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Introducing synchromodality: One missing link between transportation and supply chain management

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Abstract

This study develops and tests the synchromodality construct, a novel supply chain concept that integrates the flexible use of different transport modes based on real-time information. At a time when global supply chains are complex and subject to uncertainty, synchromodality has emerged at the forefront of research and practice as a tool to ensure efficient delivery performance and thus supply chain competitiveness. Despite synchromodality is attracting the attention of leading companies and policy makers, only scholars within the transport research community have engaged with the topic so far. We believe a supply chain management perspective is missing, but essential, to develop the full potential of synchromodality. Our study shows that synchromodality capabilities encapsulate four key elements: *visibility*, *integration*, *multi-modal transport*, and *flexibility*. Thanks to a three-stage research approach exploiting multiple methods, this study conceptualizes, develops, and validates the first synchromodality measurement model, which reflects the multidimensional nature of the concept. We hope to set the stage for a number of potential future research opportunities that can explore synchromodality implementation and outcomes.

KEYWORDS

distribution and logistics, logistics differentiation, scale development, survey methods, synchromodality, transportation

INTRODUCTION

Supply chain researchers and professionals did not need the pandemic to understand that our logistics and transportation networks have flaws. We pretend that supply chains are visible or transparent, but they are not. We preach about the digital revolution made of ubiquitous IoT sensors and technology-enabled access to data, but, in reality, supply chains are still mostly analogical and supply chain data are usually proprietary, not democratically shared. We advocate for supply chain integration, even though few companies would pass a stress test (Simchi-Levi & Simchi-Levi, 2020). We even envision a Physical Internet providing a shared transportation infrastructure (Matusiewicz, 2020), while Amazon continues its solitary expansion (BBC, 2021). As academics, we often argue about the need for cross-disciplinarity, but we largely tend to work in silos, where supply chain management, logistics, and transportation are conceptualized as separate fields.

It is time that we create the conditions for a seamless interaction between multiple transportation networks and their digital replica. It is time we rethink our supply chains and ensure that resilience resonates in the physical connections among organizations, warehouses, highways, ports, waterways, and the sky. Real-time, integrated decisions can make the difference between empty shelves in supermarkets and emergency food deliveries between the possibility of protecting healthcare workers and the need to enforce a lockdown. The current picture of the logistics infrastructure is not promising. Cities are suffocated with parcels: 3.8 billion were shipped in the UK in 2019 according to Pitney Bowes (2021). The number of logistics service providers (LSPs) is huge, mostly consisting of small to medium enterprises, all with their own information systems, all managing their own data, each with a different standard. As a result, it is difficult to optimize our transportation systems. We lack the basic tools, such as real-time data, integrated systems, and flexible decision making.

This study intends to contribute by introducing the construct of synchromodality, defined as a *multimodal transportation planning system, wherein the different agents involved in the supply chain work in an integrated and flexible way that enables them to dynamically adapt the transport mode they use based on real-time information from stakeholders, customers, and the logistic network*. Synchromodality is a new concept in transportation research that has also been developed through a few practical projects. Because we believe that a holistic supply chain perspective is required to exploit the potential of synchromodality, we focused our effort in the development of the synchromodality scale, in the belief that future research can provide a better understanding of its antecedents and outcomes.

The upward predictions of freight volume demand and fuel price fluctuations have put significant pressure on shippers, transportation companies, and policymakers to search for new strategies and practices that would allow supply chains to adapt to demand without compromising efficiency, integrate different transport modes, and alleviate the increasingly overburdened road infrastructure (McKinnon, 2015). In light of digitalization, companies are paying special attention to technologies and solutions that—through data—allow greater visibility and flexibility in their logistics networks (Choi et al., 2018; Saenz et al., 2019). At the same time, fast-growing competition in the transportation sector is pressuring LSPs to address these needs and find ways to differentiate themselves (Bontekoning & Priemus, 2010; SteadieSeifi et al., 2014).

Synchromodality addresses a central aspect in the transportation research debate, the identification of the most efficient and effective combination of transport modes. Dong et al. (2018) report on approximately fifty years of research on transport mode choices and observe that, despite the strenuous efforts of public policymakers, most companies still rely on road transport, while modal shifts to rail and water have remained modest at best. Different logistics paradigms have been introduced, including multi-modality, inter-modality, combined modality, and co-modality[1] (Reis, 2015), all implying the use of modal shifts. Initially focused on improving the efficiency of the transport system, these paradigms have come to incorporate multiple objectives to optimize the trade-off between efficiency and service level, with recent attention on sustainability (Giusti, Manerba, et al., 2019; Kapetanis et al., 2016; Perboli et al., 2017). As a matter of fact, freight modal splits are often economically and/or environmentally suboptimal (Dong et al., 2018) due to a mix of factors, including failures to internalize environmental costs, differences in regulatory and pricing regimes of alternative transport modes, greater complexity and uncertainty inherent in multi-modal transport, and deficiencies in firms' modal choices. As an example, despite the European Union investing billions to support railway projects, the share of rail transport has been declining since 2011 (European Court of Auditors, 2016).

Several scholars observe that one of the main reasons the modal split is so difficult to change is that the key stakeholders (i.e., companies, shippers, and LSPs) have not adequately taken into consideration the overall supply chain impact of multimodal transport (Ambra et al., 2019; Dong et al., 2018; Giusti, Manerba, et al., 2019). Logistics managers usually perceive trains and barges as less flexible, less frequent and slower, despite being cheaper and more sustainable. Therefore, they prefer straight truck routes to avoid the increase of in-transit inventories and handle demand fluctuations. This situation appears more and more as a missing opportunity, and multiple parties argue that "innovations are urgently needed to promote and revive modal shift as a freight policy option" (Dong et al., 2018, p. 43).

Synchromodality emerged precisely to offer a holistic supply chain view of the modal shift process and to become the new leading transportation paradigm able to deal with current supply chain trends (Ambra et al., 2019). On the one hand, synchromodality provides a framework within which shippers can manage their supply chains more flexibly to increase the potential for shifting modes. On the other hand, it introduces the idea that freight modal choices are one important component of the supply chain strategy and need to be jointly optimized with other supply chain activities. Synchromodality incorporates fundamental new features in comparison with other existing paradigms (e.g. intermodality) and—accordingly—is expected to improve flexibility in supply chains, cooperation among stakeholders, and resource utilization. In this sense, synchromodality crosses the boundaries of transport research and truly requires a supply chain perspective (Giusti, Manerba, et al., 2019).

Recent evidence from funded research projects and business cases (e.g. Port of Rotterdam, the Dutch Institute for Advanced Logistics, or the EU research project SynchroNET), and the mounting debate in transport research (Dong et al., 2018; Zhang & Pel, 2016), suggests that synchromodality can resolve the challenges related to modal shifts and guide the management of logistics networks through the next stage of development. Indeed, synchromodality has emerged as an innovative concept toward a more efficient mode balance and optimized freight service network (ALICE, 2015; Dong et al., 2018), combining multiple capabilities and related practices that previous approaches to transport modes did not encompass. The novelty of synchromodality lies both in the mix of elements that are required to manage the logistic network (Li et al., 2017) and in the presence of new elements such as the need for real-time data on the network status, the integration of demand information, and the flexible adaptation of transport modes (Brümmerstedt et al., 2017).

However, a systematic and validated conceptualization of synchromodality is missing from the literature, as scholars have thus far proposed a quite heterogeneous mix of definitions. The aim of this study was to investigate the meaning and content of synchromodality and to provide an empirical validation of its definition. The key theoretical and practical relevance of this study are the conceptual definition of synchromodality and its scale validation. Accounting for all the potential benefits of synchromodality is outside the scope of this study, but it is worth noting that early evidence shows that synchromodality can promote greater efficiency and effectiveness in terms of reduced transportation costs and increased delivery performance (Giusti, Manerba, et al., 2019; Kapetanis et al., 2016), and improve supply chain competitiveness overall (Dong et al., 2018). Considerable interest around synchromodality also depends upon the promise of increased supply chain resilience (Lee & Song, 2017) and sustainability (ALICE, 2015; Giusti, Manerba, et al., 2019; Kapetanis et al., 2016)[2].

As previous studies argue (Reis, 2015), synchromodality is not simply a restyling of previous approaches (like intermodality); it is emerging as a novel set of practices that deserves further attention. However, synchromodality's very novelty engenders a lack of understanding of its content, antecedents, and performance outcomes (Dong et al., 2018; Kurapati et al., 2017). To the best of our knowledge, no study has presented a unified, holistic definition of synchromodality, or a clear view of the capabilities that supply chains need to develop in order to embrace it. To fill this gap, we designed a three-stage research process that uses multiple methods to provide a theoretically sound and empirically grounded definition and measure of synchromodality. In this way, we hope to contribute to the existing literature by establishing the foundations of a rapidly growing concept.

In the next section, we introduce the meaning of synchromodality and explain its novelty compared to extant research and practice. Next, we summarize our research design and methods (please refer to the online supplement for all the details), resulting in the validation of the synchromodality scale. We conclude this paper with some ending remarks, managerial implications, study limitations, and avenues for future research.

DEFINING SYNCHROMODALITY

Synchromodality is the latest concept in research and practice about transport modes (Reis, 2015). The definition provided in the introduction is the result of our first stage of research (see Figure 1). Synchromodality has the potential of reducing costs, CO_2 emissions, and delivery times, and avoiding or minimizing disruptions without jeopardizing service quality (Giusti, Manerba, et al., 2019; Tavasszy et al., 2015). As such, it has received increased attention from academia, research centers like the Dutch Institute for Advanced Logistics (DINALOG, 2013; Logistiek, 2011), governmental institutions such as the Dutch Government and the European Union (EU) (ALICE, 2015; Synchro-NET, 2016), and a variety of companies including manufacturers, retailers, and LSPs (Logistiek, 2011; Samskip, 2018; Topsector Logistiek, 2018).

Despite primarily being studied within the realm of transportation research (Dong et al.,l., 2018; Kapetanis et al., 2016; Kurapati et al., 2017; Li et al.,l., 2017; van Riessen et al.,l., 2015), synchromodality is attracting the attention of a large variety of stakeholders as it encompasses several desiderata of modern supply chains. These stakeholders include, first of all, LSPs, which have been primary actors in synchromodality projects (Dong et al., 2018), and shippers, who make modal shift decisions in a different way than LSPs because they need to consider trade-offs and synergies across the supply chain as a whole (Eng-Larsson & Kohn, 2012). Considering the need to synchronize transportation with other supply chain activities, additional supply chain actors are part of the synchromodality scope, including suppliers, manufacturers, and customers as well as transportation carriers and terminals (Giusti, Manerba, et al., 2019). Finally, public administration also has a stake because synchromodality directly affects public policy objectives: For instance, synchromodality holds the promise of optimally exploiting the transportation infrastructure across countries, making it more sustainable without compromising efficiency and resilience (Giusti, Iorfida, et al., 2019).

Table 1 helps clarify the differences between synchromodality and existing paradigms of modal shift. First, synchromodality requires—for the first time—the integration of demand data in the choice of transport modes: At any given point in time, the transport mode choice takes into consideration the aggregate demand of transport service. Second, synchromodality also requires the availability of real-time information about the transport system, including, availability, transit times, congestion, delays, reliability, pricing, and so on. This inevitably connects to the latest advancements in terms of supply chain information systems: Only through the creation of standard dashboards, integrating supply chain data from multiple sources (e.g. firms, public datasets, Internet of Things (IoT) devices) is it possible to optimize transport choices. Third, "synchromodality adds the concept of adaptive mode choice" (Reis, 2015; p. 176). This means introducing real-time flexibility in terms of transport modes as a function of the transport system state and the related demand. Unlike current paradigms such as inter-modality, which use pre-defined, fixed combinations of transport modes, synchromodality allows LSPs to maintain the option of multiple modal pathways in the same corridor. It also permits LSPs to autonomously, dynamically, choose the optimal mix. Fourth, in order to translate all available data into efficient and effective decisions, firms adopting synchromodality need to move beyond information sharing. They have to design specific organizational structures and proactively coordinate their planned supply chain against actual conditions in an integrated way. Therefore, synchromodality not only implies the synchronization of different transportation modes; it also requires the synchronization of transportation with other supply chain activities such as inventory management and production scheduling (Dong et al., 2018).

For these reasons, we believe that synchromodality clearly calls for a supply chain management (SCM) perspective, as effective supply chains must embrace logistics (Ellram & Cooper, 2014; Gligor & Holcomb, 2012). A large body of transportation research focuses on the development and application of transport optimization models, adopting an operation research perspective. Distinctly, synchromodality is not only about routing algorithms and truckload saturation, it is also about managing the transportation chain in an integrated and coordinated fashion across all agents, with the aim of serving the final customer. These concepts of final demand and related transport demand, real-time information, integration, and adaptive mode choice have been neglected so far by scholars focused on other transport modes (such as multi-modal, inter-modal, or co-modal transport). This is probably due to the fact that synchromodality transcends the boundaries of transport science and actually embeds a management perspective. In this sense, we think that synchromodality brings SCM and Logistics closer.

RESEARCH DESIGN, METHODS, AND SCALE VALIDATION

In the development and validation of a new construct, researchers face two main challenges: appropriateness of the construct domain, and the selection of measurement items that are reliable and valid (Little et al., 1999; Menor & Roth, 2007). To ensure that items used in our construct operationalization truly measure what they are supposed to measure (Churchill, 1979), we followed the methodology shown in Figure 1 and described in detail in the online supplement, which is adapted from Menor and Roth (2007) and Chan et al. (2016).

Synchromodality and its sub-dimensions

In the first stage of the study, a systematic review of the literature following the steps detailed by Durach et al. (2017) helped us to define the meaning of synchromodality and its content. We found quite a variety of synchromodality definitions in the literature (see online supplement), yet many of those definitions shared some common characteristics. First, the transport mode choice is based on customer requirements such as shipping time, cost, or shipping conditions (whether refrigerated transportation is required, for example) as well as on external information, such as the network status and other operation-related circumstances (SteadieSeifi et al., 2014), which posits visibility as one of the synchromodality dimensions. Visibility is achieved through gathering data from multiple stakeholders. This information could include, but would not be limited to, demand, delays, transit times, pricing, network congestion, and so forth (Behdani et al., 2016; Reis, 2015). The large amount of real-time data in the deployment of synchromodality implies that different agents in the supply chain have to work in an integrated way (Behdani et al., 2016; van Riessen et al., 2015), which introduces integration as another distinctive feature of synchromodality. Lastly, synchromodality embraces all of the intermodal and co-modal transportation characteristics (Reis, 2015) as it includes the use of two or more transport modes in an integrated, efficient, and sustainable way. However, synchromodality goes one step further, in that it introduces the ability to adapt the network to the dynamically changing environments in which global companies operate. The movement of goods is no longer dictated by pre-fixed or pre-arranged schedules and routes, but by flexible, mode-free planning of operations (Zhang & Pel, 2016). Shippers dictate when and where the goods should be delivered, and the transportation chain has the flexibility to operate as needed to meet customer requirements (Lin et al., 2016; Tavasszy et al., 2015). Therefore, the operationalization of the transport chain is no longer fixed and contractually predefined, but dynamically adapted and periodically revisited according to information received in real time (Reis, 2015).

Our systematic literature review allowed us to identify four main dimensions of synchromodality: *visibility*, *integration*, *multi-model transport*, and *flexibility*, which we have incorporated into the definition of synchromodality provided in the introduction.

Definition and pre-test of the scales

In the second stage, we iteratively employed two main methods: literature review and qualitative interviews and focus groups. The systematic literature review was the starting point to define scale items for each synchromodality sub-construct, ensuring that each construct's operationalization truly reflects what it is supposed to measure, and providing conceptual clarity around each dimension (Churchill, 1979).

TABLE 1 Comparison between synchromodality and other modal shift paradigms

Transportation Concept	Definition	Two or more transport modes	Integration	Sustainability	Efficiency	Additional unique features of Synchromodality
Multimodality	*Transportation of goods by a sequence of at least two different transport modes* (UNECE, 2009)	√				• Match of demand and supply variables • Real-time data on the transport system • Real-time adaptation of transport modes • Synchronization of transport modes with other supply chain decisions
Intermodality	*Transportation of goods integrating at least two modes where the load is transported door to door using the same load unit* (Crainic & Kim, 2007)	√	√			
Combined	*Sustainable form of the intermodal transportation* (European Conference of Ministers of Transport, 1998)	√	√	√		
Co-modality	*Efficient transportation through optimal and sustainable use of the resources* (European Commission, 2006)	√	√	√	√	
Synchromodality	*Multimodal transportation planning in which different agents in the transport chain work in an integrated way to flexibly adapt the transport mode based on shared real-time information from stakeholders, customer needs, and network constraints*	√	√	√	√	

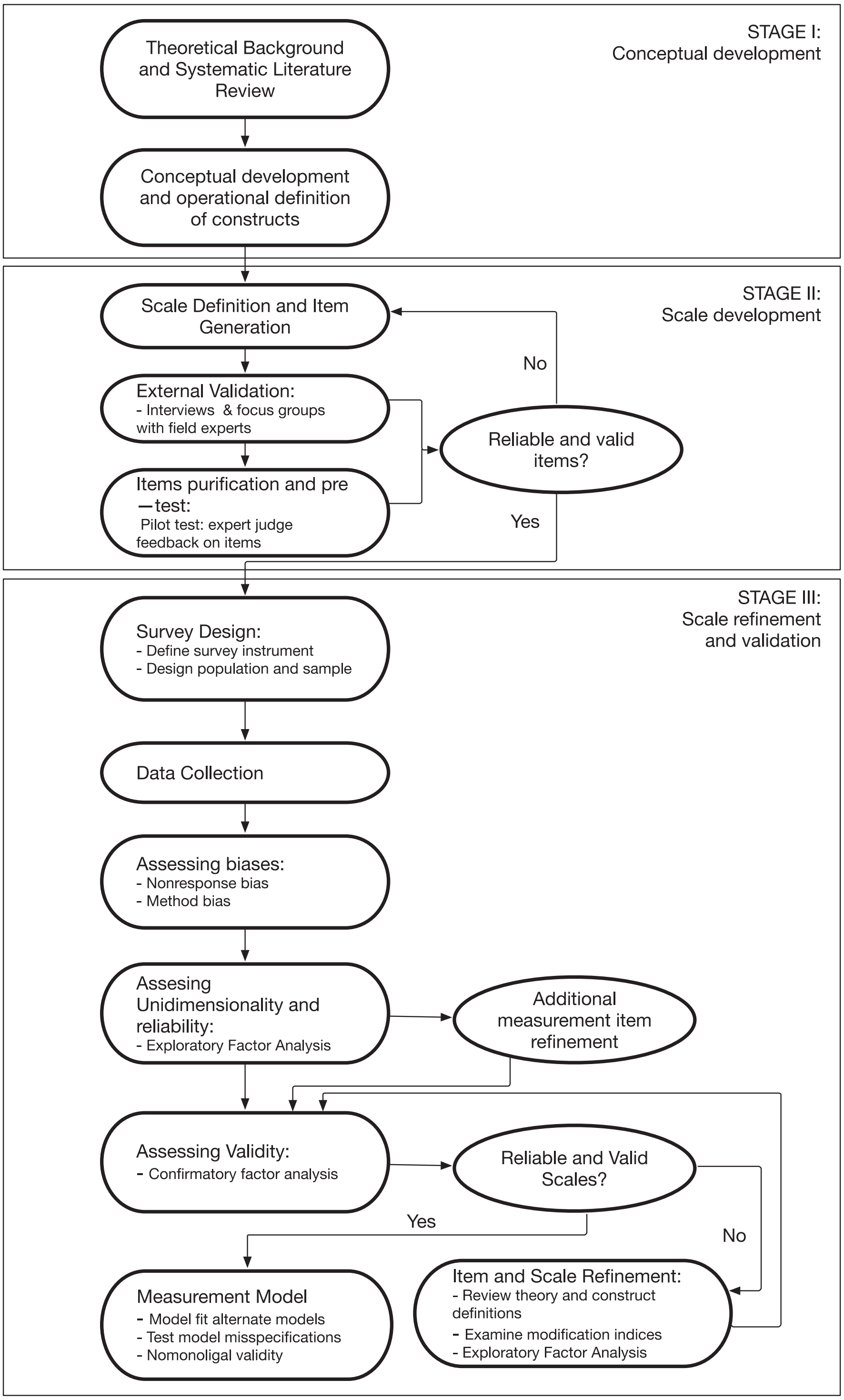

FIGURE 1 Methodology for a new construct development model. *Source:* Adapted from Menor and Roth (2007) and Chan et al. (2016)

Visibility

The literature review suggests that synchromodal environments rely on the use of real-time information from multiple sources in order to optimize and dynamically review transport operationalization (Kamalahmadi & Parst, 2016; Kurapati et al., 2017; Li et al., 2017). Information flows might include port data, vessel data, terminal data, logistics platforms, customer preference, contracts, transport availability, and network status (van Riessen et al., 2015). In addition, synchromodality requires the timely and complete availability of this information to all supply chain members to inform their decisions (Francis, 2008; Scholten & Schilder, 2015). Specialized LSPs and software companies, such as PTV Group or IXOLUTION, have developed tools deployed in transport modes that send a real-time ping from their location every five minutes, providing accurate estimations of ETA and alerts about potential disruptions (Automotive, 2015).

Integration

Van Riessen et al. (2015) and Behdani et al. (2016) emphasize that synchromodality requires an integrated operated network, meaning that the different actors in the synchromodal supply chain need to share real time information and coordinate on the choice of transport modes as well as on transport execution. By integrating all available real-time information from the network and the different stakeholders, the logistics orchestrator can find the optimal sequence of carriers using tools like the ones developed by the synchro-NET initiative or companies like IDS (Automotive, 2015; synchro-NET, 2016).

Multi-modal transport

From an operational standpoint, synchromodality also encapsulates mode and routing choices (Verweij, 2011). As in intermodality, a shipper uses different transport modes in one integrated shipment (Kapetanis et al., 2016; Kurapati et al., 2017; Zhang & Pel, 2016), and each shipment is completed in a mode-free way (Li et al., 2017; Reis, 2015). However, using synchromodality, the transport mode mix is based on real-time information from multiple stakeholders (Pfoser et al., 2016). Several companies like DHL, Cosco, Kuehne+Nagel, or Dell have developed tools to explore synchromodality's opportunities by optimizing the utilization of multi-modal transportation in different European corridors (Short Sea Shipping, 2020).

Flexibility

Another unique feature of synchromodality is the cost-neutral adaptation of transport modes based on real-time information (Alons-Hoen et al., 2019; Buiel et al., 2015; Dong et al., 2018; Samskip, 2018), which ensures greater flexibility throughout the entire supply chain. The ability to respond and adapt to unexpected circumstances becomes crucial in uncertain and competitive markets (Moon et al., 2012; Streedevi & Saranga, 2017). In the case of the logistics company H. Essers, this flexibility is materialized when shippers make mode-free or a-modal transport requests to their LSPs, leaving them the chance to combine shipments and use different transport modes such as rail, inland waterway, and roadway, based on their customers' requirements (Ambra et al., 2019; Van Dooren, 2018).

We complemented our conceptual effort with in-depth interviews and focus group discussions with supply chain and logistics experts involved in synchromodal projects. The findings of these discussions were matched with the dimensions emerging from the systematic literature review to ensure the content validity of our measurement instrument and to establish a construct domain that could be generalized with practices that were relevant. Based on these efforts, we proposed twenty measurement items that captured the four different dimensions of synchromodality. Together with the experts, we went through six iterations of our measurement instrument prior to reaching a satisfactory list of items from both a theoretical and managerial perspective.

The operationalization of the synchromodality dimensions was primarily based on existing scales from SCM literature, which needed to be adapted to the synchromodal context (please refer to the Supporting Information). Visibility, integration, and flexibility are adapted, respectively, from Williams et al. (2013); Danese et al. (2013); Flynn et al. (2010); Swafford et al. (2006); and Williams et al. (2013). Since multi-modal transport is a newly developed construct, we created items to capture the nature of the concept based on the findings of our theoretical and qualitative research efforts.

After the initial operationalization, we proceeded to purify, refine, and pre-test the different measurement items using a pilot test (Lawshe, 1975). To evaluate the items that should remain in our operationalization, we analyzed the items' substantive validity using two measures: proportion of substantive validity (p_{sa}) and substantive validity coefficient (C_{SV}) (Anderson & Gerbing, 1991). Items with $p_{sa} > 0.7$ and $c_{sv} > 0.5$ were retained. As a result, the original twenty items were reduced to eighteen. The wording of four items was also slightly changed. A final validation with experts confirmed the set of eighteen items that would be tested in the next stage.

Synchromodality scale validation

In the third stage, we administered a large-scale survey to European-based transportation companies and LSPs that are developing and implementing synchromodal projects. The online questionnaire included the 18 remaining items from the previous stage and some demographic questions in addition to the scale for logistics differentiation (adapted from Fugate et al., 2010). This would be used subsequently to test the nomological validity of the synchromodality construct.

We targeted LSPs based in Europe because they are primary actors in the implementation of synchromodality. Existing synchromodal applications like the Port of Rotterdam show that European agents of the transportation chain have been capable of successfully deploying collaborative projects that encapsulate the key premises of synchromodality. In order to identify a sufficiently broad sample and to distinguish the most reliable key informants, we worked closely with *ConsumerCo* – a multinational manufacturing company, a global leader in its market, and a pioneer of synchromodality in Europe. We contacted 210 companies through email and followed up with regular reminders. We received a total of one 110 usable responses. Respondents represent a good variety of firms in term of size, specialization, and geographical presence (see the Supporting Information), which helped to avoid possible biases (Williams et al., 2013).

Being aware of the potential problems caused by single respondents, we carefully designed Stage III to help minimize common method bias (CMB) in several ways. Given that single respondent biases can be compensated using a multi-methodology approach (Montabon et al., 2018), we also incorporated interviews with field experts in Stage II. In addition, we adopted a mix of common a priori and post-hoc remedies (Flynn et al., 2018; Podsakoff et al., 2003): (1) identifying respondents with knowledge in firm transportation operations and planning; (2) ensuring respondents' confidentiality; (3) using previously operationalized and tested items to avoid ambiguity; (4) posing objective questions to reduce evaluation apprehension; and (5) avoiding questions relating to more than one subject. The post-hoc approach for mitigating CMB involved the application of Harman's single factor test (Harman, 1976; Podsakoff et al., 2003) and a marker variable (Lindell & Whitney, 2001; Williams et al., 2010).

Finally, we tested for non-response bias by looking for statistically significant differences between early, late, and non-respondents (Armstrong & Overton, 1977; Clottey & Benton, 2013). The test did not find any significant differences between the early and late groups, or between the respondents and non-respondents, in terms of employees or revenues. This suggests that non-response bias does not pose a problem.

The final stage of our research was aimed at obtaining the synchromodality measurement model. We first

TABLE 2 CFA measurement statistics and loadings

Construct/Item	Mean (*SD*)	Std loadings
VISIBILITY [adapted from Williams et al. (2013)] AVE = 0.63; KMO = 0.78; Cronbach's α = 0.86; CR = 0.87		
V1—Our major customers share timely and complete demand forecast information with us	4.53 (1.55)	0.65
V2—Our major customers provide us with timely and complete information regarding loading readiness status in the distribution network (e.g., distribution centers, transportation)	4.61 (1.43)	0.71
V3—We gather timely and complete information from various sources to understand the overall transport network status (traffic update, customs delays…)	4.98 (1.29)	0.79
V5—Our major partners/subcontractors provide us with timely and complete information of changes in operations due to incidents or disruptions	5.34 (1.17)	0.89
INTEGRATION [adapted from Danese et al. (2013)] AVE = 0.68; KMO = 0.76; Cronbach's α = 0.89; CR = 0.89		
I1—We actively plan day to day supply chain activities to meet customers' needs	6.26 (0.90)	0.66
I2—We consider our customers' forecast in our logistics activity planning	6.25 (0.91)	0.74
I3—We believe that cooperating with our customers is beneficial	6.14 (1.01)	0.83
I4—We emphasize openness of communications in collaborating with customers	6.23 (0.92)	0.94
MULTI-MODAL TRANSPORT [adapted from Reis (2015), Tavasszy et al. (2015) and Pfoser et al. (2016)] AVE = 0.51; KMO = 0.76; Cronbach's α = 0.80; CR = 0.80		
MT1—We use different transport modes in one integrated shipment	4.52 (2.25)	0.72
MT2—Our customers give us the flexibility to decide which transport mode to use	4.25 (1.98)	0.54
MT4—In order to optimize resources, we continuously revise the transport modes we assign to each service	4.74 (1.96)	0.84
MT5—For each load unit, we work with our customers to select the best transport option	4.59 (2.13)	0.72
FLEXIBILITY [adapted from Swafford et al. (2006) and Williams et al. (2013)] AVE = 0.56; KMO = 0.7; Cronbach's α = 0.79; CR = 0.79		
SF1—Our services/equipment/operations are designed to be easily modified	5.02 (1.28)	0.77
SF2—We can change quickly from one transport service to another	5.23 (1.23)	0.69
SF3—We can easily adjust to different distribution delivery requirements to meet customers' demands	4.97 (1.27)	0.78

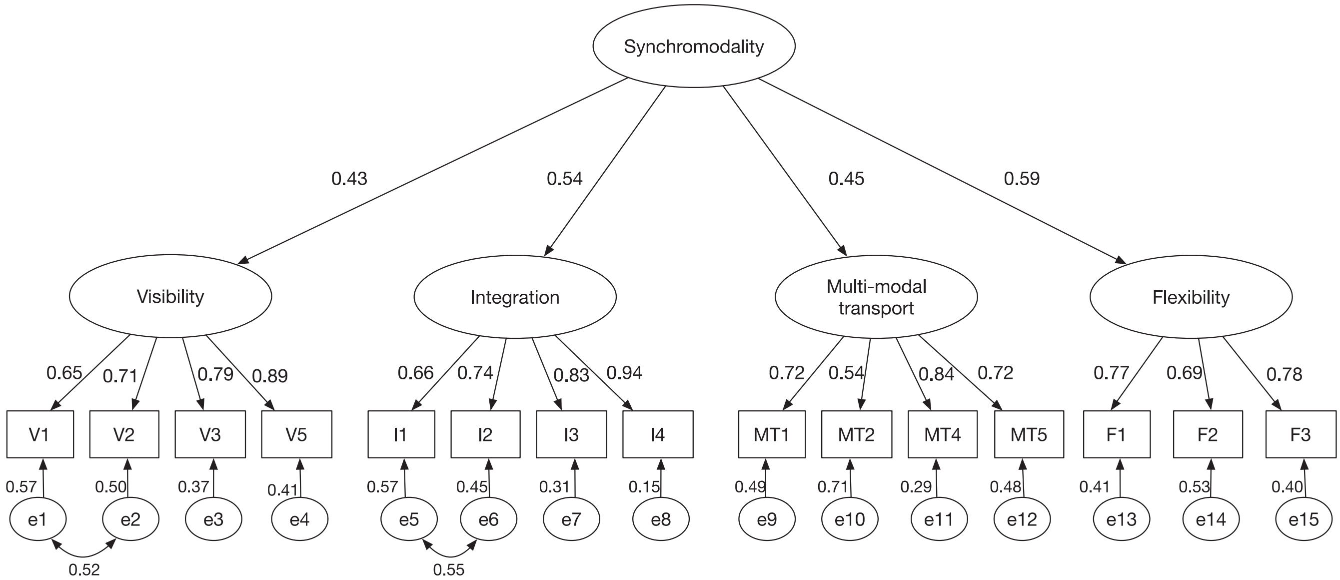

FIGURE 2 Four-factor second-order model of synchromodality with correlated errors (Model 5). Fit indexes: CFI = 0.969, TLI = 0.961, RNI = 0.969, SRMR = 0.072, RMSEA = 0.052

evaluated construct unidimensionality and reliability through exploratory factor analysis and then assessed both convergent and discriminant validity through confirmatory factory analysis (CFA) (O'Leary-Kelley & Vokurka, 1998). Details about these and additional tests are reported in the Supporting Information. For parsimony, we show only the final CFA results in Table 2, which confirms construct validity.

Next, we tested several competitive models (see the Supporting Information): (1) a one-factor, first-order model, or a model in which all fifteen items are loaded on a first-order factor; (2) an uncorrelated four-factor, first-order model in which the items are loaded on four orthogonal first-order factors; (3) a correlated four-factor, first-order model in which the items are loaded on four correlated first-order factors; (4) a four-factor, second-order model in which the four factors are loaded on a second-order factor; and finally (5) a four-factor, second-order model in which correlated errors are included to correct model misspecifications. We disregarded Models 1 and 2, as Models 3 and 4 were clearly superior, and most of the fit indices were far from the cutoff values suggested in Hair et al. (2009). Models 3 and 4 represented a considerable improvement in the fit indices, although they were not yet acceptable. This posed the questions of which model should be further analyzed and whether our measurement model was, in fact, a second-order model. To answer these questions, we analyzed both the Consistent Akaike Information Criterion (CAIC) and the target coefficient (T) as suggested by Moon et al. (2012). Based on this analysis, we confirmed the appropriateness of the second-order model.

Once confirmed, we proceeded to analyze misspecifications and expected parameter changes (EPC) of the second-order model (Saris et al., 2009). The resulting model, as shown in Figure 2, has $\chi^2 = 109.008$ and normed $\chi^2 = 1.297$. The goodness of fit indices of CFI (0.969), TLI (0.961), RNI (0.969), SRMR (0.072), and RMSEA (0.052) meet the Hair et al. (2009) criteria. We analyzed this model for MI/EPC, and no further change was suggested. The analysis of the path loadings between synchromodality and the underlying first-order factors are all significant.

These results confirm that synchromodality can be conceptualized as a multidimensional construct consisting of visibility, integration, multi-modal transport, and flexibility, and can be modeled as a four-factor, second-order construct.

DISCUSSION

Synchromodality is a novel concept that has received increasing attention over the past years. Practitioners, policymakers, and researchers not only envision synchromodality as the next generation of multimodal transportation but as a step forward in transportation efficiency, resilience, sustainability, and supply chain competitiveness overall. By developing and validating the synchromodality construct, our study furthers the understanding of synchromodality from a theoretical perspective, clarifies its components, and sets the groundwork for further research. Furthermore, our empirical research enumerates the capabilities that supply chains need to develop in order to fully embrace synchromodal operations. In the future, supply chain managers will, hopefully, be able to explore synchromodality's potential in terms of improved supply chain performance.

Although there is growing interest in synchromodality, the majority of current research is conceptual in nature (Giusti, Manerba, et al., 2019; Pfoser et al., 2016), with anecdotal evidence derived from specific business cases (Lucassen & Dogger, 2012). Our empirical investigation advances the theoretical and practical development of synchromodality by conceptualizing and validating the measures through a three-stage process (see Figure 1), and by adopting multiple research methods. In line with recent studies (e.g. Dong et al., 2018), and the experience derived from pioneering projects (e.g. ALICE, 2015), we conclude that synchromodality is a bundle of different capabilities corresponding to specific practices.

Our findings suggest that synchromodal *visibility* is reflected in the sharing of demand forecasts and distribution network status by customers, of transport network status through a variety of sources, and of timely updates by logistics partners and sub-contractors. To leading companies like *ConsumerCo*, this information is crucial to ensure an excellent service level. To this end, LSPs tightly integrate with their customers by jointly discussing forecasts and logistics planning and by establishing a collaborative and open climate (i.e., synchromodal *integration*). Furthermore, two interrelated concepts stand at the heart of synchromodality. First, in terms of transport mode, LSPs translate customer requirements into operational choices on the basis of available information. They must be able to integrate into one shipment the mix of transport modes that best satisfy customer demands. Here, the aforementioned concepts of visibility and integration support the selection and real-time revision of transport mode choices based on customer needs and the status of the logistics network. This leads to the implementation of a *multi-modal transport system*. Second, LSPs need to implement a *flexible* synchromodal system, meaning that they should easily be able to switch between transport modes on the basis of changes in transport network status or customer requirements.

We believe that this understanding of synchromodality can have important theoretical and managerial implications that are not confined to the domain of transportation research; they also touch upon key premises of SCM research, as discussed in the next section.

CONTRIBUTIONS, LIMITATIONS, AND FUTURE RESEARCH DIRECTIONS

While recent studies conceptually discuss synchromodality and provide preliminary qualitative evidence, this study is the first attempt to empirically validate a measure of synchromodality based on a systematic definition and conceptualization. Drawing on an ad-hoc research process based on current scale development literature, we unravel the complex nature of synchromodality and show it to be composed of fundamental capabilities such as visibility, integration, multi-model transport, and flexibility. Although prior studies have separately highlighted different aspects of synchromodality, to the best of our knowledge no valid measures of synchromodality have previously been put forward. As such, this study lays an important foundation to further investigate synchromodality, to compare results across empirical studies in different contexts, and to accumulate theories of synchromodality implementation that are instrumental to future research and practice.

Testing the synchromodality-performance link is outside the scope of this study, but recent studies suggest that synchromodality holds the promise of making important contributions to the management and performance of global supply chains. After the first appearance of the concept almost a decade ago, scholars have recently dedicated some effort to better understand synchromodality and its potential outcomes (Giusti, Iorfida, et al., 2019; Reis, 2015). Businesses have also started to practice synchromodality as part of multi-stakeholder coordinated projects, both privately or publicly funded (Automotive, 2015; Short Sea Shipping, 2020; Van Dooren, 2018). Dong et al. (2018, p. 45) observe that "The majority of the studies [about synchromodality] are exploratory and qualitative in nature, which is not surprising for an emerging concept." We believe that our definition and validation of synchromodality will serve fellow researchers in the development of quantitative and theory-testing studies. Several types of research are possible, such as testing antecedents and outcomes of synchromodality, its barriers and enablers, and even the potential interrelations of its subdimensions. Another interesting research avenue is an empirical comparison with other logistics concepts such as intermodality or co-modality, to understand whether synchromodality can exist alongside other concepts or eclipse them. The nomological validity test we performed already suggests a positive association between synchromodality and logistic differentiation in line with previous studies (Zhang & Pel, 2016), and the vision of notable professional think-tanks (ALICE, 2015). This will, hopefully, lead the way to a more rigorous test of supply chain performance effects.

In this regard, the vast majority of synchromodality research is currently conducted in the logistics and transportation domain. However, the synchromodality definition and dimensions identified herein clearly establish a connection with SCM literature. Recent studies acknowledge that the scope of synchromodality should not only include the planning and execution of the transportation chain, but should expand to the coordination of freight transport with other supply chain activities. Given that an integrated view of synchromodality can optimize total supply chain performance

(Dong et al., Giusti, Manerba, et al., 2019), our study represents a step forward to put synchromodality in a supply chain perspective.

In order to remain competitive, contemporary supply chains often leverage the efficiency and effectiveness of their logistics network (Fugate et al., 2012). The commoditization of the offering in mass-customized manufacturing has led to little differentiation among competing firms along traditional dimensions like product or price. As a result, logistics capabilities have become a key driver of successful supply chain management (Fugate et al., 2012): Firms that are able to achieve better delivery performance and provide higher service levels to customers can better cope with the complexity and volatility of demand patterns, thus distinguishing themselves from the competition (Oflaç et al., 2012). In this context, the complementary dimensions of synchromodality reflect difficult-to-mimic traits that can ensure competitiveness (Brümmerstedt et al., 2017; van Riessen et al., 2015). For example, visibility and integration enable superior customer service in terms of tracking and delivery requirements, while flexibility can allow real-time optimization of costs by selecting the least expensive combination of transport modes that complies with such requirements. Consequently, our results also suggest that companies should regard their transportation and logistics partners as enablers of competitive advantage (Oonk, 2016). They need to align and synchronize their flows in order to compete according to the new opportunities offered by digitalization in supply chains (Saenz & Cottrill, 2019). As such, the present study can be considered a starting point for supply chain and transportation managers who are considering the implementation of synchromodality in their daily operations.

In this regard, we believe that an important aspect of synchromodality is the connection with information and communication technologies, which are necessary conditions for supply chain synchronization. Supply chain digitization is an ongoing trend and several scholars and practitioners point to the upcoming digital revolution (Holmstrom et al., 2019; Matusiewicz, 2020; Saenz, 2020). The connection between synchromodality, digital processes, and technologies like blockchain, digital twins, or IoT are promising research avenues.

The limitations of our research design also call for replication and/or triangulation. We base our research on European data, mostly emanating from an FMCG company, collected through single respondents. It would be interesting to see if, as synchromodality expands to other regions such as North America or Asia, our findings can be confirmed and thus generalize theoretical and managerial implications. Similarly, evidence from multiple industries and data sources would contribute to the mounting debate about synchromodality.

We suggest continuing this research by analyzing specific outcomes that the adoption of this novel concept could have on supply chains, possibly using complementary research methods. On one hand, our results suggest a positive association between synchromodality and logistics differentiation, which deserves further testing. On the other hand, in line with existing conceptual studies and a few applications, it would be interesting to test the effect of synchromodality on supply chain resilience and sustainability (and the effect of potential mediating or moderating variables). Synchromodality can indeed enable fundamental capacities for resilience, like real-time information, predictive analytics, flexibility of transport modes, and coordination across the supply chain. These would allow supply chains to anticipate risks and react swiftly when disruptions occur. In addition, despite the fact that companies may look to synchromodality due to logistics differentiation, companies may also radically reduce CO_2 emissions caused by transportation (Dong et al., 2018; Giusti, Manerba, et al., 2019). This may help companies deploy sustainable strategies, especially in the logistics sector, which is seen as one of the hardest sectors to decarbonize (Guerin et al., 2014), and which is attracting both media and scholarly attention (Ellram et al., 2020; Sindreu, 2019). As such, synchromodality may not only help supply chains improve their brand perception, it may also contribute to a reduction in the expected trend of transportation emissions, which are anticipated to rise by 120 percent by 2050 (OECD/TIF, 2017).

Finally, our validated measure can also help managers exploit the potential benefits deriving from synchromodality. We provide a comprehensive list of capabilities and related tasks that managers can use to plan actions, identify improvement areas, and monitor synchromodality implementation. Thanks to the establishment of a grounded definition and a common language, our study can help managers look at the transportation part of their supply chain not only as a mere operational task, but as a holistic SCM approach to operating with visibility, integration, and flexibility at the core of the supply chain.

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ENDNOTES

[1] In the next section, we will discuss the difference between these paradigms and synchromodality.

[2] Recent evidence from pilot projects and studies about synchromodality is available in the online supplement to this article.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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