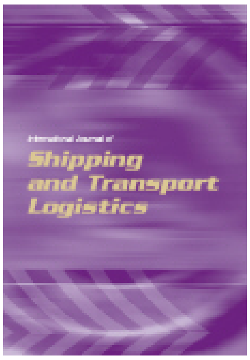

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The road to synchromodality - an exploratory study of drivers, facilitators, barriers, and components

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The road to synchromodality – an exploratory study of drivers, facilitators, barriers, and components

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Abstract: This paper augments current knowledge about synchromodality by investigating the factors that underpin the implementation of this logistical paradigm in an effort to inform managerial practice and public policy. Employing a conceptual model of drivers, facilitators, barriers, and managerial actions, we conducted a qualitative study with European experts on synchromodality. We identified drivers, such as complexity reduction or more efficient inventory management, and contextual characteristics (facilitators and barriers) that enable or hinder synchromodality, such as operational flexibility or resistance to change. Regarding managerial actions (components), we find that data governance and interfirm trust issues are salient aspects for sustaining synchromodality. Furthermore, we specified how policymakers can influence the necessary conditions and the health of partnerships for synchromodality implementation. The paper contributes to the existing logistics literature by studying synchromodality implementation issues beyond the optimisation frameworks examined by analytical models and beyond the technological focus of extant empirical studies.

Keywords: synchromodality; implementation challenges; expert interviews; policymaking; barriers; drivers.

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1 Introduction

Supply chain decision-makers are increasingly expected to design resilient and environmentally sustainable logistics networks concurrently (Sunio and Mateo-Babiano, 2021). However, while every decision-maker will aim to minimise both disruption impacts and CO_2 emissions, it can be challenging to pursue both objectives simultaneously (Miller and Engemann, 2019; Rajesh, 2018), not least because they sometimes conflict (Pavlov et al., 2019). Over the last three decades, scholars and practitioners have explored a series of modal shift paradigms to improve both the resilience and sustainability of freight transportation. Multimodal transportation involves two or more different modes, such as train and truck; intermodal transport involves two or more different modes in combination with the utilisation of a singular loading unit and integration among transport agents, such as a container being loaded onto a truck trailer; and co-modal transport employs the usage of several modalities within the same leg, such as selecting between rail and road due to speed requirements [see Reis (2015) for a thorough review of the main freight transport concepts]. In this context, synchromodality emerged in the early 2010s in the Benelux region as the latest freight transportation paradigm claiming to enable both disruption-free service and high levels of environmental performance (Acero et al., 2022; Pfoser et al., 2022). In essence, synchromodality proposes to synchronise capacity and sustainability by combining intermodal and co-modal transport with real-time monitoring of the logistics network as a whole.

While research on synchromodality has grown in recent years (Acero et al., 2022; Alons-Hoen and Somers, 2017; Pfoser et al., 2022), analytical studies predominate. These studies focus on the development of decision-support tools to determine optimal schedules (Behdani et al., 2016), prevent, and mitigate transit disruptions (Van Riessen et al., 2015a), improve mode selection (Kapetanis et al., 2016), or minimise transit time (Lin et al., 2016). However, beyond route optimisation, truckload maximisation, and capacity allocation, implementing synchromodality requires complex coordination among interdependent actors to ensure effective logistics services (Giusti et al., 2019). Although interest in the paradigm has expanded beyond Europe, most implementation attempts to date have been pursued in this regional context. For instance, the SYN-ERGIE project sought to establish a synchromodal service in a corridor between the Netherlands and Belgium, which proved to be extremely challenging (Alons-Hoen and Vannieuwenhuyse, 2021). Despite the early involvement of shippers and logistics service providers (LSPs) and the identification of sufficient load potential, most actors shied away from an unconditional commitment to the service because of the perceived uncertainty and high financial risk. In this sense, regardless of any insights provided by the analytical literature, the lack of empirical research focused on real applications has prevented a serious examination of the implementation challenges associated with this new paradigm.

Extrapolating from the European experience, there are strong indications that if synchromodal transportation networks are to become a reality, implementation hurdles related to real-time information exchange, a-modal booking formats, horizontal cooperation, and the ability to plan and integrate operational processes in real time must first be overcome (Giusti et al., 2019; Pfoser et al., 2022; Xu et al., 2022). In addition, unlike other transportation paradigms that support the independent orchestration of specialised LSPs, effective implementation of synchromodal networks also requires strong alignment within a highly diverse set of stakeholders. The same applies to concepts such as dry ports and in-transit distribution strategies. Khaslavskaya et al. (2021) highlight the importance of considering the goals of various stakeholders when developing a dry port. Hilletofth et al. (2011) point out that there is a lack of sufficient research on the implementation of in-transit strategies. In synchromodal transportation, as demonstrated by the decade-long operation of the Nextlogic platform, which optimises loading processes at the Port of Rotterdam, achieving alignment among a diverse group of stakeholders can be a complex challenge (van der Wolf, 2021). Unlike the SYN-ERGIE project, however, the Nextlogic platform (which is owned by the Rotterdam Port Authority) has facilitated the requisite collaboration among terminals and barge operators to provide the real-time information needed to maximise resource efficiency and minimise waiting times. Together with the existing literature, these examples[1] suggest that actors at the network level (including state agencies, industry associations, and third-party organisations) play an important role in orchestrating the adoption and diffusion of synchromodal transportation networks (Acero et al., 2022; Dong et al., 2018; Giusti et al., 2019).

To augment existing knowledge about synchromodality, this paper follows Giusti et al. (2019) in looking beyond the optimisation frameworks afforded by analytical models, focusing instead on the systemic factors that underpin the effective implementation of synchromodality. Our contention is that investigating these factors is urgently needed to inform managerial practice and public policy design. Therefore, our formal research question is: *what determines the effective implementation of synchromodal transportation networks?* By employing a conceptual model developed by Lambert et al. (1999), we identify several determinants and categorise them under drivers, facilitators, barriers, or components (managerial actions) that influence the prospects of synchromodality implementation. Given the exploratory nature of the research, we opted for qualitative methods as they enable the identification of nuanced factors within complex phenomena. The study contributes to the emerging literature on synchromodality by illuminating stakeholders' motivations for participating and the contextual characteristics that support or hinder implementation. In addition, as public actors and other collective entities play a key role in creating, developing, and maintaining transport infrastructures, we discuss our findings from a public policy perspective to identify actions that would accelerate the disruption-free logistics and CO_2 reduction promised by synchromodality. Given Europe's urgent emission reduction targets, synchromodal solutions offer significant potential for optimising transportation efficiency and decreasing reliance on carbon-intensive modes.

This paper is organised as follows. Section 2 outlines the concept and practice of synchromodality and summarises the current state of knowledge. Section 3 describes the sample and the analytic approach. Section 4 presents our main findings. The implications of these findings are discussed in Section 5, and the paper concludes with a review of the study's limitations and future research opportunities in Section 6.

2 Background and literature

Recent technological advances, commonly referred to as Industry 4.0, have lent new impetus to the development of fully digital supply chains. This is crystallised in the concept of Supply Chain 4.0 (Frederico et al., 2019), which emphasises the potential of digitalisation to increase supply chain sustainability through shared transportation capacity and route optimisation (Birkel and Müller, 2021). One core technology field constituent of Supply Chain 4.0 is the physical internet, which enables concurrent improvements in the sustainability, efficiency, and resilience of logistics activities (Ballot et al., 2014; Lemmens et al., 2019). In this context, synchromodality has been considered a key element in the roadmap for a fully mature physical internet (Lemmens et al., 2019; Plasch et al., 2021).

Based on the parallel usage of multiple modes, flexible mode choices, and real-time information exchange (Reis, 2015), synchromodality offers a new perspective on intermodal transport. The essence of synchromodal transport is that loads can be transferred between modalities within a short timeframe; for that reason, the approach has been applied mainly to container traffic. Within the synchromodality paradigm, the most important performance indicator is network reliability on a given corridor, which depends on real-time information to enable adaptation to disruptions as and when they arise.

Access to real-time information and flexible mode choice, in turn, depends on the interconnectivity of multiple information systems managed by multiple actors to ensure more efficient utilisation of available transport capacity and greater service reliability. To describe how firms transition to synchromodality, Alons-Hoen and Somers (2017) developed a five-level maturity model based on seven dimensions: transport planning and execution, stakeholder relationships, decision-making power, pricing policy, data exchange, and key performance indicators. In essence, the transition to synchromodality requires firms to alter their mindsets, moving away from full control of goods shipping toward an approach merely focused on the stipulation of arrival dates and container usage (Pan et al., 2017).

Early conceptualisations of synchromodality focused exclusively on the transportation of goods (Verweij, 2011). However, as in the case of intermodal and co-modal transport, the concept has since been extended to full optimisation of the supply chain (Dong et al., 2018; Giusti et al., 2019). In this view, synchromodality should also encompass sender and receiver issues of inventory and production capacity. According to Alons-Hoen and Somers (2017), the highest level of synchromodal maturity includes transport planning based on orchestrated inventory monitoring, which requires both vertical and horizontal integration (Behdani et al., 2016). As shippers differ in terms of service performance priorities (e.g., cost, quality, and flexibility) and willingness to control modal use (Khakdaman et al., 2020), the simultaneous achievement of vertical and horizontal integration across different supply chain actors can be immensely challenging (Ramirez et al., 2021; Tseng and Liao, 2015; Yu et al., 2018). For this reason, there is a specific need to empirically examine the implementation issues associated with this new transport paradigm (Pfoser et al., 2022).

Synchromodality entails the vertical integration of terminals and transport operators (rail, barge, and road) and the horizontal integration of these operators. Ultimate responsibility for this integration falls to an orchestrator (Tavasszy et al., 2018) – a neutral party that engages with all relevant actors to ensure coordinated action. Beyond terminals and operators, these include shippers and LSPs. Synchromodal freight systems must synchronise demand (goods to be transported), mobile resources (trucks, trains, and barges), and stationary resources (rails, terminals, etc.) (Behdani et al., 2016). Because economies of scale related to mobile resources can only be fully exploited if there is adequate customer demand, the orchestrator must coordinate different shippers to ensure stable flows in both directions along transport corridors. Shippers typically favour road transport because of the shorter lead times and the fact that intermodal transport often requires a stable volume commitment. Given the volatility of freight volumes and the associated financial risks, it becomes necessary to combine intermodal and road transport (Groothedde et al., 2005), as only a stable minimum quantity can be transported using an intermodal approach. By helping to reduce the overall volatility of demand, synchromodality enables a higher share of cargo to be transported using intermodal solutions by combining freight volumes from multiple shippers within a single network.

Another characteristic of synchromodality is flexible mode usage, commonly referred to as a-modal booking (Tavasszy et al., 2018). The network orchestrator requires shippers' permission to transport goods in a way that meets their scheduling requirements (specified as the latest arrival time) without specifying the route or transport modality to use. This is usually operationalised by offering different synchromodal products, such as normal and express delivery (Van Riessen et al., 2020). Full synchromodality extends the orchestrator's decision-making power from a-modal booking to transport scheduling based on inventory levels (Alons-Hoen and Somers, 2017). This depends on real-time information about the state of the transport network, freight volumes, and inventory levels, which must be operationalised from a control tower or platform (Hofman, 2014) that collects and integrates inputs from multiple sources other than the involved stakeholders, including contextual data on weather, traffic, and asset utilisation (Singh and van Sinderen, 2015). Information from these sources provides a real-time network overview that enables the optimal use of resources and helps avoid disruptions.

In practical terms, the limited development of synchromodal transport networks confirms the pressing need to investigate the factors that facilitate implementation. Driven by a concerted effort from regional institutions, pilot initiatives have predominantly been pursued in the Northwestern European context (Feport, 2022). Benefiting from an advanced infrastructure of physically interconnected networks and interoperable services, this geographical area is well positioned to achieve high synchronisation of intermodal operations through the possibilities now afforded by seamless digital communications. Furthermore, a dense network of corridors that enable road, water, and air modes of transport is served by two of the world's major ports (Antwerp and Rotterdam). This geographical predominance explains why existing studies examining critical success factors include Pfoser et al. (2016) in the Netherlands and van Duin et al. (2019) in the port of Rotterdam. Conversely, Alons-Hoen and Vannieuwenhuyse (2021) identified barriers to developing synchromodal services in a Belgian-Dutch corridor. In this sense, existing evidence suggests that implementation attempts are being pursued but fails to provide a systematic analysis of implementation issues.

A structured search was performed on articles using keywords 'synchromodal', 'synchromodal transport', and 'synchromodality' in the ScienceDirect search engine. This yielded 185, 172, and 185 articles, respectively. We initially screened each article's title, abstract, and keywords. This careful examination deemed 47 articles potentially relevant. Articles were deemed relevant if they provided empirical data, conceptual frameworks, analytical models or substantive discussions of synchromodal drivers, facilitators, barriers, or operational components. In cases in which this was not immediately discernible, we read the entire article. Studies lacking detailed treatment of synchromodality or focusing on unrelated logistics concepts were excluded. We retrieved eight additional studies through a similar search via Google Scholar and directly from authors known to study the subject. Tables 1a and 1b summarise recent synchromodal literature, segmented into analytical, conceptual, and empirical studies. As signaled by Table 1b, the relative scarcity of empirical studies evidences the need to collect more observational data to generate insights into the complex challenges facing implementation processes. The few empirical studies identified by our review uncover key capabilities for effective synchromodal logistics (Acero et al., 2022) and indicate that shippers currently exhibit a higher level of maturity in the adoption of synchromodal practices than LSPs (Alons-Hoen et al., 2021). These studies also reveal that power and trust dynamics (Rogerson et al., 2021) together with knowledge asymmetries (van Duin et al., 2019) among different logistic actors play a significant role in determining the cooperative behaviours required for synchromodal operations. Taken together, this evidence suggests reasons for which synchromodality initiatives may fail, but none of them directly targets implementation issues as a research focus. Filling this gap is the main thrust of our study.

Table 1a Classification of synchromodality literature

Analytical [# of articles]		*Conceptual/reviews [# of articles]*	
Transport planning in synchromodal networks [24]	SteadieSeifi et al. (2014), Van Riessen et al. (2015a, 2015b), Behdani et al. (2016), Kapetanis et al. (2016), Lin et al. (2016), Mes and Iacob (2016), Tsertou et al. (2016), Van Riessen et al. (2016), Zhang and Pel (2016), Li et al. (2017), Dong et al. (2018), Giusti et al. (2018), Farahani et al. (2018), Ambra et al. (2019), Lemmens et al. (2019), Pérez Rivera and Mes (2019), Qu et al. (2019), Resat and Turkay (2019), Guo et al. (2020), Batarlienė and Šakalys (2021), Crainic et al. (2021), Guo et al. (2021), He et al. (2021), Hrušovský et al. (2021), Larsen et al. (2021), Yee et al. (2021), Pamucar et al. (2022), Zahid et al. (2022), Zhang et al. (2022a, 2022b, 2022c), Durán-Micco et al. (2023), Giusti et al. (2023), Larsen et al. (2023), Oudani (2023), Zhang et al. (2023), Ferjani et al. (2024) and Guo et al. (2024)	Data exchange/ architecture in synchromodal networks [3]	Hofman (2014), Singh and van Sinderen (2015), Giusti et al. (2019) and Behdani et al. (2016)
Synchromodal pricing [2]	Van Riessen et al. (2017, 2020) and Wang et al. (2023)	New or improved modalities in synchromodal [2]	Pfoser et al. (2018) and Giusti et al. (2021)
Shipper preferences mode-free booking [2]	Khakdaman et al. (2020, 2022) and Farahani et al. (2023)	Uncertainty and barriers/enablers of synchromodal [3]	Tavasszy et al. (2018), Delbart et al. (2021) and Pfoser et al. (2022)
		Supply chain collaboration in synchromodal network [1]	Plasch et al. (2021) and Sakti et al. (2023)
	46		*11*

Table 1b Empirical synchromodal research

Authors [# of citations]	*Topic empirical synchromodal study*
Pfoser et al. (2016) [106]	Conducted expert interviews in the Netherlands. Identified and detailed critical success factors for synchromodal implementation. Success factors are ranked using feedback from 44 stakeholders.
van Duin et al. (2019) [6]	Interviews with firms in port logistics. Found that firms with some experience with synchromodal transport struggle with operational issues related to data sharing and customer requirements, while firms with no experience reveal a lack of knowledge and understanding.

Table 1b Empirical synchromodal research (continued)

Authors [# of citations]	*Topic empirical synchromodal study*
Alons-Hoen et al. (2021) [2]	Assessed the synchromodal maturity level of logistics firms in Belgium and the Netherlands. Found that vertical collaboration between LSPs and shippers is more prevalent than the requisite horizontal collaboration for higher levels of synchromodal maturity.
Rogerson et al. (2021) [3]	Investigated the role of power and trust on modal shift solutions in Sweden. Found that power is effective in initiating shifts towards synchromodality, but trust is required for long-term continuation.
Acero et al. (2022) [37]	Surveyed European LSPs involved in synchromodal projects. Uncovered four constituents of synchromodal operations to assess their synchromodal capabilities around four key elements (visibility, integration, multi-modal transport, and flexibility).
Ceulemans et al. (2025)	Using a focus group, maps stakeholders that should be involved in synchromodality, defines their decision-making responsibilities and relationships of collaboration.

Only two studies have emphasised a clear concern about implementation. Pfoser et al. (2016) identified seven enablers of effective implementation, while Giusti et al. (2019) directed their focus to one of these, namely digital technologies. We built on these two studies to pursue our investigation of implementation requirements. For an excellent review of real implementation experiences, the reader is invited to consult Giusti et al. (2019, Section 5). This article offers several useful insights regarding the employment of synchromodal networks based on an overview of the existing empirical literature. It focuses primarily on the technological aspects of implementation by detailing the role of specific enabling technologies in domains such as optimisation and data integration platforms. At the same time, this study also acknowledges the need to increase our understanding regarding further enabling factors, such as managerial, social, and regulatory aspects. The main goal of the present paper is to build on Giusti et al. (2019) and offer a broader investigation of this multifaceted issue.

To provide a coherent picture of implementation determinants beyond technology enablers only, the present study draws on Lambert et al.'s (1999) conceptual model of success factors in interorganisational partnerships. This model explains partnerships' success as a function of the motivations of individual organisations to partner (labelled as drivers), the environmental factors that lubricate mutual engagement with the partnership (labelled as facilitators), and the joint managerial actions partnering organisations must undertake to build and sustain a partnership (labelled as components). The model distinguishes between a priori characteristics (drivers and facilitators) that are present before the partnership is established and a posteriori characteristics (components) that are required for the partnership's success once established. We use this model to conceptualise and categorise the different aspects that influence the prospects of partnership formation for synchromodality within a structured framework. The model has been previously used to explain several supply chain management outcomes, such as levels of integration (Alfalla-Luque et al., 2013), collaborative performance (Zybell, 2013), or outsourcing decisions (Sanders et al., 2007). The model has also been specifically used to understand the determinants of logistics partnerships (Makukha and Gray, 2004).

To the best of our knowledge, the process of implementing synchromodality has only previously been explored from a very narrow perspective. Research to date has focused mainly on transport planning or enabling ICT systems (Alons-Hoen et al., 2021) while neglecting the key issue of strategic collaboration. By distinguishing between a priori and a posteriori elements, the present study develops new insights into the challenges of implementation with a view to helping firms and policymakers improve and accelerate that process.

3 Methodology

We used semi-structured expert interviews to gain in-depth knowledge about the challenges of implementing synchromodality. We decided to use a qualitative research approach in light of the lack of knowledge about synchromodal implementation. This approach is well-suited for research that explores nuanced factors influencing a complex phenomenon (Hennink et al., 2020). We opted for semi-structured interviews, because they provide the flexibility needed to probe subjects on complex, situational aspects of synchromodality, which are difficult to capture through structured methods (Brinkmann, 2014). However, the dearth of implementation experience renders practical knowledge about synchromodality scarce. The decision to sample experts in a broad sense stemmed from the need to obtain factual knowledge from individuals with privileged access to synchromodality implementation experiences, either as practitioners or as researchers. Expert interviews allowed us to elicit viewpoints about organisational and individual behaviours during specific synchromodality initiatives and shed light on the rationale for complex decision-making processes (Bogner et al., 2009). In our effort to access the sparse expertise available regarding synchromodality implementation experiences, we decided to look for experts beyond logistics practitioners only. This approach is particularly recommended due to the immaturity of the phenomenon and the lack of successful implementation initiatives (Van Audenhove and Donders, 2019). Reliance on selected experts is common in the scarce empirical literature (e.g., Acero et al., 2022). In terms of the analytical approach, considering the exploratory nature of the study, we aimed to use experts to provide an inventory of implementation challenges rather than to establish their relative importance or likelihood of occurrence. With this aim in mind, we resorted to the methodology of thematic analysis (Braun and Clarke, 2006). This method identifies and analyses thematic patterns in the data, without committing researchers to develop a complete theoretical framework or to engage in iterative theoretical sampling, as is the case with grounded theory (Nowell et al., 2017). Furthermore, contrary to grounded theory, thematic analysis is not specifically geared toward understanding processes of meaning construction among individual actors within a constructivist ontology (Suddaby, 2006).

3.1 Sampling and interview procedure

The participating experts were selected for their extensive knowledge and experience of synchromodality implementation initiatives. Based on these criteria, we conducted desk research to identify potential interviewees through academic and practitioner publications. Deliberately targeting different stakeholder groups, we secured the participation of three academics, two top managers from LSPs, and three consultants who are specialists in synchromodal logistics (see Table 2 for a breakdown of their characteristics). In light of the relative maturity of synchromodality initiatives within the country, most of the experts are based in the Netherlands. As it is, the country is a global leader in logistics infrastructure, frequently topping the ranks of World Bank's Logistics Performance Index (Arvis et al., 2024). While we acknowledge that eight experts constitute a compact sample size, we are confident that it facilitates a comprehensive coverage of the topic since saturation is oftentimes reached within 6–12 interviewees (Francis et al., 2010; Guest et al., 2006; Marshall, 1996). Furthermore, such sizes are not atypical in logistics research studies that need to resort to interviewing scarce experts (e.g., Buldeo Rai et al., 2019; Pushpamali et al., 2021; Raza et al., 2023). We assessed their level of expertise by reading their published research articles and white papers, examining the results of pilot projects they managed, and inspecting their titles and institutional positions. In view of the newness of the topic and the lack of widespread examples of synchromodality in operation, our selection privileged the experts who had been involved with the topic for a longer period. The background of the selected group of experts was meant to cover a comprehensive examination of the salient issues.

Table 2 Study's participants

Participant	*Position*	*Years of experience*	*Affiliation*	*# of employees*	*Country*
1	Professor	14	University	7,500	Germany/China
2	Professor	8	University	4,000	Netherlands
3	Chief operating officer	22	Logistics service provider	170	Netherlands
4	Professor	15	University	5,000	Netherlands
5	Consultant	7	Information technology consultant	4,000	Netherlands/India
6	Sales manager	31	Logistic service provider	80	Netherlands
7	Consultant/ambassador	33	Industry association	25	Netherlands
8	Consultant	27	Supply chain management consultancy	10	Netherlands

The semi-structured interview protocol focused on key topics while facilitating further exploration of any additional issues raised by the participants. The interview questions asked about the participants' experiences of studying, advising, and managing the implementation of synchromodality in practice, including factors that enable or inhibit its effectiveness and how these should be handled. Questions diverted from experts' personal biographies and focused on eliciting descriptive accounts of implementation initiatives (interview protocol found in Appendix). Once focus was achieved on specific accounts, questions became customised to the particular narratives in an attempt to explore points of view about challenges and enablers. Interviews lasted between 25 and 50 min and were conducted in person or via online video calls. All interviews were recorded and later fully transcribed. From these transcripts, we were able to identify themes related to the process of implementing synchromodality.

3.2 Data analysis

To analyse the data, we followed a number of steps. First, we generated open concepts from the raw interview data. From the interviews, we derived 106 concepts (averaging 13 concepts per interview and ranging from a minimum of 11 to a maximum of 17). In Table A1, we present the concepts derived per interview. One researcher derived the first open concepts from each interview, and subsequently, the other three went over the interviews collectively to confirm or reject these concepts and detect new ones. The concepts generated through this deliberative process constituted our final list of open codes. In the next step, we reviewed the concepts and grouped them into 22 thematic clusters. Three researchers performed this coding independently, and the emerging themes were then discussed collectively. We again required several iterations to refine the analysis, deliberate on disagreements, and converge on labels for the 22 themes. Iterations were required to compare and contrast emergent analytical categories, discuss conflicting views about pieces of data and their interrelationships, and decide on the most effective markers for classification. To aggregate the themes into final analytical categories, we resorted to logistic partnership literature. In particular, we drew on the framework of Lambert et al. (1999), which models the effectiveness of such partnerships as a function of drivers, facilitators, and components. Figure 1 represents the partnering process as first described by Lambert et al. (1996), which constitutes a method of partnership development and implementation based on 18 cases of actual relationships. Prior to engaging in a partnership drives and facilitators are discussed and, upon agreement of a mutual benefit, the implementation of the components ensures proper execution.

The interview data identified horizontal and vertical collaboration practices as the key to implementing synchromodality. In addition to drivers (reasons for partnering), facilitators (environmental factors that make partnership possible), and components (joint activities to build and sustain partnerships), we introduced a fourth category (*barriers*) to refer to issues that directly hinder firms' engagement in synchromodality initiatives. Barriers are closely related to facilitators because both refer to contextual factors in the overall environment.

We achieved triangulation of data sources by capturing perspectives from diverse stakeholders, and methodological triangulation through collaborative thematic analysis among the authors. Moreover, we approached the study with an awareness of our biases as scholars and regularly discussed the potential influence of personal perspectives on data collection and interpretation. Each member reflected on their preconceptions related to synchromodal logistics, which were shared in regular team meetings to ensure a balanced pursuit of the research. To assess the soundness of the methods utilised, our analyses were designed to meet the trustworthiness criteria traditionally associated with qualitative inquiries (Nowell et al., 2017): credibility, dependability, confirmability, and transferability. Table 3 shows the extent to which the data and analysis meet these criteria.

Table 4 summarises the assignment of concepts to cluster themes and analytical categories. Almost half of these concepts were associated with components (managerial actions required to make collaboration work), which generated eight themes. While barriers outnumbered facilitators (29 versus 20), the latter extended across more themes.

Table 3 Qualitative research trustworthiness criteria

Trustworthiness criteria	*Purpose*	*Actions*
Credibility	To generate confidence that the findings represent the interviewees' true opinions	We conducted desk research to collect background information on interviewed experts prior to the interview
		We sent interview transcripts to the interviewees for review (only very minor revisions were sent back)
		Interviewers had the required expertise to conduct research on synchromodality
Dependability	To increase the likelihood of the findings being replicated	We executed the interview protocol consistently throughout the data collection
		We documented the data collection process in detail
		We iterated between individual and collective coding for every category
Confirmability	To generate confidence that the findings would be corroborated by different researchers	We had regular meetings throughout the study to reflect on emerging findings
		We triangulated the analysis among the four researchers
Transferability	To increase the likelihood that the findings are generalisable to other contexts	We deployed purposeful sampling to cover the topic domain
		We checked for the extent of data saturation

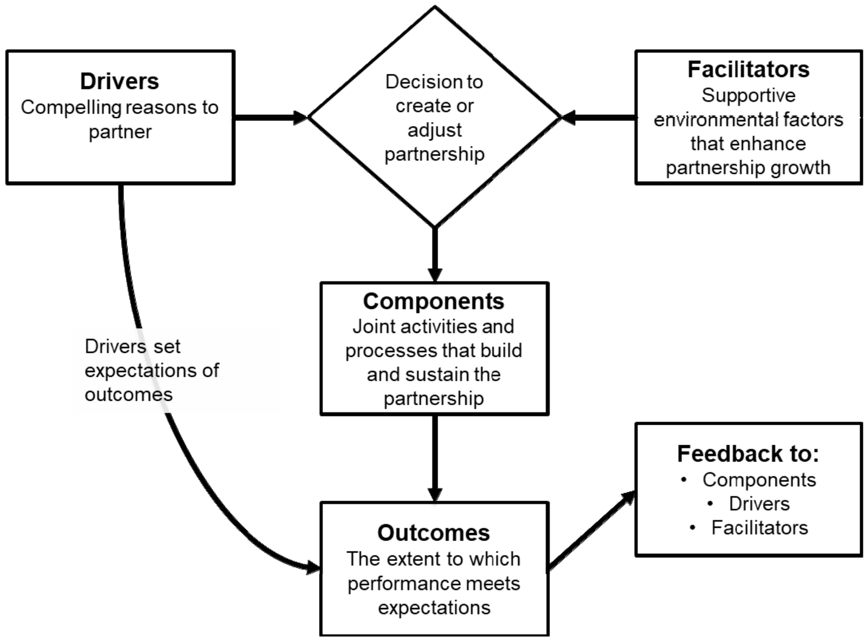
Table 4 Division of concepts into categories and cluster themes

Category	*Amount of concepts*	*Cluster themes*
Barriers	29	5
Facilitators	20	6
Drivers	8	3
Components	49	8
Total	*106*	*22*

4 Findings

As detailed above, we organised our findings using the framework developed by Lambert et al. (1999). To enhance the transparency of the analytical process, all first-order codes were labelled based on each informant's language (Strauss and Corbin, 1990). We then grouped these first-order categories into second order. This step led to the generation of a data structure, which served as the basis for a general framework for managing a sustainable supply network. Tables 5–8 show the data structure generated from grouping first-order concepts into second-order cluster themes (the integers in parentheses indicate the frequency of mention during the interviews). We also note that we have used representative quotes to illustrate important insights (participant number as used in Table 2 in parentheses).

Figure 1 The partnering process



Source: Lambert et al. (1996)

4.1 Drivers

Drivers are the key reasons or motivations for implementing synchromodality and the expected benefits of synchromodal transport. Our findings identify three core themes of drivers. *Inventory optimisation* refers to advantages related to the management of stocks of inputs and outputs: "sometimes you have an outbreak and you need to replenish toilet paper suddenly, unexpectedly, so then you can account for these kinds of unexpected events, and you can be more prepped with your replenishment" (participant 1). Synchromodality enables more efficient inventory management by mitigating the impact of delays and other disruptions and reducing the need for inventory buffers to maintain service levels. *Complexity reduction* refers to the benefits of having fewer supply chain partners, which mitigates coordination challenges. Implementing a synchromodal transport network is challenging for LSPs, but from the shipper's perspective, the number and variety of interactions are reduced. Finally, synchromodality offers *increased flexibility* by leveraging opportunities for real-time modal shifts. As stated by one of our practitioner interviewees, "I am looking for flexibility to put in different alternatives, so purchasing with a tender who only offers sea shipments, then it is over" (p.3). In a business environment characterised by high volatility, increased responsiveness is a significant driver.

Table 5 Drivers

Concepts	*Cluster themes*
Shortening inventory time	Inventory optimisation
High inventory levels	
Modal choice connect to supply chain management	
Complexity and unclear advantages	Complexity reduction
Fewer parties involved in a chain	
Pressure is shifted to LSPs	
Planning's change	Increased flexibility
Outsourcing	

4.2 Facilitators

As contextual characteristics that support the implementation of synchromodality, facilitators indicate the likelihood of success, but unlike drivers, they are beyond the direct influence of any single entity and, as such, are more rigid in the short term. Our findings identify six themes that describe such characteristics. *Data reliability* relates to the information infrastructure required to support real-time modal shifts. For example, decision-makers need data on availability and traffic conditions for alternative modes when switching transport modes to avoid disruptions. For the successful implementation of synchromodality, these data must be accurate and accessible by the relevant supply chain actors, and they must be collected in real time. *Loading unit characteristics* are specific features of shipped goods, such as being perishable, high volume, temperature-sensitive, or engineered-to-order. These features generate equipment requirements that may reduce or expand the number of logistics channels used to bundle loads. Our findings also highlight the importance of a *collaborative culture* in the supply chain: "I think there is a lot of possibilities there too, a piece of cooperation and community building needs to take place, which is also important also for people on the other side of the supply chain" (p.1). Synchromodal transport depends on real-time collaboration between different network actors, and this requires a culture that curtails opportunistic behaviours and encourages cooperation among supply chain partners. *Infrastructure* is arguably the most critical facilitator, as it is impossible to implement a multimodal transportation paradigm without the appropriate facilities, systems, and physical structures: "The big ports have a proper rail network, but for example a port such as Vlissingen, they have you a small train network, but there are capabilities to serve the European hinterland. The same is true for certain French ports, and if you look at it from a large scale, almost all sea containers from southern Europe go through Antwerp, Rotterdam, or Hamburg, but if they come from Asia, they sail right next to Italy for example. There are definitely opportunities" (p.7). *Operational flexibility* refers to the process agility needed to enable supply chain actors to make timely decisions – for instance, about order bundling or inventory management. To the extent that increased flexibility is an expected outcome of synchromodal transport networks, there is a minimum threshold of prior requisite operational flexibility if supply chain actors are to benefit from that outcome. Finally, *high internal integration* is an important facilitator because synchromodal networks involve high levels of coordination across the supply chain, and individual actors must already have a correspondingly high level of achieved internal integration within their own operations to make external integration possible. As commented by a practitioner, “We worked with large parties that have a department road, a department rail, a department sea. And they don’t really speak to each other. If they would work more collectively, then I am sure that better collaboration with us would be possible” (p.6).

Table 6 Facilitators

Concepts	*Cluster themes*
Reliability of data	Data reliability
Availability of data	
Data quality	
Type of product (3)	Loading unit characteristics
Type of industry	
Capacity issues	
Finding consensus	Collaborative culture
The parties involved should be flexible	
Flexibility	
Company specifics	
Increasing awareness	
Bring barge transport outside of the harbour	Infrastructure
Infrastructural innovations	
Congestion on roads	
Focus on a specific part of SC	Operational flexibility
Inventory management	
Aggregated demand	
Size of the company	
Internal integration	High internal integration
Internal collaboration	

4.3 Barriers

As opposed to the enabling qualities of facilitators, barriers are environmental features that hinder the implementation of synchromodality. Our findings identify five such barriers. As explained in Section 2, sharing data on inventory, traffic, capacity, and other salient factors is critical for the success of synchromodal transport networks. It follows that any element of *data protectionism* among supply chain partners hinders the development of the information-sharing infrastructure that makes the requisite real-time synchronisation possible: “To have this transparency, everybody needs to share their information, and that is already a barrier that you come across. Everyone is afraid that the information they do not want to share with their competitor is in such a platform, where all the modalities are used, will be used by multiple companies. How can the information-sharing guarantee that your data will not end up at a third party’s place where it is not meant to end up? That is why everybody is a bit scared to share all their information" (p.2). *Inflexibility* caused by the need to comply with minimum entry requirements is also a barrier to the development of synchromodal logistics networks: "When you say to me that I have to be in Venlo at 6am with a container, and I depend on synchromodal transportation, which goes partly over the road, partly over the water, partly over the rail, and then the last mile through road, with congestion and other stuff, it is very difficult to align them so that I can align enough demand to reach Venlo at 6 am" (p.6). As the purpose of synchromodality is precisely to enhance the flexibility of modal choice for a given route, the perception that participation entails high load volumes and long distances may deter some potential stakeholders. *Congestion* is a somewhat counterintuitive barrier grounded in the fear that demand for synchromodal transportation may exceed available capacity, especially in terminals: "You constantly come across the limitations of synchromodal transportation, and that is the congestion in the harbor, where the sea ships always go prior to the barge; so if there is a delay there, the other one gets delayed too" (p.8). *Resistance to change* was also identified as a general barrier to necessary adjustments related, for example, to internal operations, suppliers, and customer relationships: "You have to align it with one another so that you interpret the data in the same way and use it in the same way and that is also often different, because everybody often wants to keep doing their own thing" (p.8). One particular concern in this regard is the perceived need for persuasion and change management across multiple stakeholders. As manifested by one of the academic experts, "The narrow-mindedness, the people that do their own thing despite the consequences for the rest of the chain; if they would look at the entire chain, we would do much better" (p.4). Finally, *dysfunctional communication* as a barrier again highlights the importance of information sharing and the risk of miscommunication among the many actors that contribute to the success of a synchromodal network: "So, oftentimes there was not much communication between the transportation management system and the production management system. There was not much communication between the transportation manager and the production manager/plant manager" (p.3).

4.4 Components

Components are the managerial activities and processes that must be put in place by the different actors involved to implement synchromodality. Our findings identify eight themes related to such components, with a particular emphasis on the issue of data governance. *Data availability* refers to the need for all parties to make their own data available to other relevant actors and to perform transformations that apply common standards to make these data more understandable. As stated by a practitioner, "That could be because of data sharing. I had an encounter at Neuss, close to Dusseldorf, where a terminal was partly used as a storage space for containers of a certain factory. And those containers stood there for 3 or 4 weeks; so the entire chain should be filled with that information to use a quick modality, why would it have to go on a truck, when you could transport it with barge or train?" (p. 3). *Data architecture* is the technological infrastructure required for real-time data collection, storage, and retrieval by every actor in the network. "We all work with different systems, with our own people, and possibilities, and the first difficulty is how we can couple all this information in a central space where it is processed and we make that insightful, so that everybody can benefit from it" (p. 5). *Data security* refers to measures taken to protect data from unwanted parties. Investment in *external integration* improves collaboration and cooperation among network members in terms of goals and processes: "This integration doesn't take one day, it's an ongoing process and that's why the risk commerce has been setup, that's why risk itself has been setup, to make it more interoperable, to tackle these kinds of challenges" (p. 8). *Liability management* refers to the need to design contracts that ensure both the flexibility required for synchromodal operations and the requisite accountability of the multiple actors involved. As one of the experts put it, "The question is who is liable for the data. The question is what if it's misused … and there is also quite a lot of regulations involved, so …, these kinds of aspects will gain a lot of traction" (p. 2). One particular dimension of such contractual agreements relates to *pricing strategy*, which must ensure that every party benefits from collaborative arrangements. An *integrated planning system* ensures partner alignment in terms of transportation modes, load volumes, and inventory decisions: "The problem is that for this you would need an integrated platform, let's say an aggregated platform that combines these infrastructural things … and once you have this all combined then you can develop better planning and algorithms to actually optimise the flows of synchromodal transportation" (p. 7). Finally, the need to *build trust* among the participating network actors reflects the high levels of cooperation needed to implement synchromodality: "There are parties that have worked together for 100 years, thus they know each other very well and they know their way of working very well. And through that, they trust each other and that's why they start purchasing synchromodality" (p.1).

In view of the increased political interest in synchromodal corridors and the role of the public sector in infrastructural investment, the policy implications of our findings are discussed at the end of the next section.

Table 7 Barriers

Concepts	*Cluster themes*
Data protection	Data protectionism
Poor infrastructure of information provision and business processes	
Incompatible IT processes in the chain	
No flexibility in terminal choice and container-free mode	Inflexibility
Rushed delivery	
Fixed-time delivery trend in warehouses	
Differences between countries	
Short distance	
Transportation is unpredictable	
Time inefficient port causing harbour to be unreliable	
Capacity booking	
High capacity is needed	
Larger quantities are needed (2)	
Scalability	

Table 7 Barriers (continued)

Concepts	*Cluster themes*
Fragmentation of the chain	Resistance to change
Fragmented market	
Segmented organisations in the chain	
Too many parties in the chain	
Many different SCs	
Convince parties	
Entities need to be convinced	
Company policies	
Insecurity of working with dynamic systems	
Lock-ins	
Parties often do not look further than their own environment	
Congestion at harbours	Congestion
Congestion on rail	
Reliability transportation network	
Many entities involved	Dysfunctional communication
Transparency	
Coordination and communication	
Communication between parties	

Table 8 Components

Concepts	*Cluster themes*
Measure products in the same units	Data governance: availability
Misunderstandings because of differently interpreted data among parties	
Availability of contextual information	
Data availability across the chain	
Client and LSP do not have an insight into the SC dimension	
Interoperability of data systems with SC	Data governance: architecture
Interoperability	
Use of new technology	
Platform for communication exchange	
Neutral platform	
Transparency by using clouds	
Data visibility (2)	Data governance: security
Information streams are separate	
Data are secure (2)	
Vertical integration	External integration
Extra party for coordination	
Integrators	
Collaboration (2)	

Table 8 Components (continued)

Concepts	*Cluster themes*
Flexible contract (2)	Liability management
Responsible party when something goes wrong	
Profitable for all parties involved	Pricing strategy
Everybody needs to gain something	
Dynamic planning	Integrated planning system
Forecasting model	
Outhouse inventory	
Bundling	
Bundling shipments	
Create a footprint to know which modalities are possible	
Algorithms on data availability	
Priority rules	
Holistic SC view	
Optimising system and individual performances	
Ports signed that max 30% can be done with trucks	
The LSP should combine the wishes/KPIs of the terminal and the shipper	
Research with simulation models	
Trust (4)	Build trust

5 Discussion

The present study augments existing knowledge by investigating the drivers, facilitators, barriers, and managerial components that influence the effective implementation of synchromodality. In particular, our interviewees corroborated the conceptual requirements for synchromodality advanced by Dong et al. (2018) and Giusti et al. (2019), which include broader supply chain parameters related to inventory, production scheduling, and service level targets. Among the three drivers we identified, inventory optimisation appears to be a key motivation for shippers because synchromodality is not simply about transportation but involves the integration of logistics with supply chain management (Delbart et al., 2021). Given that price is usually an important factor in logistics decisions (Flodén et al., 2017) and that shippers typically seek a high share of service cost improvements (45.7%) (Khakdaman et al., 2020), it is surprising that cost factors were not identified as either drivers or barriers. As a matter of fact, our findings fail to uncover a particular relevance of financial implications for logistics service providers and shippers, even though the implementation of synchromodal networks will necessarily involve initial investments.

Table 9 Juxtaposition of the critical success factors of Pfoser et al. (2016) to the concepts uncovered in the current study

Concepts			*Critical success factors*						
			Network, collaboration and trust	*Sophisticated planning*	*Physical infrastructure*	*Legal and political framework*	*Awareness and mental shift*	*Pricing, cost, service*	*ICT/ITS technologies*
Concepts of current research	Facilitators	Data reliability							
		Loading unit characteristics							
		Collaborative culture	x				x		
		Infrastructure			x				
		Operational flexibility					x		
		High internal integration							
	Barriers	Data protectionism							
		Inflexibility							
		Resistance to change					x		
		Congestion							
		Dysfunctional communication							
	Components	Data governance: availability		x					x
		Data governance: architecture							x
		Data governance: security				x			x
		External integration	x						
		Building trust					x		
		Pricing strategy						x	
		Integrated planning system		x					
		Liability management				x			

Table 10 Critical success factors of synchromodality, enabling technologies, and the related concepts of collaboration, adapted from Giusti et al. (2019)

		Critical success factors					
		Network, collaboration, and trust	*Sophisticated planning*	*Physical infrastructure*	*Legal and political framework*	*Awareness and mental shift*	*Pricing, cost, service*
Enabling technologies of Giusti et al. (2019)	Traceability	x	x				
	Intelligent systems			x		x	
	Data analytics				x	x	x
	Optimisation			x	x	x	
	Simulation	x		x		x	x
	Integration platforms	x	x		x		x
Concepts of current research improved by technology		External integration	Data governance: availability; integrated planning system	Infrastructure	Data governance: security; liability management	Operational flexibility	Pricing strategy
Concepts of current research aided by technology		Collaborative culture				Collaborative culture; resistance to change; building trust	

Our findings, specifically regarding facilitators, barriers, and components, are closely related to the critical success factors identified in Pfoser et al. (2016) and revisited in Giusti et al. (2019) (we consider drivers to be conceptually different and are therefore excluded from this comparison). In Table 9, we map our 19 concepts onto the latter's categories. We assessed each concept on the extent to which it corresponded with Pfoser's categories and were able to match 15 of the 19 concepts to one of those critical success factors. By juxtaposing the two sets of findings in Table 9, we offer suggestive evidence that some success factors seem to be more relevant in the initial stages of implementation (i.e., they are facilitators), whereas others appear definitely more required in consolidation stages (i.e., they are components). Moreover, our findings offer a more granular view of the insights of Pfoser et al. (2016) in that, for example, our results are able to unpack different aspects in which the required mental shift still has to occur.

To further emphasise our contribution, in Table 10 we map the findings that overlap between our study and Pfoser et al.'s (2016) onto the enabling technologies identified by Giusti et al. (2019). While some of the concepts we derived can be directly enabled by one of the technologies, we note that the ones at the bottom represent elements for which technologies alone cannot be effective. These elements pose particular challenges for business strategists and policymakers: creating a collaborative culture among different logistic actors, building trust within their relationships, and overcoming resistance to change.

We also identify elements that fail to fit with the previous framework; among others, *data reliability* is a facilitator, and *data protectionism* is a barrier. These findings clearly indicate that, beyond the development of appropriate ICT technologies, accurate and voluntarily shared data inputs are of paramount importance. Our findings also identify *high internal integration* within shippers and LSPs as a critical prerequisite for effective integration with external partners. While this principle is well established in the empirical literature on supply chain strategy (Cao and Zhang, 2011; Flynn et al., 2010; Zhao et al., 2011; Zhong et al., 2022), the synchromodality literature has until now focused predominantly on the technological enablers of synchromodality (Giusti et al., 2019; Singh and van Sinderen, 2016) while neglecting organisational and broader socioeconomic aspects (Pfoser et al., 2022).

Beyond expectations of improved inventory management, our findings illuminate other motivations for engagement in synchromodal networks. Among these, experts anticipated that outsourcing mode-booking choices to a network orchestrator would reduce the complexity of their decision-making, thus enhancing shippers' operational performance. In particular, our findings identify increased flexibility and responsiveness as expected benefits of synchromodality. This aligns with the synchromodal paradigm's promised amelioration of disruptions, such as delivery delays, natural disasters, vehicle breakdowns, and traffic congestion (Acero et al., 2022). However, the same cannot be said for environmental sustainability gains, as we found no evidence that emission reduction is a core driver of participation in synchromodal networks. This finding also offers an important insight into the analytical literature, which is inherently unequipped to investigate actual intentions regarding the motivational variables to include in optimisation and simulation studies. In general, a contribution of our study is the uncovering of empirical elements that can serve as inputs to the development of mathematical models and prototype designs for synchromodal transport.

In any event, while some pilot projects suggest that motivational factors, such as incentives and operational goals, play a role in synchromodality implementation, our findings indicate that failures in implementation are not always primarily due to these drivers. Instead, key managerial components, specifically external integration and trust-building, emerge as critical enablers for successful implementation. For instance, in the case of Nextlogic, where five terminals and two depots exchange real-time data about barge locations and waiting times (Nextlogic, 2021), the success of data-sharing through a common IT system fundamentally relies on mutual trust among participants (Alons-Hoen et al., 2021). Our findings corroborate this view, identifying external integration and trust as essential managerial activities for enabling synchromodality. These aspects are often overlooked in the predominance of analytical literature, which may benefit from focusing on these foundational managerial elements in guiding synchromodal initiatives. Moreover, our findings support previous studies showing that integration and trust are crucial components for synchromodality (Pfoser et al., 2016) and that network partners must continually foster these components to sustain a synchromodal system (Rogerson et al., 2021). Such insights can motivate analytical studies focused on practical issues like information sharing and contracting within synchromodal networks. Additionally, the ongoing need for relationship-building and integration underscores the importance of identifying enabling factors for effective managerial and policymaking initiatives (Pfoser et al., 2022), which are often more challenging to implement than purely technological solutions (Pfoser et al., 2016).

While the literature acknowledges the need for guidance to help policymakers secure the adoption of synchromodality (Pfoser et al., 2016), empirical research has lagged behind (Pfoser et al., 2022). Evidence-based guidance of this kind is clearly needed in light of the apparent political interest in implementing synchromodal corridors (Zijm and Klumpp, 2016), the historical relevance of the public sector in orchestrating the creation, development, and maintenance of logistic infrastructures (Savy, 2016), and the importance of neutral parties in ensuring the success of pilot projects (Alons-Hoen and Vannieuwenhuyse, 2021; Nextlogic, 2021). Viewing our findings through a public policy lens, we submit that policymakers play a key role in designing a supportive environment for synchromodality implementation. In particular, our findings indicate that policymakers must attend to three key facilitating roles:

1 To address the *infrastructural needs* of synchromodality and marshal the requisite investment of financial and operational resources.

2 To tackle the issue of *loading unit characteristics* by developing regulations that standardise containers and packages while acting as matchmakers to connect partners with similar characteristics. As an example of the latter, the Dutch lean and green off-road runners initiative (Bolt, 2020) helps suitable shippers and carriers use all available inland, rail, and short sea corridors to provide synchromodal transport in every region of the Netherlands.

3 To foster a *collaborative culture* by bringing public agencies, research institutes, and private companies together to support the implementation of synchromodality.

Policymakers also have a role in dismantling any barriers that obstruct the implementation of synchromodality or at least in mitigating their effect. While the task is not easily defined, policymakers can help dispel some of the concerns that underpin *data protectionism* and *resistance to change* by developing initiatives that inform and clarify stakeholders about the nature and benefits of synchromodal networks. In this regard, policymakers should devise incentive schemes to reduce the perceived risk for hesitant stakeholders. In particular, policymakers can mitigate the barriers related to *congestion* by leading the effort to secure infrastructural investment.

Finally, we examined the potential of policy to sustain synchromodality by encouraging appropriate managerial actions. In this regard, our findings highlight the significance of *data governance* issues, and government regulations and initiatives can play a key role in establishing standards for interfirm data sharing. For example, the Netherlands has implemented the open trip model as an interface for sharing real-time transport information along with a standard called iShare for safe data exchange. These initiatives have the potential to enhance mutual trust among stakeholders, which our findings clearly identify as a key issue. Effective synchromodal corridors depend on cooperation and mutual trust among multiple stakeholders that differ in size and market power. In developing and maintaining this trust, government institutions acting as neutral brokers can help ensure fair and clear *liability management* and *pricing strategies*. Furthermore, policies can foster this requisite trust by devising templates for formal contractual agreements outlining mutual expectations from partners, by enforcing communication protocols that ensure transparency, and by mandating shared governance structures that give all partners a voice in decision-making.

Besides policy-making implications, the study also directly informs managers of individual firms on key components for implementing synchromodal networks effectively. For managers looking to implement data governance frameworks, the Nextlogic model suggests the importance of establishing clear data-sharing protocols, defining ownership and access rights, and ensuring compliance with privacy regulations. By implementing similar governance structures, managers can mitigate data security risks and foster a controlled and transparent environment for information sharing. Operational managers can use these practices to establish day-to-day data governance protocols and maintain trust within project teams, while senior executives can embed these principles into broader organisational strategies. In addition, the synchromodal collaborations observed in the European logistics sector, the requisite trust between partners is built through regular joint decision-making sessions and transparent performance metrics. These approaches help ensure that parties are aligned and committed, which is critical for data sharing and collaborative planning in synchromodal networks.

6 Conclusions, future research opportunities, and limitations

Based on expert interviews, the present study identified drivers, facilitators, barriers, and components that affect the implementation of synchromodal networks. Key drivers included performance benefits accruing from complexity reduction, increased operational flexibility, and more efficient inventory management. This aligns with the findings of Acero et al. (2022), who identified four key components of synchromodal operations – visibility, integration, multimodal transport, and flexibility – as essential elements for evaluating synchromodal capabilities. Our findings reveal that successful implementation is aided by strong intra-firm integration and operational flexibility, while obstacles such as resistance to change and dysfunctional communication act as barriers. This expands on the work of Giusti et al. (2019), who primarily focused on the technological aspects of implementation, including the role of enabling technologies in areas like optimisation and data integration platforms. In addition to these technological factors, our study places greater emphasis on enabling factors such as managerial, social, and regulatory aspects, offering a more in-depth exploration of these dimensions. Our findings show that data governance and trust issues are key managerial concerns in maintaining synchromodality. Rogerson et al. (2021) highlight that power and trust dynamics, along with knowledge asymmetries among various logistics actors (van Duin et al., 2019), significantly influence the cooperative behaviours essential for synchromodal operations. While this body of evidence helps explain why synchromodality initiatives may struggle, none of these studies specifically focus on the challenges of implementation as a primary research focus. None of the reviewed papers provide specific guidance on how policymakers can improve the necessary conditions – both barriers and facilitators – or influence the critical components that determine the health of partnerships for implementing synchromodality.

Future research should explore the effectiveness and impact of different policy initiatives. Another direction for future research relates to data-sharing standards. Looking beyond the cited examples from the Netherlands, other European and global initiatives should also be evaluated, as many goods travel across borders. It would also be useful to map existing synchromodality orchestrators and to investigate how they are organised. For example, are LSPs better equipped than neutral or government-sponsored actors to play the role of orchestrator as it is more closely linked to their core competencies? A further issue of interest is the relationship between firm size and willingness or ability to participate in synchromodal networks and the factors that constrain stakeholders of different types. For instance, smaller companies may be more willing to collaborate yet lack the financial resources to make the necessary investments, and it would be useful to determine how policymakers can help in this regard. Another important pathway should be to quantitatively assess the CO_2 reduction potential of synchromodal networks and integrating sustainability metrics so that implemented synchromodal operations can prioritise environmentally sustainable transport modes and avoid carbon-intensive logistics options. Finally, future research would benefit from a comprehensive cost-benefit analysis of synchromodal implementation. Specifically, exploring how synchromodality impacts pricing strategies and financial risk management would address key concerns for profit-driven logistics service providers and shippers.

Naturally, the study is not without limitations. The findings presented here are based on a relatively small sample (eight experts). As experiences with synchromodality grow, it is important to continue to survey experts and individuals with direct managerial roles that are able to convey key viewpoints on this complex issue. Besides its size, our sample also consists of experts exclusively based in Northwestern Europe, more specifically in the Netherlands. Even though their knowledge of synchromodality initiatives extends beyond this region, it is reasonable to suppose that the lens through which they analyse their effectiveness is restricted. As example would be the importance given to barriers such as congestion. Looking at the Netherlands' score in the World Bank's Logistics Performance Index (Arvis et al., 2024), we observe that, in spite of the country's global leadership in the sector, its ability to conduct international shipments is relatively lower than in other dimensions of logistics performance, which could have influenced the salience our experts attributed to certain factors. Going forward, it would be important to assemble experts based in other regions of the globe to corroborate the insights gleaned from European-based experts and to augment the set of challenges identified in this geographical area. Nevertheless, the commonality between factors and the overlap with previously identified critical success factors suggests that our investigation was able to capture the phenomenon with a certain breadth. Another limitation is that we could not rank the factors in terms of importance, which invites further research. Finally, as we did not interview any shipping firm representatives, our findings may under-represent relevant enablers, as seen by these stakeholders.

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Notes

1 While it is clear that most pilot implementations of synchromodality have taken place in the Benelux region, other countries, such as Germany or France, have equally manifested strong interest in the topic. There have also been initiatives taking place outside of Europe, such as in Turkey [please see ALICE Corridors, Hubs and Synchromodality WG2 (2014) for a review of synchromodality-related initiatives in the first half of the 2010s]. Likewise, a synchromodal network has been put forth as a strategic target of the high-profile one-belt-one-road infrastructure development project led by the Chinese Government (see for example, Zahid et al., 2022). The fact remains that, even though the concept is being embraced globally, practical examples of finalized synchromodality projects are still scant, which constitutes further testament to the implementation challenges that motivate our research.

Appendix

Interview protocol

- What, from your perspective, is synchromodality?
- Can you give me examples from practice?
- How does it benefit planning ability in the supply chain?
- What is missing for synchromodal initiatives to be more successful?
- How would you enable the creation of collaboration platforms?

- What do you think is necessary for people to share the requisite data?
- How can you overcome fears related to data security?
- What do you think are the main difficulties when pursuing synchromodality projects?
- What entities are more difficult to persuade and why?
- Which new problems do you expect if we would fully operating in a synchromodal world?
- What do you think the role of formal contracts is or can be?
- What do you think about the number of parties that need to be involved?
- Are there aspects in which you think governments can do more?

In Table A1, we reveal the open concepts generated from the raw data per each interview conducted. For readability, we break the information into two separate tables.

Table A1 Concepts derived per interview

Participant 1	*Participant 2*	*Participant 3*	*Participant 4*
Fragmented market	Lock-ins	No flexibility in terminal choice and container-free mode	Data governance
Differences between countries	Capacity booking	Larger quantities are needed	Entities need to be convinced
Finding consensus	Company policies	Client and LSP do not have an insight into the SC dimensions	Optimising system and individual performances
Aggregated demand	High capacity is needed	Time inefficient port causing harbour to be unreliable	Insecurity of working with dynamic systems
Flexible contract	Interoperability of data systems with SC	Priority rules	Modal choice connected to SCM
Capacity issues from one mode	Reliability of data	Congestion	Inventory management
Type of product	Profitable for all parties involved	Everybody needs to gain something	Many entities involved
Internal integration	Visibility of data	Ports signed that max 30% can be done with trucks	Availability of contextual information
Holistic SC view	Availability of data	Collaboration	Interoperability
Outsourcing	Convince parties	Trust	Research with simulation models

Table A1 Concepts derived per interview (continued)

Participant 5	*Participant 6*	*Participant 7*	*Participant 8*
Less parties involved in a chain	Flexible contract	Company specifics	High inventory levels
	Type of product	Bring barge outside of the harbour with, e.g., an internal train	Vertical integration
	Dynamic planning	The LSP should combine the wishes/ KPIs of the terminal and the shipper	Use of new technology
	The parties involved should be flexible		Forecasting model
			Type of product
			Platform for communication exchange
			Transparency
Congestion on road and rail	Data availability across the chain	Rushed delivery	Planning's change
Scalability	Information streams are separate	Reliability of transportation network	You need a large volume
Data protection	Data protection	Segmented organisations in the chain	Data quality
Fragmentation of the chain	Incompatible IT processes in the chain	Complexity and unclear advantages	Many different SCs
Parties often do not look further than their own environment	Misunderstandings because of differently interpreted data among parties	Short distance	Poor infrastructure of information provision and business processes
Increasing awareness	Transportation is unpredictable	Trust	Transparency by using clouds
Bundling	Responsible party when something goes wrong	Size of the company	Measure products in the same units
Focus on a specific part of the SC	Too many parties in the chain	Internal collaboration	Bundling shipments
Trust	Pressure is shifted instead of released	Type of industry	Communication between parties
Shortening inventory time	Fixed-time delivery trend in warehouses	Extra party for coordination	Create a footprint to know which modalities are possible

Table A1 Concepts derived per interview (continued)

Participant 5	*Participant 6*	*Participant 7*	*Participant 8*
Integrators	Collaboration	Outhouse inventory	Algorithms on data availability
Infrastructural innovations	Flexibility		
Coordination and communication	Trust		
Neutral platform			
Data visibility			