahmed Karam conducted the review and developed the conceptual model as well as the graphical representation of the results. Ahmed Karam, Anders Julius Klejs Jensen, and Mohamed Hussein explained the findings. In paper writing, all authors participated. The author(s) read and approved the final manuscript.

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Data availability
The search queries used in Scopus and WoS during the study are available from the corresponding authors on reasonable requests.

Declarations

Competing interests
The authors declare that they have no competing interests.

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References

1. European commission. (2020). *Transport* —. European Environment Agency.
2. European commission (2020). Multimodal and combined transport.
3. Caris, A., Macharis, C., & Janssens, G. K. (2013). Decision support in intermodal transport: A new research agenda. *Computers in Industry*, *64*, 105–112. https://doi.org/10.1016/J.COMPIND.2012.12.001.
4. Bontekoning, Y. M., Macharis, C., & Trip, J. J. (2004). Is a new applied transportation research field emerging?––A review of intermodal rail–truck freight transport literature. *Transp Res Part A Policy Pract*, *38*, 1–34. https://doi.org/10.1016/J.TRA.2003.06.001.
5. Steadieseifi, M., Dellaert, N. P., Nuijten, W., et al. (2014). Multimodal freight transportation planning: A literature review. *European Journal of Operational Research*, *233*, 1–15. https://doi.org/10.1016/J.EJOR.2013.06.055.
6. Macharis, C., & Bontekoning, Y. M. (2004). Opportunities for OR in intermodal freight transport research: A review. *European Journal of Operational Research*, *153*, 400–416. https://doi.org/10.1016/S0377-2217(03)00161-9.
7. Hussein, M., Karam, A., Eltoukhy, A. E. E., et al. (2023). Optimized multimodal logistics planning of modular integrated construction using hybrid multi-agent and metamodeling. *Automation in Construction*, *145*, 104637. https://doi.org/10.1016/j.autcon.2022.104637.
8. Eurostate (2020). Freight transport statistics - modal split - Statistics Explained. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Freight_transport_statistics_-_modal_split. Accessed 7 Mar 2023.
9. Flodén, J., Bärthel, F., & Sorkina, E. (2017). Transport buyers choice of transport service – A literature review of empirical results. *Research in Transportation Business & Management*, *23*, 35–45. https://doi.org/10.1016/J.RTBM.2017.02.001.
10. Islam, D. M. Z. (2014). Barriers to and enablers for European rail freight transport for integrated door-to-door logistics service. Part 1: Barriers to multimodal rail freight transport. *Transport Problems*, *9*, 43–56.
11. Elbert, R., & Seikowsky, L. (2017). The influences of behavioral biases, barriers and facilitators on the willingness of forwarders' decision makers to modal shift from unimodal road freight transport to intermodal road–rail freight transport. *Journal of Business Economics*, *87*, 1083–1123. https://doi.org/10.1007/S11573-017-0847-7.
12. Islam, D. M. Z. (2014). Barriers to and enablers for European rail freight transport for integrated door-to-door logistics service. Part 2: Barriers to multimodal rail freight transport. *Transport Problems* 9.
13. Tsamboulas, D., Vrenken, H., & Lekka, A. M. (2007). Assessment of a transport policy potential for intermodal mode shift on a European scale. *Transp Res Part A Policy Pract*, *41*, 715–733. https://doi.org/10.1016/J.TRA.2006.12.003.
14. Kumar, A., & Anbanandam, R. (2020). Analyzing interrelationships and prioritising the factors influencing sustainable intermodal freight transport system:

A grey-DANP approach. *Journal of Cleaner Production*, *252*, 119769. https://doi.org/10.1016/J.JCLEPRO.2019.119769.

15. Rodemann, H., & Templar, S. (2014). The enablers and inhibitors of intermodal rail freight between Asia and Europe. *Journal of Rail Transport Planning & Management*, *4*, 70–86. https://doi.org/10.1016/J.JRTPM.2014.10.001.
16. EC (2011). Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system.
17. Europe UNationsEC for, Transport, E. C. of, & Commission, M. (2001). E Terminologie En Transports Combines = Terminology on Combined Transport. United Nations. Economic Commission for Europe.
18. Ghaderi, H., Cahoon, S., & Nguyen, H. O. (2016). The role of intermodal terminals in the development of non-bulk rail freight market in Australia. *Case Studies in Transport Policy*, *4*, 294–305. https://doi.org/10.1016/J.CSTP.2016.09.003.
19. Islam, D. M. Z., Ricci, S., & Nelldal, B. L. (2016). How to make modal shift from road to rail possible in the European transport market, as aspired to in the EU Transport White Paper 2011. *European Transport Research Review*, *8*, 1–14. https://doi.org/10.1007/S12544-016-0204-X/FIGURES/9.
20. Woodburn, A. (2008). Intermodal Rail Freight in Britain: A terminal problem? *Planning Practice & Research*, *23*, 441–460. https://doi.org/10.1080/02697450802423708.
21. Islam, D. M. Z., Jackson, R., Zunder, T. H., & Burgess, A. (2015). Assessing the impact of the 2011 EU Transport White Paper - a rail freight demand forecast up to 2050 for the EU27. *European Transport Research Review*, *7*, 1–9. https://doi.org/10.1007/S12544-015-0171-7/TABLES/6.
22. Trip, J. J., & Bontekoning, Y. (2002). Integration of small freight flows in the intermodal transport system. *Journal of Transport Geography*, *10*, 221–229. https://doi.org/10.1016/S0966-6923(02)00008-X.
23. Santos, B. F., Limbourg, S., & Carreira, J. S. (2015). The impact of transport policies on railroad intermodal freight competitiveness – the case of Belgium. *Transp Res D Transp Environ*, *34*, 230–244. https://doi.org/10.1016/J.TRD.2014.10.015.
24. Macharis, C., & Pekin, E. (2009). Assessing policy measures for the stimulation of intermodal transport: A GIS-based policy analysis. *Journal of Transport Geography*, *17*, 500–508. https://doi.org/10.1016/J.JTRANGEO.2008.10.004.
25. UIC (2007). Workpackage A1 trends in Domestic Combined Transport.
26. Dablanc, L. (2009). Regional policy issues for rail freight services. *Transp Policy (Oxf)*, *16*, 163–172. https://doi.org/10.1016/J.TRANPOL.2009.05.003.
27. Marchet, G., Perego, A., & Perotti, S. (2009). An exploratory study of ICT adoption in the Italian freight transportation industry. *International Journal of Physical Distribution and Logistics Management*, *39*, 785–812. https://doi.org/10.1108/09600030911008201/FULL/XML.
28. Behrends, S., & Flodén, J. (2012). The effect of transhipment costs on the performance of intermodal line-trains. *Logistics Research*, *4*, 127–136. https://doi.org/10.1007/S12159-012-0066-0/FIGURES/9.
29. Janic, M. (2007). Modelling the full costs of an intermodal and road freight transport network. *Transp Res D Transp Environ*, *12*, 33–44. https://doi.org/10.1016/J.TRD.2006.10.004.
30. Woodburn, A., & Whiteing, A. (2010). *Transferring freight to 'greener' transport modes*. In: Improving the Environmental Sustainability of Logistics.
31. Tayyeb, H., Kassim, A., Al-Falahi -, M., et al. (2018). Decarbonizing intraregional freight systems with a focus on modal shift. *Environmental Research Letters*, *13*, 083001. https://doi.org/10.1088/1748-9326/AAD56C.
32. Troch, F., Vanelslander, T., Sys, C., et al. (2017). A road map for explorative scenario creation on Belgian rail freight transport development. *Competition and Regulation in Network Industries*, *18*, 3–21. https://doi.org/10.1177/1783591717734792/ASSET/IMAGES/LARGE/10.1177_1783591717734792-FIG4.JPEG.
33. Lachal, J., Revah-Levy, A., Orri, M., & Moro, M. R. (2017). Metasynthesis: An original method to synthesize qualitative literature in Psychiatry. *Frontiers in Psychiatry*, *8*, 269. https://doi.org/10.3389/fpsyt.2017.00269.
34. Karam, A., Reinau, K. H., & Østergaard, C. R. (2021). Horizontal collaboration in the freight transport sector: Barrier and decision-making frameworks. *European Transport Research Review*, *13*, 1–22. https://doi.org/10.1186/S12544-021-00512-3/FIGURES/2.
35. Brogan, J. J., Aeppli, A. E., Beagan, D. F., et al. (2013). *Freight Transportation Modal Shares*. Scenarios for a Low-Carbon Future.
36. Arencibia, A. I., Feo-Valero, M., García-Menéndez, L., & Román, C. (2015). Modelling mode choice for freight transport using advanced choice experiments. *Transp Res Part A Policy Pract*, *75*, 252–267. https://doi.org/10.1016/J.TRA.2015.03.027.
37. Walker, W. E., Van Grol, H. J. M., Rahman, S. A., et al. (2004). Improving the Intermodal Freight Transport System linking Western Europe with Central and Eastern Europe: Identifying and prioritizing policies. *Transportation Research Record*, *1873*, 109–119. https://doi.org/10.3141/1873-13.
38. Mueller, M. A., Wiegmans, B., & van Duin, J. H. R. (2020). The geography of container port choice: Modelling the impact of hinterland changes on port choice. *Maritime Economics and Logistics*, *22*, 26–52. https://doi.org/10.1057/S41278-019-00142-6/FIGURES/4.
39. Woodburn, A. G. (2003). A logistical perspective on the potential for modal shift of freight from road to rail in Great Britain. *International Journal of Transport Management*, *1*, 237–245. https://doi.org/10.1016/J.IJTM.2004.05.001.
40. Eng-Larsson, F., & Kohn, C. (2012). Modal shift for greener logistics - the shipper's perspective. *International Journal of Physical Distribution and Logistics Management*, *42*, 36–59. https://doi.org/10.1108/09600031211202463/FULL/PDF.
41. Fowkes, A. S., Firmin, P. E., Tweddle, G., & Whiteing, A. E. (2004). How highly does the freight transport industry value journey time reliability—and for what reasons? *International Journal of Logistics: Research and Applications*, *7*, 33–43. https://doi.org/10.1080/13675560310001619259.
42. Hasan, K. R., Zhang, W., & Shi, W. (2021). Barriers to intermodal freight diversion: A total logistics cost approach. *Maritime Economics and Logistics*, *23*, 569–586. https://doi.org/10.1057/S41278-020-00182-3/TABLES/2.
43. Saeedi, H., Behdani, B., Wiegmans, B., & Zuidwijk, R. (2019). Assessing the technical efficiency of intermodal freight transport chains using a modified network DEA approach. *Transp Res E Logist Transp Rev*, *126*, 66–86. https://doi.org/10.1016/J.TRE.2019.04.003.
44. Shipping Australia Limited. (2011). *Metropolitan intermodal terminal*. Sydney.
45. Paixão, A. C., & Marlow, P. B. (2002). Strengths and weaknesses of short sea shipping. *Mar Policy*, *26*, 167–178. https://doi.org/10.1016/S0308-597X(01)00047-1.
46. Beškovnik, B., & Golnar, M. (2020). Eliminating Barriers for Sustainable Transport Systems on Maritime Silk Road and Baltic–Adriatic Corridor under BRI. Sustainability 2020, Vol 12, Page 7412 12:7412. https://doi.org/10.3390/SU12187412.
47. Behrends, S. (2017). Burden or opportunity for modal shift? – embracing the urban dimension of intermodal road-rail transport. *Transp Policy (Oxf)*, *59*, 10–16. https://doi.org/10.1016/J.TRANPOL.2017.06.004.
48. Konings, J. W. (1996). Integrated centres for the transshipment, storage, collection and distribution of goods: A survey of the possibilities for a high-quality intermodal transport concept. *Transp Policy (Oxf)*, *3*, 3–11. https://doi.org/10.1016/0967-070X(96)00007-8.
49. Woxenius, J. (1998). Development of small-scale intermodal freight transportation in a systems context.
50. Jackson, R., Matsika, E., Zunder, T., & Mahler, S. (2013). Conceptualisation of an Innovative Rail Freight Vehicle for Transporting LDHV Cargo in an EU Context. In: World Congress on Railway Research (WCRR). Newcastle University.
51. Truschkin, E., & Elbert, R. (2013). Horizontal transshipment technologies as enablers of combined transport: Impact of transport policies on the modal split. *Transp Res Part A Policy Pract*, *49*, 91–109. https://doi.org/10.1016/J.TRA.2013.01.024.
52. Zunder, T. H., & Islam, D. M. Z. (2018). Assessment of existing and future rail freight services and technologies for low Density High Value Goods in Europe. *European Transport Research Review*, *10*, 1–12.
53. Dalla Chiara, B., Deflorio, F. P., & Spione, D. (2008). The rolling road between the Italian and French alps: Modeling the modal split. *Transp Res E Logist Transp Rev*, *44*, 1162–1174. https://doi.org/10.1016/J.TRE.2007.10.001.
54. Vrenken, H., Macharis, C., & Wolters, P. (2005). *Intermodal Transport in Europe*. European intermodal association (EIA).
55. Azab, A., Karam, A., Eltawil, A., et al. (2019). A simulation-based optimization approach for external trucks appointment scheduling in container terminals scheduling in container terminals. *International Journal of Modelling and Simulation*, *00*, 1–18. https://doi.org/10.1080/02286203.2019.1615261.
56. Tsiulin, S., Reinau, K. H., Hilmola, O. P., et al. (2020). Blockchain-based applications in shipping and port management: A literature review towards defining key conceptual frameworks. *Review of International Business and Strategy*, *30*, 201–224. https://doi.org/10.1108/RIBS-04-2019-0051/FULL/PDF.
57. Smith, N., Chow, G., & Ferreira, L. (2002). E-Business challenges for Intermodal Freight: Some international comparisons. *Transportation Research Record*, 20–28. https://doi.org/10.3141/1790-03.
58. Gonzalez-Aregall, M., Cullinane, K., & Vierth, I. (2021). A Review of Port Initiatives to Promote Freight Modal Shifts in Europe: Evidence from Port

Governance Systems. Sustainability 2021, Vol 13, Page 5907 13:5907. https://doi.org/10.3390/SU13115907.

59. Harris, I., Wang, Y., & Wang, H. (2015). ICT in multimodal transport and technological trends: Unleashing potential for the future. *International Journal of Production Economics*, *159*, 88–103. https://doi.org/10.1016/J.IJPE.2014.09.005.
60. Ruiz-Garcia, L., Barreiro, P., Rodríguez-Bermejo, J., & Robla, J. I. (2007). Monitoring the intermodal, refrigerated transport of fruit using sensor networks. *Spanish Journal of Agricultural Research*, *5*, 142–156.
61. Rich, J., Kveiborg, O., & Hansen, C. O. (2011). On structural inelasticity of modal substitution in freight transport. *Journal of Transport Geography*, *19*, 134–146. https://doi.org/10.1016/J.JTRANGEO.2009.09.012.
62. Christoph Vollath Francesco Dionori Simon Ellis, Ranghetti, D., Konrad Bablinski, L. C., & Soutra, C. (2015). *Freight on Road: Why EU Shippers Prefer Truck to train*. European Parliamentary Research Service.
63. ;, Port of Esbjerg, & Grontmij, I. (2015). A/S A study on an intermodal terminal at the Port of Esbjerg.
64. Behrends, S. (2015). The modal shift potential of intermodal line-trains from a haulier's perspective: Drivers and barriers in the mode choice process. *World Review of Intermodal Transportation Research*, *5*, 369–386. https://doi.org/10.1504/WRITR.2015.076925.
65. Woodburn, A. (2015). An empirical study of the variability in the composition of British freight trains. *Journal of Rail Transport Planning & Management*, *5*, 294–308. https://doi.org/10.1016/J.JRTPM.2015.12.001.
66. UIC (2007). Developing infrastructure and operating models for intermodal shift. Paris.
67. Kreutzberger, E. (2010). Lowest cost intermodal rail freight transport bundling networks: Conceptual structuring and identification. *European Journal of Transport and Infrastructure Research*, *10*, 158–180.
68. El Yaagoubi, A., Ferjani, A., Essaghir, Y., et al. (2022). A logistic model for a French intermodal rail/road freight transportation system. *Transp Res E Logist Transp Rev*, *164*, 102819. https://doi.org/10.1016/J.TRE.2022.102819.
69. Islam, D. M. Z., & Mortimer, P. N. (2017). Longer, faster and heavier freight trains: Is this the solution for European railways? Findings from a case study. *Benchmarking*, *24*, 994–1012. https://doi.org/10.1108/BIJ-05-2015-0051/FULL/PDF.
70. Kordnejad, B. (2016). Stakeholder analysis in intermodal urban freight transport. *Transportation Research Procedia*, *12*, 750–764. https://doi.org/10.1016/j.trpro.2016.02.029.
71. Watson, I., Ali, A., & Bayyati, A. (2019). Freight transport using high-speed railways. *International Journal of Transport Development and Integration*, *3*, 103–116.
72. Francisco, F., Teixeira, P. F., Toubol, A., & Nelldal, B. L. (2021). Is large technological investment really a solution for a major shift to rail? A discussion based on a Mediterranean freight corridor case-study. *Journal of Rail Transport Planning & Management*, *19*, 100271. https://doi.org/10.1016/J.JRTPM.2021.100271.
73. Belforte, P., Cheli, F., Diana, G., & Melzi, S. (2009). Numerical and experimental approach for the evaluation of severe longitudinal dynamics of heavy freight trains. https://doi.org/101080/00423110802037180 46:937–955. https://doi.org/10.1080/00423110802037180.
74. Stokłosa, J., Jaśkiewicz, M., & SIMULATION STUDY OF LONGITUDINAL FORCES IN THE COUPLING DEVICE OF HEAVY FREIGHT TRAINS. (2014). *Advances in Science and Technology Research Journal* 8:24–30. https://doi.org/10.12913/22998624.1091874.
75. Dick, C. T., Atanassov, I., Kippen, F. B., & Mussanov, D. (2018). Relative train length and the infrastructure required to mitigate delays from operating combinations of normal and over-length freight trains on single-track railway lines in North America. 233:731–742. https://doi.org/10.1177/0954409718809204.
76. Gurri', S., Bocchieri, M., Galasso, D., et al. (2023). Assessing the speed of an electric multiple-unit freight Train on high-speed lines. *INGEGNERIA FERROVIARIA*, 393–415. https://doi.org/10.57597/IF.05.2023.ART.1.
77. Merchan, A. L., Belboom, S., & Léonard, A. (2020). Life cycle assessment of rail freight transport in Belgium. *Clean Technologies and Environmental Policy*, *22*, 1109–1131. https://doi.org/10.1007/S10098-020-01853-8/FIGURES/5.
78. Fan, B., Roberts, C., & Weston, P. (2012). A comparison of algorithms for minimising delay costs in disturbed railway traffic scenarios. *Journal of Rail Transport Planning and Management*, *2*, 23–33. https://doi.org/10.1016/j.jrtpm.2012.09.002.
79. Winebrake, J. J., Corbett, J. J., Falzarano, A., et al. (2012). Assessing Energy, Environmental, and Economic tradeoffs in Intermodal Freight Transportation. *J Air Waste Manage Assoc*, *58*, 1004–1013. https://doi.org/10.3155/1047-3289.58.8.1004.
80. Xu, W., & Rong, M. (2022). Research on optimization of Expressway Logistics path based on the Advantages of Multimodal Transport in the environment of internet of things. *Wirel Pers Commun*, *126*, 1981–1997. https://doi.org/10.1007/S11277-021-08755-Y/FIGURES/5.
81. Lehtinen, J., & Bask, A. H. (2012). Analysis of business models for potential 3Mode transport corridor. *Journal of Transport Geography*, *22*, 96–108. https://doi.org/10.1016/J.JTRANGEO.2011.12.001.
82. Pfoser, S., Treiblmaier, H., & Schauer, O. (2016). Critical success factors of synchromodality: Results from a case study and literature review. *Transportation Research Procedia*, *14*, 1463–1471. https://doi.org/10.1016/J.TRPRO.2016.05.220.
83. Dong, C., Boute, R., McKinnon, A., & Verelst, M. (2018). Investigating synchromodality from a supply chain perspective. *Transp Res D Transp Environ*, *61*, 42–57. https://doi.org/10.1016/J.TRD.2017.05.011.
84. Lucassen, I. M. P. J., & Dogger, T. (2012). Synchromodality pilot study: Identification of bottlenecks and possibilities for a network between Rotterdam, Moerdijk and Tilburg.
85. Hrušovský, M., Demir, E., Jammernegg, W., & Van Woensel, T. (2021). Real-time disruption management approach for intermodal freight transportation. *Journal of Cleaner Production*, *280*, 124826. https://doi.org/10.1016/J.JCLEPRO.2020.124826.
86. Ghaderi, H., Cahoon, S., & Nguyen, H. O. (2017). Evaluation of impediments to the competitiveness of the rail sector in Australia: Empirical research and evidence. *Asia Pacific Journal of Marketing and Logistics*, *29*, 1097–1115. https://doi.org/10.1108/APJML-02-2017-0034/FULL/PDF.
87. Bank, W., IRU (2016). *Road freight transport services reform*. guiding principles for practitioners and policy makers.
88. Spychalski, J. C., & Thomchick, E. (2009). Drivers of intermodal rail freight growth in North America. *European Journal of Transport and Infrastructure Research* 9.
89. Saeedi, H., Wiegmans, B., Behdani, B., & Zuidwijk, R. (2017). Analyzing competition in intermodal freight transport networks: The market implication of business consolidation strategies. *Research in Transportation Business & Management*, *23*, 12–20. https://doi.org/10.1016/J.RTBM.2017.02.009.
90. Elmar Ockenfels, Roggenkamp, M. (2016). Development of business models supporting cooperation within the rail freight sector.
91. Macharis, C., Vanhaverbeke, L., van Lier, T., et al. (2012). Bringing intermodal transport to the potential customers: An interactive modal shift website tool. *Research in Transportation Business & Management*, *5*, 67–77. https://doi.org/10.1016/J.RTBM.2012.11.005.
92. European commission (2004). Global Intermodal Freight Transport System.
93. Jensen, A., & Flodén, J. (2007). *Modelling Intermodal Freight*. Transport-The Potential of Combined Transport in Sweden.
94. Lammgård, C. (2012). Intermodal Train services: A business challenge and a measure for decarbonisation for logistics service providers. *Research in Transportation Business & Management*, *5*, 48–56. https://doi.org/10.1016/J.RTBM.2012.11.001.
95. Van Essen, H. P., Boon, B. H., Schroten, A. (2008). Internalisation measures and policy for the external cost of transport.
96. Krykavskyy, Y., & Stasiuk, K. (2019). Railway freight transportation liberalization as a solution for improving client services quality. In: SHS Web of Conferences.
97. Gouvernal, E., & Daydou, J. (2007). Container Railfreight services in North-West Europe: Diversity of Organizational forms in a liberalizing environment. *Transp Rev*, *25*, 557–571. https://doi.org/10.1080/01441640500072127.
98. European court of auditors. (2016). *Rail freight transport in the EU*. still not on the right track.
99. Karam, A., & Reinau, K. H. (2021). Evaluating the Effects of the A-Double Vehicle Combinations If Introduced to a Line-Haul Freight Transport Network. Sustainability 2021, Vol 13, Page 8622 13:8622. https://doi.org/10.3390/SU13158622.
100. Liimatainen, H., Pöllänen, M., & Nykänen, L. (2020). Impacts of increasing maximum truck weight – case Finland. *European Transport Research Review*, *12*, 1–12. https://doi.org/10.1186/S12544-020-00403-Z/TABLES/6.
101. Pålsson, H., Winslott Hiselius, L., Wandel, S., et al. (2017). Longer and heavier road freight vehicles in Sweden: Effects on tonne- and vehicle-kilometres, CO2 and socio-economics. *International Journal of Physical Distribution and Logistics Management*, *47*, 603–622. https://doi.org/10.1108/IJPDLM-02-2017-0118/FULL/PDF.
102. Meers, D., van Lier, T., & Macharis, C. (2018). Longer and heavier vehicles in Belgium: A threat for the intermodal sector? *Transp Res D Transp Environ*, *61*, 459–470. https://doi.org/10.1016/j.trd.2016.08.007.

103. Sina Mohri, S., & Thompson, R. (2022). Designing sustainable intermodal freight transportation networks using a controlled rail tariff discounting policy – the Iranian case. *Transp Res Part A Policy Pract*, *157*, 59–77. https://doi.org/10.1016/J.TRA.2022.01.012.
104. Rotaris, L., Tonelli, S., & Capoani, L. (2022). Combined transport: Cheaper and greener. A successful Italian case study. *Research in Transportation Business & Management*, *43*, 100792. https://doi.org/10.1016/J.RTBM.2022.100792.
105. Pfoser, S. (2022). Developing user-centered measures to increase the share of multimodal freight transport. *Research in Transportation Business and Management*, *43*, 100729. https://doi.org/10.1016/j.rtbm.2021.100729.
106. Dalla Chiara, B., & Pellicelli, M. (2011). On the cost of road-rail combined transport Sul costo del trasporto combinato strada rotaia. *Ingegneria Ferroviaria*, *66*, 951–965.
107. Tavasszy, L. A. (2011). *Modal Shift Target for Freight Transport above 300 km*. An Assessment.
108. Bergqvist, R., & Monios, J. (2016). The last mile, inbound logistics and intermodal high capacity transport - the case of Jula in Sweden. *World Review of Intermodal Transportation Research*, *6*, 74–92. https://doi.org/10.1504/WRITR.2016.078157.
109. Carruthers, R. C. (2013). What Prospects for Transport Infrastructure and Impacts on Growth in Southern and Eastern Mediterranean Countries?.
110. Sommar, R. (2006). Intermodal Transport in Less-than-Truckload Networks.
111. Truschkin, E., Elbert, R., & Günter, A. (2014). Is transport subcontracting a barrier to modal shift? Empirical evidence from Germany in the context of horizontal transshipment technologies. *Business Research*, *7*, 77–103. https://doi.org/10.1007/S40685-014-0004-X/TABLES/6.
112. Marzano, V., Tocchi, D., Papola, A., et al. (2018). Incentives to freight railway undertakings compensating for infrastructural gaps: Methodology and practical application to Italy. *Transp Res Part A Policy Pract*, *110*, 177–188. https://doi.org/10.1016/J.TRA.2018.01.040.
113. REORIENT (2007). Implementing Change in the European Railway System.
114. Peters, G. (2016). The path to a new era of signalling across Europe - Railway Technology. https://www.railway-technology.com/features/featurethe-path-to-a-new-era-of-signalling-across-europe-5660894/. Accessed 1 Apr 2022.
115. Regmi, M. B., & Hanaoka, S. (2012). Assessment of intermodal transport corridors: Cases from North-East and Central Asia. *Research in Transportation Business & Management*, *5*, 27–37. https://doi.org/10.1016/J.RTBM.2012.11.002.
116. Konstantinus, A., Zuidgeest, M., Christodoulou, A. (2019). Barriers and Enablers for Short Sea Shipping in the Southern African Development Community. Sustainability 2019, Vol 11, Page 1532 11:1532. https://doi.org/10.3390/SU11061532.
117. COMCIS (2007). Mobilising Global Freight Data - A Vision Delivered. http://www.comcis.eu/. Accessed 2 Feb 2023.
118. Li, N., Chen, G., Govindan, K., & Jin, Z. (2018). Disruption management for truck appointment system at a container terminal: A green initiative. *Transp Res D Transp Environ*, *61*, 261–273. https://doi.org/10.1016/J.TRD.2015.12.014.
119. Tavasszy, L., Behdani, B., & Konings, R. (2017). Intermodality and synchromodality. *Ports and networks* (pp. 251–266). Routledge.
120. Veenstra, A., Zuidwijk, R., & Van Asperen, E. (2012). The extended gate concept for container terminals: Expanding the notion of dry ports. *Maritime Economics and Logistics*, *14*, 14–32. https://doi.org/10.1057/MEL.2011.15/FIGURES/3.
121. Roso, V., Woxenius, J., & Lumsden, K. (2009). The dry port concept: Connecting container seaports with the hinterland. *Journal of Transport Geography*, *17*, 338–345. https://doi.org/10.1016/J.JTRANGEO.2008.10.008.
122. Torkjazi, M., Huynh, N., & Shiri, S. (2018). Truck appointment systems considering impact to drayage truck tours. *Transp Res E Logist Transp Rev*, *116*, 208–228. https://doi.org/10.1016/J.TRE.2018.06.003.
123. Behdani, B., Fan, Y., Wiegmans, B., & Zuidwijk, R. (2016). Multimodal schedule design for synchromodal freight transport systems. *European Journal of Transport and Infrastructure Research*, *16*, https://doi.org/10.18757/ejtir.2016.16.3.3151.
124. Islam, S. (2017). Simulation of truck arrival process at a seaport: evaluating truck-sharing benefits for empty trips reduction. https://doi.org/101080/13675567201171353067 21:94–112. https://doi.org/10.1080/13675567.2017.1353067.
125. Karam, A., & Attia, E. A. (2019). Integrating collaborative and outsourcing strategies for yard trucks assignment in ports with multiple container terminals. *International Journal of Logistics Systems and Management*, *32*, 372–394.
126. Chen, R., Meng, Q., & Jia, P. (2022). Container port drayage operations and management: Past and future. *Transp Res E Logist Transp Rev*, *159*, 102633. https://doi.org/10.1016/J.TRE.2022.102633.
127. Karam, A., Reinau, K. H., & Østergaard, C. R. (2021). Towards a collaborative decision support system for the Freight Transport: A pilot test-based analysis. *IFAC-PapersOnLine*, *54*, 342–347. https://doi.org/10.1016/J.IFACOL.2021.06.040.
128. Beuthe, M., Degrandsart, F., Geerts, J. F., & Jourquin, B. (2002). External costs of the Belgian interurban freight traffic: A network analysis of their internalisation. *Transp Res D Transp Environ*, *7*, 285–301. https://doi.org/10.1016/S1361-9209(01)00025-6.
129. Teter, J., Cazzola, P., Gul, T., et al. (2017). *The future of trucks*. Implications for energy and the environment.
130. Danielis, R., & Marcucci, E. (2007). Attribute cut-offs in freight service selection. *Transp Res E Logist Transp Rev*, *43*, 506–515. https://doi.org/10.1016/J.TRE.2005.10.002.
131. Liedtke, G. T. (2012). Estimation of the benefits for shippers from a multimodal transport network. *Logistics Research*, *4*, 113–125. https://doi.org/10.1007/S12159-012-0073-1/FIGURES/10.
132. Schilk, G., & Seemann, L. (2012). Use of ITS technologies for multimodal transport operations–river information services (RIS) transport logistics services. *Procedia-Social and Behavioral Sciences*, *48*, 622–631.
133. Knight, I., Newton, W., Barlow, T. (2008). Longer and/or longer and heavier good vehicles (LHVs): A study of the likely effects if permitted in the UK: final report.

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