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Freight Mobility as a Service: Open platforms for synchromodal transport

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ABSTRACT

We propose user-centric booking platforms for end-to-end freight transport as a requirement for the scaling of synchromodal transport and a new avenue for transport and logistics research. We start with the assertion that synchromodal transport is still an unapplied concept due to the strong heterogeneity and disconnection of the transport offer and the huge variety of cargo requests. We suggest that open digital platforms with a focus on shippers can help create transparency that benefits shippers and carriers, and may increase the efficiency in the use of network capacity. We denote the concept *Freight Mobility as a Service* (FMaaS). Current digital platforms predominantly operate under the assumption that transport services are on-demand, often with flexible lead times, overlooking the structured nature of most actual transport operations. FMaaS challenges this paradigm by recognizing that a significant portion of transport – such as rail, barge, and short sea shipping – is inherently scheduled, not chartered, and must be integrated accordingly. Finally, FMaaS is an open market where the visibility of the transport service offer for the shipper is global and not limited to contracts between the platform operator and the service suppliers. The applicability of FMaaS presents barriers and questions that open possibilities for a rich multidisciplinary research agenda. One of the main barriers to this concept is the acceptance of the actors involved, along with the lack of scientific evidence on how a user-centric platform system can help achieve the sustainability challenge. Also, the development of centralized platforms may pose serious commercial and legal threats. This paper aims to describe the requirements and possible research avenues of this new paradigm in the wake of an emerging market.

1. Introduction

Freight transportation is a major cause of CO_2 emissions and congestion worldwide, accounting for 11% of global greenhouse gas emissions, which are expected to double by 2050. Despite several attempts to create a modal shift to greener modalities, such as rail and waterborne transport, we still experience a predominantly truck-based system that does not exploit well-connected networks, deployed capacity, and multimodal options. One of the main causes is the heterogeneity and disconnection of the market, both on the demand and supply sides. In addition, the heavy presence of intermediaries and non-digitized and relationship-based modi operandi, especially in small and medium enterprises, do not favor the exploitation of global network capacity (Acero et al., 2022). Finally, we argue that the existence of scheduled services has led to the emergence of various types of intermediaries that aggregate shipper demands for transportation to match with scheduled intermodal services. In addition to aggregation, these intermediaries also shape

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the transport demand and arrange drayage to and from the intermodal terminals. While this service provided by intermediaries may provide value, it typically leads to higher prices and longer lead times, reducing the opportunity to make use of these services, especially in a dynamic manner as has been proposed in the concept of synchromodal transport.

A solution is to transition to digital booking platforms. In other industries, e.g., airline and hospitality, booking platforms have favored synchronization and matching between supply and demand, thereby achieving better capacity utilization by increasing the visibility of the offer and providing a user-centered perspective. Likewise, online platforms in freight transport can favor synchronization between shippers and transport providers by offering seamless matching, execution, monitoring, and payment of transportation services. Moreover, such platforms can be a catalyst for synchromodal transport by enabling more control over the status of the freight and the available capacity to deal with schedule disruption. In recent years, freight platforms have emerged globally. By analyzing the current market, we can observe the following. (I) The majority of platforms are focused on road-based modes of transport; (II) Current digital platforms predominantly operate under the assumption that transport services are on-demand, often with flexible lead times, overlooking the structured nature of rail and waterborne transport operating with scheduled services, making them not sufficiently covered; (III) the transport offer is limited to the contractual agreements between the platform owner and the transport operator, limiting the full visibility of the transport offer (IV) multimodal solutions and composite services are hard to offer without intermediation, which typically generate higher prices and longer leadtimes.

We define the concept of Freight Mobility as a Service (FMaaS), taking inspiration from the MaaS concept already defined for passenger mobility (Jittrapirom et al., 2017). Although a common definition of MaaS seems absent (Maas, 2022), the concept can be described as "the collection of different transport options in a digital platform where users can easily plan, book, and pay for their journey, and switch between transport modalities". MaaS is essentially a digital intermediary that helps connect users with transport operators, considering their needs (e.g., time, services) and their willingness to pay. The translation to freight is not that obvious. Each user, named *shipper* in this context, potentially has several units to dispatch with various conditions and necessities regarding logistics services and transport constraints such as origins, destinations, and time frames. Hence, more challenges arise in several aspects. First, while private users can autonomously change the mode of transport, for freight transport, the change is in the hands of the transport operators, and both the feasibility and the liability may be difficult to assess. Secondly, the nature of the cargo, whose value of time is typically lower than that of the passengers (Daganzo, 2005), makes a wider range of transport options and regional connections applicable. Considering the case of container transport in northern Europe, it may be equally interesting to discharge a container from a sea vessel at one of the three main seaports, Rotterdam, Antwerp, and Hamburg. For travelers, choosing an airport is usually influenced by the vicinity of their home and also by the limited waiting time (Sarangi and Kay, 2024). Thirdly, compared to passenger transport, there is much less heterogeneity in the market in terms of willingness to pay (e.g., business class vs economy in airlines) within the same transport mode, so prices tend to degenerate. Fourth, the emergence of a global centralized platform can pose serious risks to the market. Hence, it is interesting to understand how public systems may be efficient against centralized private marketplaces that cover a subset of the transport offer. Lastly, the role of intermediaries is still essential to organize and synchronize the different parties for complex multimodal legs, but their business model may need to be readapted to the functionalities and global coverage of the platform.

Our goal in this paper is to conceptualize and characterize the FMaaS concept and provide guidelines for future research. We propose a research agenda whose objective is to understand how stakeholders can embrace this new concept and how the platform should be designed for successful implementation. Although the majority of transportation-related research is within the disciplines of Operations Research and Transport Economics, we expect the concept will stimulate multi and interdisciplinary research. In particular, behavioral and business models and legal frameworks will create new knowledge for understanding adoption mechanisms, policies, and success factors. In turn, more technical avenues, such as OR, IT, AI, and data science in general, are required to develop the technical layers based on the new paradigm of 'matching' and user-centered perspective in transportation.

This article is structured as follows. In Section 2, we provide some information background for the focal setting with a set of common definitions and an analysis of the current freight platform market. In Section 3, we develop an overview of freight- and platform-related research, whereas in Section 4, we describe the FMaaS concept in detail. In Section 5, we develop the research agenda. Section 6 concludes our paper.

2. Background

Freight transportation is defined as the movement of goods, commodities, or materials, generally through standardized loading units (e.g., boxes, pallets, containers). Bulk transport (e.g., coal, oil) can also be considered within this classification, but it is not considered in this paper. Origins, destinations, logistics requirements, and time frames may vary significantly based on the nature of the goods. A classical supply chain perspective looks at the lifetime of goods from production to shelves, typically starting from raw materials and going through manufacturing or inventory points, where the goods' status and ownership can change throughout the chain. Logistics is what enables the storage and transfer of goods. For a complete overview, we refer to Tavasszy et al. (2017) and to Bouchery et al. (2014) for a focus on container supply chains.

In this section, we first provide a set of definitions. Next, an overview of the current market status concerning freight matching platforms is provided. For ease of exposition, we focus on Full Truck Load (FTL) (or Full Container Load) transportation to abstract from combining pallets or even smaller units, but the principles can also be applied to LTL transport, nevertheless.

2.1. Main definitions

In this framework, several players are involved. Definitions are sometimes not unique, but we attempt to give the most generic definitions that are useful for our purpose.

Actor	Definition
Shipper	An actor that requests transport services and is typically the manufacturer or owner of the goods, or an agent such as a freight forwarder acting on their behalf.
Manufacturer	An actor that produces goods and may act as a shipper or consignor.
Consignee	An actor that physically receives the goods; this actor may also be the shipper.
Sender/Consignor	An actor that physically holds the goods at the origin; this actor may also be the shipper.
Transport Operator/Provider	An actor that organizes transportation, either using owned means of transport or by outsourcing to carriers.
Carrier	An actor that physically performs the transportation.
Logistics Operator	An actor that supports transportation through logistical activities such as storage and handling; this actor may also be a transport operator and typically owns facilities like terminals and warehouses.
(Digital) Freight Forwarder	An actor that organizes transportation for shippers based on available capacity and acts as an intermediary between shippers and transport operators or carriers. This actor usually holds contractual relationships with stakeholders and handles organizational tasks such as coordination and liability. Some freight forwarders offer services via digital platforms and may be contractually identified as the shipper.
Shipping Line	An actor that manufactures and operates deep-sea vessels and containers for overseas transport. This actor may enter into contracts with shippers to cover the full container journey (carrier haulage) or part of it (merchant haulage). In some contexts, this actor is also referred to as a carrier.
Port/Hub Owner	An actor that owns physical hubs where cargo is received or stored. This class may include transport operators and plays a key role in enabling multimodal transport, coordinating parties, and managing system constraints.
Digital Match-maker	An actor that connects relevant stakeholders through digital online platforms.

In addition, several types of transportation services and options may apply to freight transport:

Term	Definition
Unimodal Transport	A transport operation that involves only a single mode of transport throughout the journey.
Intermodal Transport	A transport operation using multiple modes of transport under a single contract with one carrier or transport operator. Some definitions require the use of a single loading unit throughout the journey.
Multimodal Transport	A transport operation that involves multiple modes of transport, typically of different types, with different contracts and actors involved (e.g., multiple carriers or transport operators).

Synchromodal Transport	A form of multimodal transport where the selected transport mode(s) can be flexibly changed during the journey based on real-time capacity and network status.
Less-than-Truck/Container-Load (LTL/LCL)	A modality in which the cargo of multiple shippers is consolidated in a single transport unit. This approach reduces shipping costs for shippers and increases capacity utilization for carriers but requires more complex contracts and handling.
Full-Truck/Container-Load (FTL/FCL)	A modality in which the entire transport unit is dedicated to a single shipper's cargo. This option is more expensive for shippers but minimizes risks of damage and contamination. It also simplifies handling for carriers, though it may result in lower capacity utilization.
Logistics Services	A set of supporting services around freight transportation, including tracking, storing, refrigeration, and handling.
Carrier Haulage	A transport arrangement in which the entire container movement is managed by the shipping line that rents out the container to the shipper. This typically offers higher reliability due to single-entity responsibility but comes at a higher cost.
Merchant Haulage	A transport arrangement in which parts of the container movement are managed independently by transport operators instead of the shipping line. This may offer cost advantages to the shipper but results in more fragmented responsibility and may incur additional fees, such as demurrage and detention.
Demurrage	A fee charged by the shipping line when a container is not removed from the port area within the agreed time frame.
Detention	A fee charged by the shipping line when a container is not returned to the port or designated depot within the specified period.

2.2. Current status of freight matching platforms

Freight transportation plays a vital role in the economy. In Europe, logistics represents about 7% of the total GDP, and freight transport contributes about 2.5% (Eurostat, 2024). Although these numbers look small, they are quite remarkable, considering that logistics is, in principle, a support activity. With respect to mode usage, for inland freight transportation, excluding maritime, truck transport is globally the predominant mode, accounting for about 75% of volume. Rail has an average share of about 20%, followed by inland shipping with about 5%. In some countries, such as Lithuania, shares of rail transport can exceed 37%. In the Netherlands, where rivers are abundant, inland shipping accounts for about 35% of the total volume of containers (Bouchery et al., 2014). In general, air cargo has a small percentage due to its high costs and, thus, is mainly dedicated to expensive items. Regarding greenhouse emissions, transportation accounts for about 29% of the total in Europe, and 40% of this is generated by freight (EEA, 2024; International transport forum, 2021). Combustion-based truck transport is the mode emitting the most, with about ten times the CO_2 emissions of rail, and it also has the largest share.

In the last two decades, governments have focused on creating a modal shift that promotes the increased use of rail and inland shipping (Fazi et al., 2015). However, in recent years, a reverse modal shift has occurred, with trucks becoming more and more attractive to the current market. There are several reasons, mainly of an economic, structural, and logistical nature. First, recent supply chain disruptions, due to, for example, the recent pandemic, military conflicts, and trade barriers. Second, the growth of e-Commerce is driving freight transport toward smaller, more frequent and on-time deliveries. Third, looking at Europe, the possibilities of trucking have increased due to the large availability of means and drivers from central and eastern European countries. Poland and Lithuania, for example, have developed large truck fleets that offer competitive long-haul services, leveraging their lower wages and the aging driver population in Western Europe. Finally, booking truck transport is becoming easier due to the emergence of digital platforms and auction mechanisms. The increased competition within these marketplaces can drive prices down, weakening the margins and competitiveness of rail and barge services (Helwing et al., 2023).

The platform market is growing steadily, but is mainly focused on road transport. The main elements of the freight booking platforms are geographic coverage, type of business model, modal focus, matching logic, and pricing. The current realm of digital freight platforms can be divided into three categories: digital marketplaces (DM), digital freight forwarders (DFF), and freight brokerage platforms (FBP). A DM is a technology platform that connects shippers directly with carriers. It works in real-time or on-demand and is typically focused on road transport. A DFF is a freight forwarder that has digitized the entire logistics process using platform technology. Digital freight forwarders typically handle more complex end-to-end shipments that may involve multiple modes of transport. They are responsible for finding the best combination of services in terms of price and quality. Unlike a digital marketplace, they can control every stage of transportation, including customs clearance and documentation. The possibility of tackling more complex transportation reduces the level of automation in the platforms. Finally, an FBP has a mere intermediary role between shippers and carriers and negotiates rates.

Table 1
Criteria for selecting and evaluating current freight platforms.

Criterion	Description
Market Relevance	The platform is active in the freight market and has a significant presence, either regionally or globally. Preference was given to platforms with known market activity in Europe or North America.
Digital Integration	Only platforms with core digital functionality (e.g., automated matching, online booking, digital documentation, or real-time tracking) were included.
Business Model Clarity	Clearly defined model: either as a marketplace (DM), forwarder (DFF), brokerage (FBP), or hybrid.
Publicly Verifiable Information	Company features, services, and roles confirmed via official websites, press releases, and reputable sources.
Type of Matching	Evaluated whether the platform facilitates Shipper–Carrier (S–C), or Shipper-side (S-side) management.
Transport Modalities	Considered the primary transport modes supported.
Pricing Model Transparency	Platforms were assessed based on how pricing is determined. Inclusion requires identifiable, publicly disclosed pricing approaches.

Table 2
Overview of some of the major players in the current freight platform market in Europe and the US. DM stands for Digital Matchmaker. DFF stands for Digital Freight Forwarder. FBP stands for Freight Brokerage Platform. S–C stands for Shipper–Carrier. S-side stands for Shipper-side. This list was last updated on June 10, 2025.

Platform	Role	Matching type	Transport modes	Region	Pricing model
UTURN	DM	S–C	Mainly road	Europe (Benelux + Germany)	Carrier-set Fixed
Uber Freight	DM	S–C	Road	USA, expanding to Europe	Fixed, Dynamic
Convoy	DM	S–C	Road	USA	Fixed, Dynamic
Flexport	DFF	S-side	Ocean, Air, Intermodal	Global	Fixed, Tailored
Freightos	DFF	S–C	Ocean, Air, Rail	Global	Bidding
C.H. Robinson	FBP	S–C	Multimodal	Global	Fixed & Bidding
DB Schenker	DFF/FBP	S-side	Multimodal	Global	Fixed, Negotiated
FreightHub (Forto)	DFF	S-side	Ocean, Air, Road	Europe	Fixed
Sennder	DFF	S–C	Road	Europe	Fixed
Coyote Logistics	FBP	S–C	Multimodal	USA, Europe	Fixed & Bidding
XPO Logistics	FBP	S–C	Mainly road	USA, Europe	Fixed, Custom
Trans.eu	DM	S–C	Road	Europe	Fixed & Bidding
Transporeon	DM	S–C	Road, Multimodal	Europe, Global	Bidding, Fixed, Subscription

From a matching point of view, these platforms can either favor the matching between shippers and carriers (Shipper–Carrier, S–C), or primarily offer logistics services to shippers (Shipper side, S-side). The latter, S-side, may offer some interface with carriers, but not necessarily offer an open matching with several available carriers. The focus is mainly on supporting, planning, and execution, Customs controls, documentation, tracking, and procurement. Prices are typically fixed or tailored. An S–C platform focuses on matching shippers and carriers in a transactional environment. Shippers post their cargo on the platform and the carriers post their capacity. The matches are either suggested algorithmically or based on price. There are two primary pricing models, namely bidding and fixed-rate models. In a bidding system, after shippers post loads, carriers can bid to obtain the shipment based on current capacity or market trends. In a fixed-rate model, carriers set their rates, and shippers can book without negotiation.

We to provide a nonexhaustive overview of the current market using publicly available information. In Table 1 we provide the selection criteria, and in Table 2 an overview of the major current platforms that are present in Europe and the US, and their main features. These platforms are highly automated, favor transactions, and possibly offer updates and track and trace services.

The current market has several drawbacks. Due to the large fragmentation, the complete visibility of the transport offer is lacking. In particular, rail and barge services are poorly covered, due mainly to the preference of transport operators to work through traditional channels where freight forwarders book complete journeys and guarantee that capacity is filled. Our overview shows that these services are mainly covered by digital freight forwarders. Secondly, digital freight forwarders and matchmakers work independently, and this entails that the usage of alternatives and the visibility of the network offer are limited. Third, rail and barge work mainly with long-term established contracts, preventing the attraction of demand from the spot market. In particular, reduced tariffs to fill up vacant spaces are hard to offer. Moreover, we argue that there is a misalignment between the business models of on-demand platforms and the quite rigid structure of rail and waterborne services. These modes of transport are mostly *scheduled* services operating at a pre-announced time, and visiting a series of terminals at more or less scheduled times, whereas full truck load road transport carriers can be chartered almost on-demand at relatively short notice.

To conclude, while digital freight forwarders offer intermodal services, the digital freight marketplaces largely abstain from offering such services, except for the traditional brokerage service providers in the US. Our argument is that this is not coincidental, but a consequence of the scheduled service nature of intermodal and multimodal logistics operations.

3. Literature review

Freight transportation can be considered a relatively young research domain. While the first scientific publications in the first half of the 20th century mainly addressed legal aspects concerning liability, in the second half, the scientific community started to address the topic from different angles, among others, societal, technical, economic, and managerial. This was caused by the relentless increase in transport volumes worldwide, especially after the introduction of ocean containers, which has reduced transportation cost, increased international trade, and severely affected the environment (the largest share of CO_2 emissions) throughout the years and the economy. Transportation costs also heavily impact the final price of goods, especially due to the massive relocation of production activities to countries with low labor costs in Asia (Fransoo and Lee, 2013).

While on the one hand, the transport economy can be considered a major pillar and backbone of our society, on the other hand, it has evolved in a very heterogeneous way with respect to standardization, level of digitization, and integration. Scientific efforts have addressed most of the resulting issues, elaborating on business models, policies, and legal aspects. Operations management and operations research have striven to minimize the impact of freight transport from the perspective of CO_2 emissions and costs, which are often assumed to head in the same direction. In the last two decades, massive freight consolidation has been a focal topic with intensive research on multimodal transportation, bundling strategies on a local and international scale (Crainic and Kim, 2007). In this respect, examples of the main research avenues have been: multimodal service network design (Wang et al., 2023; Crainic and Rei, 2024), development and location of consolidation centers, such as dry ports or urban depots (Roso and Lumsden, 2010; Allen et al., 2012), rail and waterway-based transport routing (Fazi et al., 2020; Chouman and Crainic, 2021), truck scheduling with empty containers management (Braekers et al., 2013; Fazi et al., 2023), and synchromodality (Giusti et al., 2019).

In recent years, the scientific community has focused more and more on topics such as digitalization and platformization. This is evident from the exponential growth in scientific publications in the last decade (Sardarabady and Durst, 2024). Winkelhaus and Grosse (2020) provide a literature review and a framework on how new technologies such as Internet of Things, cloud computing, mobile, and social media-based systems can impact logistics. More and more researchers are seeking to provide insight into the transition of the market to this digitalization era and also hypotheses on how transport systems will adapt to it (Wang and Sarkis, 2021). However, the scientific landscape is quite fragmented and cannot yet provide a coherent indication for generic transport systems, let alone multimodal ones. Recent developments, such as IoT, Physical Internet, and Industry 4.0, are still at an early stage and require more ground-to-earth perspectives of their applications to real systems by better indicating how this transition can be effectuated (Sarkis et al., 2021). Harris et al. (2015) present potential reasons for the slow adoption of digital solutions in multimodal systems and discuss barriers inhibiting it.

The concept of Freight Mobility-as-a-Service leans on two main concepts: MaaS, and synchromodality. The following sections aim to give a short state-of-the-art of these building blocks.

3.1. MaaS and matching platforms

The term MaaS started to appear in the early 2000s with a few technical reports on urban mobility and some sporadic projects (Zajdler and Beim, 2003; Mulley, 2017). The first definitions appear in Kamargianni et al. (2016) and Jittrapirom et al. (2017), and a first review of the literature in Maas (2022). The present literature is fairly scattered. Several frameworks have been proposed to assess the conditions of MaaS in the urban context; see, for example, Wong et al. (2020), Becker et al. (2020), and Hensher et al. (2023). Among others, Chen et al. (2023) explore choice models for the tourism market. Alonso-González et al. (2020) identify drivers and barriers to the adoption of MaaS using a survey. They cluster the respondents according to their use of the mode of transport and find that the most likely individuals to adopt MaaS are those with multi-modal mobility patterns.

Although the focus of MaaS has been predominantly on public transport, researchers have only recently started considering adding freight to the functionality of MaaS, mainly as a means of combining urban freight and passengers. Le Pira et al. (2021) propose a framework for an extended version of MaaS, including freight called “MaaS for Passenger and Freight”. Other efforts in this direction are focused on crowd-shipping, namely the possibility of individuals carrying parcels on their daily trips for extra income (Le et al., 2019).

Literature specifically focusing on platforms for freight transport has started to emerge in the last two decades, but targeting mainly trucking or unimodal transportation. The early explorative research of Janssen and Verbraeck (2008) compares the strengths and weaknesses of real-time matching mechanisms over the Internet from the carriers’ and shippers’ perspectives. Heinbach et al. (2022) recognize that already, within road freight operators, the business environment is quite fragmented and that the trend is to provide a user-centric definition of the platforms. This recent study provides findings on how platforms should be designed in terms of input and output, stressing the fact that the problem is multidimensional and that research on business models, optimization, and data management is required. Zhou and Wan (2022) analyze how digital freight matching platforms can affect road logistics firms. They show that the profitability of large trucking companies has increased after the advent of this emerging technology. Kantari et al. (2021) focus on the spot market for freight transport and analyze the matching process of carriers and shippers on a platform by means of a simulation approach. The goal is to find a trade-off between the profit of the platform and the reliability of the shipments by trying different matching strategies. Wang et al. (2020) propose a two-sided matching model to study loss aversion for shippers and carriers on matches. An evolutionary game model is also developed to investigate relevant matching and selection factors. Jain et al. (2020) analyze the implementation of a multimodal platform with a maturity growth framework, which aims to promote online matching for combinations of truck and rail services. Xu et al. (2020) take a supply chain perspective and investigates the coordination problem between a manufacturer and a retailer. They show analytically that the platform is capable of enlarge market

shares and coordinate the parties via cost-sharing contracts. Sarangi and Kay (2024) provide a study that compares a centralized platform with a public one. The study shows how a public platform where data is not centralized can have a wider reach to more shipments and carriers. A centralized platform that owns the market can save in consolidation cost, but the risk of cannibalistic effects can arise. Thus, a scenario with six platforms is conducted, showing that the total cost is higher than the public consolidation mechanism.

(Guo et al., 2020) address the multimodal aspect of matching, but uniquely from the perspective of the transport operator. They propose an optimization framework where the information about the shipments is dynamic and stochastic. Using an anticipatory approach with advanced information helps to better match the shipments with the transport capacity. The model assumes that shippers will accept the matching if the route complies with requests. However, within a freight platform, pricing mechanisms have a dominant role in matching. Park et al. (2023) look at data of an existing unimodal platform and, through discrete choice modeling, they find that matching is more successful if the platforms allow large price adjustments and more flexibility in time for the shippers to assign their shipments to the transport operator. Earlier, Lee et al. (2015) make a first attempt to evaluate price policies, looking at the case of an ocean carrier and shippers. Through a sequential game, the authors show how to apply a refund policy when the spot market price is lower than the one agreed ex-ante with the goal of attracting more volumes in advance. Guo et al. (2022) analyze a double-auction matching mechanism where both the shippers and carriers first decide their bids, and then the platform takes care of the transaction costs and matching.

3.2. Synchromodality

Synchromodality is a relatively new term in the literature. It became popular around 2010, fostered by Dutch researchers due to the interest of the North European main ports to boost the use of rail and inland shipping against trucks (van Riessen et al., 2015). Van Der Horst and De Langen (2008) highlight several challenges to facilitate coordination between transport modes. Among those, information asymmetry, the fragmentation of the market, the lack of a dominant firm, and risk-averse behavior are the major causes of a quite conservative market. Sakti et al. (2023) propose one of the latest reviews on synchromodality and analyze the inherent element of synchronization. In this respect, they emphasize how behavioral studies are necessary for the success of synchromodality and also the understanding the attitudes of the stakeholders toward time, cost, control, reliability, flexibility, and value-added service, in order to adopt the concept. Also, their findings suggest that the harmonization of information systems and data sharing under the umbrella of a platform is an essential enabler. Finally, they propose a framework where it is suggested that shippers should give control to freight forwarders (or Logistics service providers). On the other hand, the FMaaS concept is based on a user-centric perspective, where shippers are independent decision-makers and the platform supports, promotes, and highlights good decisions from a system perspective.

(Tavasszy et al., 2017) explain barriers, enablers, and required changes for synchromodality. Regarding transactions, the authors see the need for new collaboration structures for horizontal integration, business models, and ways to align data. The challenge is creating a system for data sharing and tackling administrative and liability issues. In contrast to a matching paradigm, the shippers should leave complete freedom to transport operators to decide the modes of transport. However, partnerships among transport operators are quite difficult due to different business models and pricing schemes, and it is almost impossible to find agreements on costs and revenue sharing. Dong et al. (2018) propose a supply chain perspective, encouraging shippers to take a more active role in the mode choice and to integrate it into their production and inventory management. Finally, Pfoser et al. (2016) list some critical success factors, among which are collaboration between competitors and the presence of adequate IT infrastructure to access data. Giusti et al. (2019) introduce a demand-driven supply chain and integration platforms as enablers for cooperation and interaction. The challenge is behind sharing data and creating secure protocols to enable trust. In this respect, from an IT perspectives, a few architectures were developed for data sharing, see Bol Raap et al. (2016) and Singh (2014). Acero et al. (2022) provide a thorough conceptualization and validation of the term, along with a supply chain perspective required to embrace the concept.

From a modeling perspective, synchromodality was tackled both from a revenue management perspective and an operational one. The common denominator is the transport operator, who acts as the main decision-maker. From the operational perspective, we found a few contributions. Qu et al. (2019) develop a mixed integer linear programming model to reschedule cargo affected by disruption and consider flexibility in replanning and splitting it into several shipments. Guo et al. (2020) investigate a dynamic shipment problem where a platform suggests, in real-time, matches between shipment requests and transport options from a set of carriers. The platform owner decides the matches in a rolling-horizon fashion using a heuristic. Mes and Iacob (2016) tackle a variant of the k-shortest paths problem to provide the best k multimodal routes considering costs, emissions, and reliability of the service. Zhang et al. (2022) propose a synchromodal planning problem with multiple objectives and consider fixed vehicles with predefined schedules and flexible vehicles. A hybrid VRP model is developed, which also considers the synchronization of the vehicles for transshipment. With respect to revenue management, van Riessen et al. (2017) show that in a multimodal setting, the introduction of fare classes based on service can help improve the utilization of capacity and increase revenues. The model was later extended, considering multiple corridors in Van Riessen et al. (2021). Bilegan et al. (2022) integrate revenue management into service network design models to plan intermodal freight transportation.

Although synchromodality is recognized as one of the main solutions to contrast unimodal road transport, several constraints are in place. According to the maturity model developed by Alons-Hoen et al. (2019), one of the requirements is horizontal collaboration and the presence of a control tower to manage the flow. However, its development requires acceptance and adoption of several players to make it effective. Acero et al. (2022) argue that synchromodality requires real-time information on the transport network

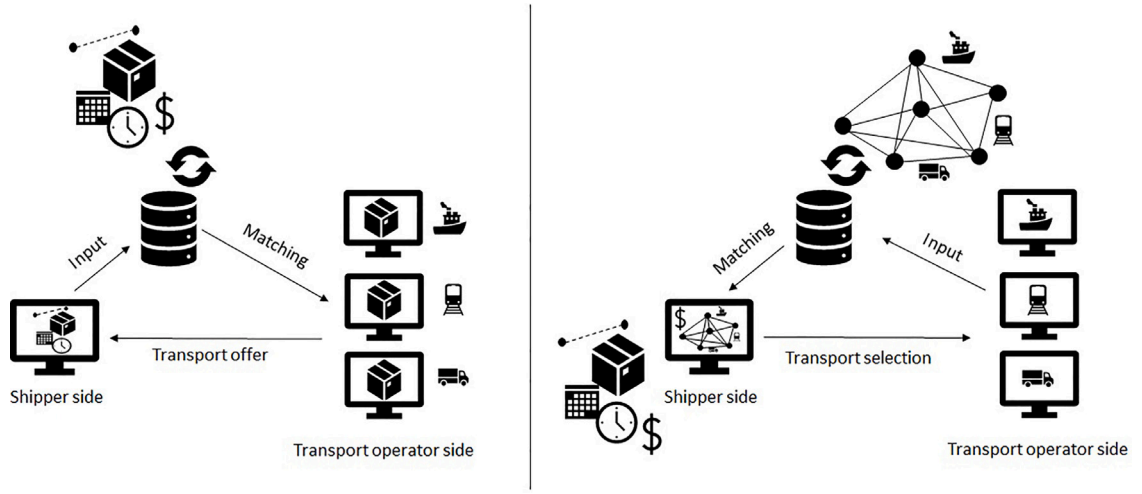

Fig. 1. The concept of an inclusive matching platform in freight ("FMaaS") may require more visibility of the transport offer and the possibility for the shipper to autonomously select a transport option. On the left side, the figure shows a more traditional platform setting, where the shipper inputs their cargo on the platform, and transport operators can compete for it. On the right side, in a more user-centric perspective, the transport operators disclose (part) of their operations, which become fully visible to the shipper.

and necessarily requires the creation of standard dashboards and digital tools that favor data sharing and visibility. Also, they emphasize how the concept is even more relevant when it addresses transportation across countries.

In this respect, synchromodality is still an unapplied concept on a large scale. Our investigation of logistics companies shows that only a few mention the concept of synchromodality (e.g., Contargo, H. Essers). However, as these companies offer multimodal transport, the application is within the same company and does not consider (systematically) other stakeholders in the network.

4. The FMaaS concept

We define Freight mobility as a service (FMaaS) as an open digital platform dedicated to freight transport and logistics services, with a user-centric perspective, where shippers have full visibility of the transport offer and can, through matching mechanisms, select combined services in a favorable way. The platform supports the shippers in finding suitable and compatible transport services according to their requirements in terms of time, origin, destination, required level of service and available budget. In a more conventional setting, shippers input their cargo onto the platform and transport operators compete for it. With an FMaaS user-centric perspective, shippers can autonomously select services. FMaaS enhances the visibility of multimodal services, including rail and barge, and increases their competitiveness by reducing the markup on the final price due to heavy intermediation. Freight forwarding roles are maintained to handle liability, contracts, and coordination issues between parties. The right side of Fig. 1 provides a graphical representation of an FMaaS system, whereas on the left side, we show a more traditional setting where decision-making is still predominantly in the hands of transport operators and freight forwarders.

The focus of FMaaS is on complex multimodal services, by consolidating and combining services from multiple sources in a central marketplace. Hence, another key feature is to promote horizontal collaboration between players by exploiting the real-time availability of shipments and transport services in the system.

4.1. FMaaS main elements

The concept leans on five key elements: a user-centric perspective, multi- and synchro-modality, inclusiveness, sustainability, and fairness.

User-centric perspective

On several platforms, shippers input their cargo, and the platform engages transport operators to shape their offer. In most cases, auctions are activated to decide upon the price (Park et al., 2023). Hence, transport operators have a major role, whereas shippers have a rather passive one. FMaaS shifts the focus from the transport operators to the shippers (users) and extends the basic functionality of booking platforms by offering seamless planning, execution, monitoring, and payment of the entire transport chain booked by a shipper. The user-centric position gives the ability to the shipper to have a direct overview of the available capacity, access discounts in the spot market, avoid hidden intermediaries' costs, proactively choose transport options, and create collaboration with other shippers for cargo consolidation. In turn, the transport operators can steer the demand advantageously

where it is needed, gain more visibility, create opportunities for collaboration with other parties, and facilitate the reuse of logistics and transport equipment.

This user-centric perspective requires transport operators to display available capacity and timetables for barge and rail services. Whether prices should be open, driven by the market, or auction-based is still an open question. In an auction-based system, the risk is that prices for trucking services can go too low compared to multimodal solutions. Market-driven pricing may lead to market stagnation and slow reaction to market dynamics. An open, fully visible price, similar to other industries, may be hard to attain in the short term due to the current heavy presence of contracts.

Multi and synchromodality

In most countries, rail and barge transport strive to gain leverage against truck transport. The FMaaS concept is focused on complex journeys with multiple legs in order to exploit the available network capacity. FMaaS creates value for these modalities by boosting their visibility and facilitating access to them. Other modalities like air and sea shipping should also be included, exploiting the network effect. FMaaS should support the connection of different transport legs and provide optional contingency plans to tackle the possibilities of disruptions. Shippers should be able to select their favorite transport plan, along with the possibility of free mode choice in case of disruptions.

Inclusiveness

At the moment, in the freight industry, intermediaries have a dominant role in the decision-making process and are typically linked to a limited portion of transport operators. They can potentially steer the market in a way that can benefit the system locally but not globally. This also applies to current freight platforms, which are linked to a selection of carriers and whose offers are not linked by a global search engine.

Although in general, platforms discourage the role of intermediaries to book transport services, in such complex multimodal systems, the role of freight forwarders is essential to tackle liability issues and coordinate different players, especially in conditions of disruptions. The concept of FMaaS requires intermediaries, but more on the level of guarantors, rather than matchmakers. The composition of routes can involve transport operators that are linked to different freight forwarders. The platform should indicate the level of compatibility between transport segments, even stemming from different platforms. This level may increase or decrease based on customers' experiences.

Sustainability

The multimodal component of FMaaS should lead to sustainable choices, given the focus on multimodal transport, and to ultimate efficiency in the scheduled transport networks. Shipments should be steered to low-utilized parts of the network to access discounts and exploit available capacity. The consolidation of cargo is key and can be dynamically increased in the platform by boosting the visibility of specific transport solutions.

Fairness

With platforms in some countries starting to dominate trade in various industries and countries, there is increasing concern about fairness, especially for small players, such as many of the trucking companies or barge operators, who may lose out in an unfair manner. While research on fairness in operations is still nascent, most recent work has been grounded in the concept of fairness in allocation problems that has been developed by Bertsimas et al. (2012). Deploying this concept in freight matching platforms in general and in FMaaS in particular remains an open question.

In Fig. 2, we show how these core elements interact. In some cases, elements are the result of one another; in others, it is the platform that enables the connection through matching mechanisms. For example, the user-centric perspective should enable inclusion and fairness by creating a more transparent marketplace. However, sustainable and multimodal solutions should be fostered by the matching mechanisms of the platform. Also, an inclusive platform enables more visibility of transport options, but the platform should steer the demand towards sustainable options.

4.2. FMaaS in practice

In the Netherlands a few attempts were made to create, in part, the FMaaS concept. Among others, BargeSpot was a platform developed for the Port of Rotterdam hinterland system to simplify the booking of transport services for small shippers. The platform also aimed to boost multimodal services. One of the main challenges for this platform was getting all stakeholders to fully embrace the digital platform by changing their traditional booking methods and sharing data. Also, the solution represented a paradox for barge operators. While, on the one hand, they were keen to increase their share with additional bookings, on the other hand, they were reluctant to increase the transparency in their services. They feared that the transparency could undermine their flexibility with shippers and, consequently, their power in the system (Roukouni and Zuidwijk, 2020).

With respect to real-world applications, the platform could tackle some operational challenges hindering the efficiency of the transport systems. For example, the Port of Rotterdam obliges barge and rail operators to close the bookings for their trips one to

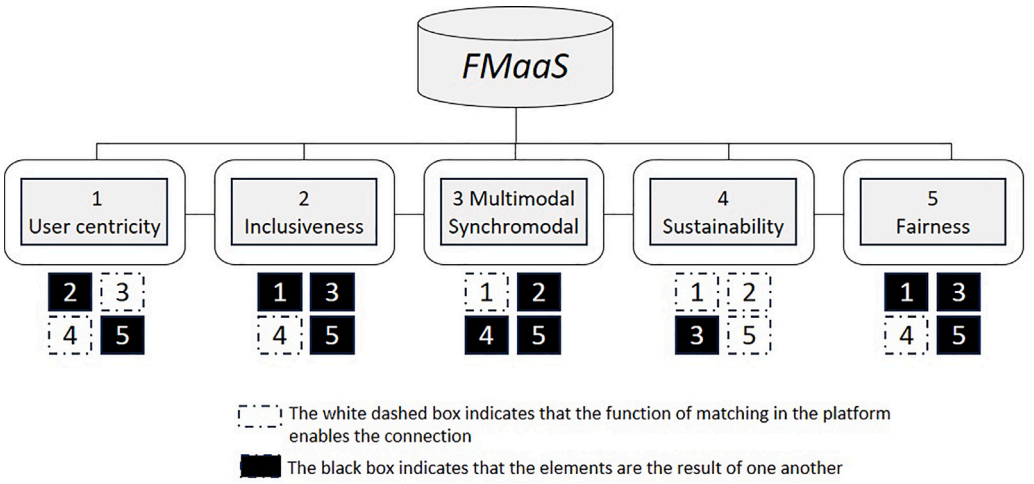

Fig. 2. Interconnection of the core elements of FMaaS.

two days before departure. This obligation is due to the request by sea terminals to send in advance the container list and limits to a large extent any access to the spot market. Surprisingly, this is not the case for truck transport, which has a notice period of a few hours. One of the reasons is that the terminals may need this information to better plan the cranes, especially for barges. However, once the platform can guarantee, via specific booking mechanisms, the desired level of barge utilization and real-time information sharing with the terminal, this hard constraint may be softened. From an operational standpoint, cases of no-shows, especially from contracted shippers, are recurrent. The platform could help increase capacity utilization by pulling demand from the spot market and also help predict the barge fill rate by assessing the reliability of shippers. In principle, this creates a nice case study to foster the introduction of barge operators to FMaaS and remove the first barriers to adoption.

Finally, the platform could favor coordination between shippers, shipping lines, and transport operators for empty container repositioning, which entails important logistical challenges. For example, reusing empty containers is somehow difficult due to the presence of demurrage and detention tariffs (Fazi and Roodbergen, 2018). FMaaS could enable seamless tracking of empty containers and possible immediate reuse, especially when dealing with goods that do not require cleaning activities for the container after it is returned to the shipping line. In that case, containers can be rented on the fly without repositioning the containers in empty depots. FMaaS can boost the visibility of these empty containers in the network and allow immediate booking.

5. Research agenda

The FMaaS concept requires a multi- and inter-disciplinary agenda. This new paradigm, shifting the decision-making role to the shippers, creates new research opportunities and the need of new models to enable synchromodal and sustainable solutions. The heterogeneity of the transport market and a successful inclusion of multimodal services require a deep understanding of barriers and enablers at different levels. Also a compartmentalized vision of FMaaS may create the risk of defining assumptions that would lead to unrealistic scenarios to be researched. For example, the level of data sharing in FMaaS must be considered carefully before creating operational rules, regulations, or business models.

We propose five research avenues that target different domains: business models, operations, legal frameworks, data and trust, and artificial intelligence. For a successful design of FMaaS, these disciplines need to be connected in the way assumptions are constructed.

Operations management and operations research models

The main assumption of the large majority of operational models in the literature related to multimodal transport, such as routing and allocation, is that transport operators are the sole decision-makers, and the shippers' demand is usually taken as input. A review by SteadieSeifi et al. (2014) on multimodality shows how the different strategic, tactical, and operational decisions concern mainly problems for carriers or transport operators. The introduction of FMaaS fundamentally changes the static and traditional way to approach multimodal freight transportation from a scientific perspective, by inverting the roles of the main stakeholders. Namely, FMaaS proposes to change the role of transport operators and carriers to a more passive one. They are expected to show information on transport capacity in the network and wait for input from shippers, which in turn will have a more active role. Under an FMaaS regime, models instruct shippers to make better choices in a platform setting where a mix of readily available and scheduled services is available, and also instruct transport operators how to manage their offer on the platform.

From the transport operators' perspective, the main objective changes from routing or network design decisions – which are rather considered inputs in the FMaaS concept – to better accommodating demand and managing the capacity based on the platform's

dynamics. Revenue management models taking into account the different modalities are lacking in the literature. Overbooking strategies may be applied to barge and rail services, considering trucking services as back-up options for overbooked cargo. Also, discrete-event simulation models could be developed to compare different booking strategies in highly stochastic environments. Market retention considerations could be included in the decision-making process for cargo selection, since transport operators are mainly concerned not to lose their market shares. Finally, queueing models in line with the work of Taylor (2018) could be developed to understand how and when to accept orders. Decisions can relate to when to stop looking for new orders and accept the requests already available on the platform before the order cut-off time. The risk is that waiting too long may result in losing such requests.

From a shipper's perspective, game-theoretical or bi-level models applied to freight networks would be interesting to model shippers' behaviors in relation to price changes, carriers' ratings, and varying CO_2 emissions per unit shipped. The theory of two-sided matching, first introduced by Gale and Shapley (1962) for college admission and only recently implemented on freight matching platforms by Wang et al. (2020), could be extended further to a multimodal framework. Efforts on modal choices for shippers are quite scattered in the literature (e.g., Brooks et al., 2012; Khakdaman et al., 2022) and could be further extended considering multimodal choices, the dynamic setting, and the functionalities of digital platforms. With respect to CO_2 emissions, the higher the utilization of a train or a barge, the lower the emissions per unit (Wang et al., 2025). FMaaS can help support these decisions by showing the varying levels of emissions as more loads are consolidated or by means of incentives in the form of certificates, for example, to be reutilized and exchanged between shippers as credits to buy services.

From a global network perspective, it is interesting to understand how to steer demand to low-utilized transport services and what the matching mechanisms could be to favor it. Orders can be treated as a queueing system where priority can be decided based on shipment size, shipper reliability, and willingness to accept greener and more flexible solutions.

From the platform perspective, choice behavior models are relevant to assess the level of acceptance and adoption of a multimodal platform. Understanding needs and fears can be pivotal for accepting a switch to new technological systems in general, in the uncharted freight transport domain. Also the modal choice from the shipper's perspective could be modeled considering new attributes provided by the platform (e.g., rating systems, reliability). Finally, the composition of complex multimodal routes handled by different transport operators is a key functionality of the platform. By offering different services of (possibly uncoordinated) players, the task is to try to establish transport paths that are feasible in terms of compatibility of the transport options. Such compatibility can be measured between transport operators and shippers, based on the offered services and needs, or between transport operators based on how effectively they can collaborate during the transfer of the shipment between them. The compatibility can dynamically change over time as more services are offered or based on new alliances or the outcome of recent operations. Enhanced "path-search" models could be developed to compose potentially compatible multi-leg journeys.

What sets freight matching platforms, in general, and freight matching service platforms in particular, apart from much of the matching platform literature is the issue of the value of time. Shippers would want to secure their transport ahead of the desired pick-up and delivery time, while carriers would like to have their capacity sold ahead. However, pricing is dynamic and may change over time. Much of the current matching platform literature tends to focus on immediate matching and clearing. As such, the analogy to booking platforms might be more appropriate than that of (transport) matching platforms.

Other operational constraints, related to more traditional OR models, should be assessed. For barge transport, container stowage is paramount and may prevent full utilization (Fazi, 2019). The selection of cargo to fit the stowage is relevant and should lead to more elaborate models and algorithms to be embedded in the platform. For rail transport, coordination and information sharing between terminals is more relevant due to the higher speed compared to barge transport.

IT, data management and trust

An important element for FMaaS is the inclusion of as many transport operators as possible to show the transport capacity. Hence, trust mechanisms in multimodal transport, as well as the network effect for multimodal freight systems, need to be investigated. For transport operators, the disclosure of prices and operational activities (e.g., frequency, capacity) may result in competitive risk; that is why federated, decentralized systems may be preferred.

It is an open question whether a multimodal freight platform should be private or public. Some recent efforts indicate that public systems may support this. For example, in India, the Open Network for Digital Commerce has been launched to create a public ecosystem to exchange goods and services over digital or electronic networks. Consumers can connect to any product or supplier using any compatible application (McKinsey & Company, 2023). Given the fragmentation of the platform market, it could be investigated whether FMaaS could also be conceived as a collector and aggregator of services provided by different platforms.

More technical avenues may relate to the payment process, RFID, and blockchain technologies to enhance trust and transparency. The integration of automated payment systems can address administrative complexity by enabling features such as real-time invoicing and expedited disbursements to carriers. RFID and IoT-based solutions can contribute to operational transparency by enabling continuous tracking of shipments, automated gate-in/gate-out procedures, and environmental monitoring (e.g., temperature or tampering), which are particularly beneficial for time- or condition-sensitive cargo. These factors may play a crucial role in the acceptance and adoption of FMaaS, and it can be investigated how these can be integrated within a shipper-centered platform.

Artificial intelligence and algorithms

Artificial intelligence and machine learning algorithms are more and more prominent in platforms. In FMaaS, algorithms should support both sides in making decisions. From the transport operator's perspective, pricing is a delicate topic. Barge and rail operators rely heavily on established contracts. That is why spot market rates cannot be substantially lower than contract-based prices. However, differences in terms of offered services, flexibility for synchromodal transport, and features of the containers may play a role in the pricing. For barge transport, it is tricky to reach 100% utilization due to stowage constraints, and containers to fill up vacant capacity should match specific requirements in terms of weight, size, destination, and time windows. From the shipper's side, the intelligence should provide good options based on the shipment. From this perspective, research should focus not only on the routing or service network design models, but also on the compatibility of the different stakeholders involved in the multileg route, including reference freight forwarders to tackle cargo handover and tracking.

Business models

FMaaS requires changes in the business models of several actors, in particular, shippers, transport operators, and freight forwarders. Current practices of barge and rail operators are quite conservative regarding the use of platforms and transport data disclosure. FMaaS requires a more active role from them, especially in the realm of small and medium enterprises. Disintermediation from freight forwarders is required to attract spot-market demand. However, their role is still crucial when composing complex journeys, tackling legal and liability issues, and connecting the different parties. Shippers are encouraged to actively use the platform and to book transport services without intermediation. It is important in this case to distinguish between regular and infrequent bookings. Regular bookings may still be tackled with contracts, whereas the others will require the use of the platform. To our knowledge, these aspects are not covered in depth in the literature, especially when looking at complex multimodal systems.

Governance

The acceptance of FMaaS requires a toolbox of legislative measures and contractual templates for industry stakeholders, policymakers, and advocacy groups. These policy measures should target competition law, labor law, and data protection law. All FMaaS stakeholders (including cargo interested parties, operational service providers, and software service providers) should be aware of the impact of FMaaS on their contractual risks and have the tools to develop a proper risk management strategy, thereby turning contract law frameworks into a catalyst for innovation instead of being an obstacle.

Another element that requires attention is power concentration. FMaaS also needs to deal with the paradox of platform power. As a network technology, platform effects are largely depending on the platform's market penetration. This leads to a vicious circle where a bigger penetration increases the platform power, allowing it to provide better functionalities to platform users. While platforms thus need the users to realize their full potential, at the same time in a mature ecosystem, platform users will often be in a very depending position vis-à-vis the platform which acts as a gatekeeper (by allowing or refusing actors market access), private legislator (by determining one-sided not only the contract terms in the relations between the platform and the platform actors, but also within the underlying relationships between the platform-actors) and illusive actor (by marketing functionalities without taking up the responsibilities associated with them). Current regulation is ill-equipped to manage excess platform power. Interventions are either unsuccessful or instead restrictive towards platform functionalities, thus eliminating the positive impact of platform power for the ecosystem, together with the negative overspill effects.

6. Conclusions

In this paper, we presented the concept of Freight Mobility-as-a-Service (FMaas). FMaaS is a user-centric, inclusive, fair, multi- and synchromodal, trust-worthy, and sustainable platform to connect the different stakeholders of the freight sector. Our preliminary analysis showed how the current platform market is heavily dedicated to road transport. The transition to multimodal transport, so the inclusion of rail and barge services, is trickier and requires more coordination due to the fragmentation of the market and the business models of the transport operators.

The practical implementation of the concept requires the creation of a new paradigm in transport research. Shippers have a more predominant role in the decision-making process and should be the focus of the models. The underlying assumption is that transport operators work in a quite fixed setting where it is difficult to change constraints and modus operandi.

FMaaS requires a multi-disciplinary research agenda. From an operations management and operations research perspective, models should focus on the interplay between the platform and the shippers, focusing on the latter to steer the decisions on green and multimodal solutions. From the transport operator side, classical OR models can be extended to fit with the scope of the platform; revenue and capacity management models are more and more relevant. Also, data management and trust are crucial elements to create adoption along with the IT architecture. Business models need to be redefined. In particular, the role of freight forwarders becomes less dominant, but still essential to coordinate demand and supply. Transport operators are required to share more information to make their offer more visible, but it should be investigated to what extent to prevent unfair competition. From a legal standpoint, FMaaS raises questions on liability, governance, contracting, and competition laws. Finally, AI techniques should support such a dynamic environment with algorithms able to predict and drive demand advantageously.

CRediT authorship contribution statement

Stefano Fazi: Writing – review & editing, Writing – original draft, Methodology, Investigation, Funding acquisition, Conceptualization. **Jan C. Fransoo:** Writing – review & editing, Validation, Investigation, Funding acquisition, Conceptualization.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT in order to help find the list of current platforms in the US and Europe included in Table 2. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Stefano Fazi reports financial support was provided by Dutch Research Council. Jan C. Fransoo reports financial support was provided by Dutch Research Council. Jan C. Fransoo reports a relationship with UTURN BV that includes: board membership. Stefano Fazi reports a relationship with Waypoint Netherlands that includes: board membership. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

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

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