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A conceptual framework for synchromodol port: an extension of synchromodality from hinterland transport to marine operations

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A CONCEPTUAL FRAMEWORK FOR SYNCHROMODAL PORT: AN EXTENSION OF SYNCHROMODALITY FROM HINTERLAND TRANSPORT TO MARINE OPERATIONS

By

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India

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Declaration

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

(Signature): ....

(Date): 2022-09-21
....

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Abstract

Title of Dissertation: **A Conceptual Framework for Synchromodal Port: An Extension of Synchromodality from Hinterland Transport to Marine Operations**

Degree: **Master of Science**

The emphasis of this study is to identify the current state of understanding in the emerging fields of synchromodality and physical internet in transport, especially in the context of a seaport. This includes the development of a framework for the extension of this innovative transport concept from hinterland transport to the marine operations of a port as well as the identification of the mechanisms, enablers, and dimensions for a synchromodal port.

The study combines a qualitative content-based and quantitative survey approaches to literature review to analyse a final sample of 116 publications related to the concepts of synchromodality and physical internet. This study identifies that synchromodality is an innovative transport concept in its infancy which has been researched mostly from the aspect of hinterland transport. The study contributes to the body of knowledge in this field by extending the concept of synchromodality to the marine operations of a port. This was done by adding 4 mechanisms (real-time communication, coordinated vessel arrival system, smart port operations & management, and favourable contracts of carriage by sea) and 3 dimensions (operational, managerial, and policy) to the existing framework for hinterland transport while extending it to the marine operations within a port.

The study identifies practical limitations while researching an emerging concept like synchromodality as there is very limited practical application in the industry so far and the available literature in the field is also very limited. The study concludes by suggesting several areas for future researchers in this field.

KEYWORDS: Synchromodality, Synchromodal Transport, Physical Internet, Logistics, Intermodal Transport, Port Business, Port Operations, Hinterland, Transport.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

AI	Artificial Intelligence
ALICE	Alliance for Logistics Innovation Through Collaboration in Europe
BCO	Beneficial Cargo Owner
CIMO	Context, Mechanism, Intervention, Outcome
COGSA	Carriage of Goods by Sea Act
ECT	Europe Container Terminals
EGS	European Gateway Services
ET	Estimated Time
ETP	European technology Platform
EU	European Union
FCL	Full Container Load
GDP	Gross Domestic product
GHG	Green House Gas
H&M	Hull & Machinery
IFT	Intermodal Freight Transport
IMO	International Maritime Organisation
IoT	Internet of Things
ITF	International Transport Federation
JIT	Just In Time
LA/LB	Los Angeles/Long Beach
LCL	Less than Container Load
LSP	Logistics Service Provider
OECD	Organisation for Economic Cooperation and Development
P&I	Protection & Indemnity
PBP	Pilot Boarding Point
PI	Physical Internet
RTA	Requested Time of Arrival
SLR	Systematic Literature Review
SSS	Short Sea Shipping
TEU	Twenty-foot Equivalent Unit
TKM	Tonne Kilo Meter
ULCV	Ultra Large Container Vessel
UNCTAD	United Nations Conference on Trade and Development

1. CHAPTER 1: INTRODUCTION

1.1. <u>TRANSPORT DEMAND & TRADE</u>

International trade and commerce is the backbone of today's globalized world and the role of freight transport is a cornerstone for the success of globalization. Since time immemorial, mankind has been trading between distant geographies and the evolution of transportation has played a key role in the development of trade and civilizations around the globe. In the modern-day globalized world, international trade, as we know it, would cease to flourish if there was no freight transportation to move the goods traded. Transport is a secondary demand, also referred to as derived demand, meaning the demand for transport depends on the demand for the goods that are being traded *(Ma, 2021).* While international freight transport is characterized by maritime trade, it is important to remember that maritime transport is only a part of the overall freight transport chain which also includes the freight transport that happens within the country once the goods are unloaded from the ship at a seaport. As a country becomes more and more globalized in trade, its merchandise trade volume increases. With the increase in export and import volumes, there is an increase in the demand for freight transport services. The demand for seaborne trade is dependent on the GDP growth of a country *(Ma, 2021)*. Figure 1 presents a comparison between the rising seaborne trade per capita and its correlation with GDP per capita growth.

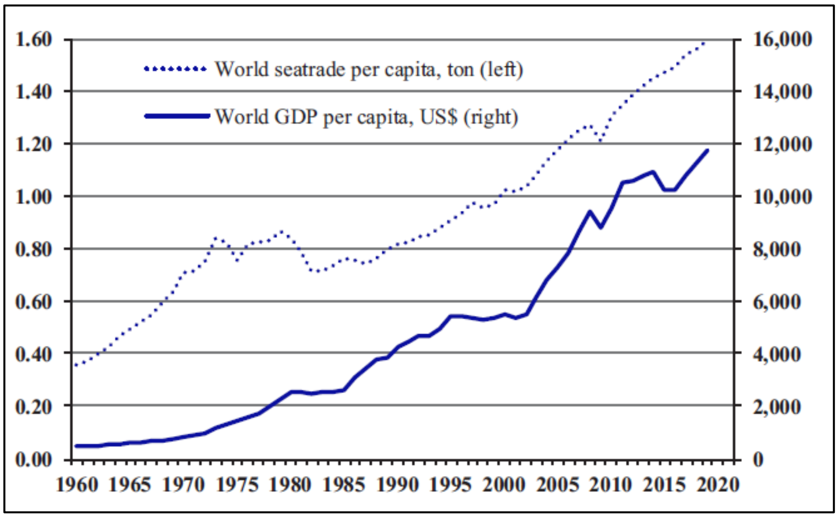

Figure 1 *Rising seaborne trade per capita and correlation with GDP per capita growth.*
Source: *Economics of Maritime Business, 1st Edition, Shuo Ma, 2019*

Figure 1 shows that there is a close correlation between the GDP growth of a region and the merchandise trade. Given this fact, it could be argued that the demand for trade will be robust in the future as the GDP growth is expected to be robust in emerging economies, particularly in Asia, Africa, and Latin America. With the increase in merchandise trade, there would be increased demand for freight transport.

If we consider the European Union (EU) as our focus area for this study, the role of freight transport within the EU is of vital importance for the economy of this region. As per the data from World Bank, in 2021 the GDP has grown by 5.4% for the European Union, and the share of merchandise trade as % of GDP was 76.6%. This highlights the importance of merchandise trade in the economy of EU countries. The value of intra-EU trade in goods was 1.6 times as high as the value of extra-EU trade in goods in 2021 *(Eurostat 2021)*. Such a high level of intra-regional trade implies that the demand for non-maritime freight transport (road, rail, and inland barges) will also be higher in this region.

1.2 MODAL SPLIT & EXTERNALITIES

At this stage, it is important to highlight the importance of a concept called ‘modal split’ in transportation engineering. Modal Split, also known as modal share or modal choice, is an important indicator used in transportation engineering to evaluate the transportation behaviour of the users. It shows the percentage of transport users using a particular mode of transport compared to the ratio of all transport activities in a time period *(Ungvarai, 2019)*. According to the ITF-OECD report of 2022 on Mode Choice in Freight Transport, the modal shift in freight transport has been also a recurrent objective of freight transport policies of the European Union, most recently in the EU Sustainable and Smart Mobility Strategy, released in 2020. Modal shift ambitions are sometimes expressed in targets for the desired modal split or modal shift. Such targets often take the form of a desired share of non-road transport in the modal split. The modes most regularly preferred to road transport are rail, inland waterways, and short-sea shipping (SSS). An often-cited modal shift target comes from the EU Mobility Strategy, released in 2011 which aims at a 30% modal shift away from road transport by 2030 and 50% by 2050. The Netherlands has formulated a more specific target to shift 5 million tonnes and 0.7 million standard containers (TEUs) from road to rail and waterways within the East and Southeast freight corridors in the Netherlands. Frequently, countries have modal shift ambitions included in their freight transport policies without specifying an explicit target. The main motivation for governments to formulate modal shift policies appears to be the reduction of externalities generated from freight transport.

As per Eurostat 2021 report, road transport has the largest share of EU freight transport performance among the three inland transport modes. Figure 2 shows that in 2020 road transport accounted for more than three quarters (77.4%) of the total inland freight transport (based on tonne-kilometres).

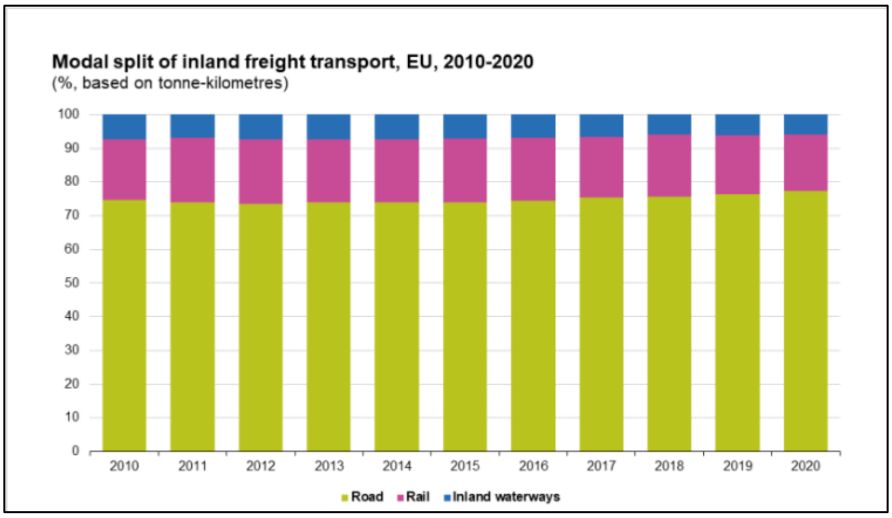

***Figure 2**. Modal split of inland freight transport, EU, 2010-2020 (%, based on tonne-kilometres)*
***Source:** Eurostat*

It can be observed from the above chart that road transport is the dominant mode of inland freight movement in the EU and it has maintained its dominant position over the years. Rail transport and inland transport have struggled to increase their share. While freight transport plays a major role in the development of an economy, it also has some undesirable externalities attached to it. Externalities are changes in welfare caused by economic activities but not reflected in market prices. In the field of transport, these externalities arise when transport consumers/producers impose additional costs on society and its individuals without having to bear these costs themselves. External costs are externalities expressed in monetary terms. Regarding the external costs of road transport, there is an important distinction between the 'intra-sectoral externalities' and 'inter-sectoral externalities. Intra-sectoral externalities are those that are imposed upon each other by the users themselves (e.g., congestion, external accident costs, etc.). Inter-sectoral externalities are those that are related to environmental externalities, noise nuisance, and external accident costs imposed upon society at large *(Macharis, C., & Melo, S., 2011)*.

As evident from figure 2 above, road transport is having the dominant position in the modal split for freight transport. This is not a desirable situation because of the externalities generated by road transport. It is a well-known fact that out of the three modes (road, rail, and inland barge), road transport is the most polluting mode as compared to the other two modes. According to a study presented by the European Commission in 2019, Freight trains emit 80% less CO_2 than HGV per TKM (one ton transported in one kilometer). Besides that, they also cause fewer external costs as compared to road transport (in terms of accidents, air pollution, climate change, noise, congestion, well-to-tank emissions, and habitat damage). However, these external costs of road transport are not reflected in the user costs and therefore the cost of road transport usage is often less compared to rail transport. Due to this reason, users prefer road transport over rail transport. Apart from this reason, factors like flexibility, reliability, and available capacity are also favoring road transport against rail transport. According to the Transport & Environment Report 2021 of the European Environment Agency, transport is solely responsible for a quarter of the EU's greenhouse gas (GHG) emissions, with road transport representing the greatest share of 72% in 2019 (Figure 3).

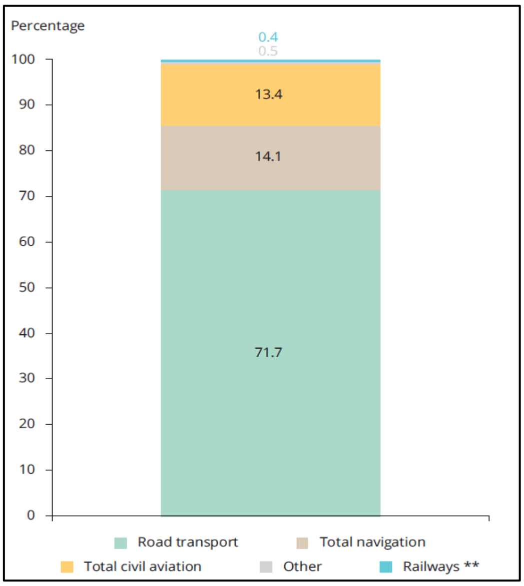

Figure 3: *Transport GHG emissions by mode in the EU-27, 2019*, ***Source:*** *European Environment Agency*

Note: ***a.*** *Transport include international bunkers (international aviation and international maritime transport,* ***b.*** *Excluding indirect emissions from electricity consumption.*

Although the climate and energy policies in the EU have resulted in a significant reduction in GHG emissions in all sectors, the transport sector has failed to reduce its GHG emissions. On the contrary, the emissions from the transport sector increased by more than 33% between 1990 to 2019, and road transport emissions by 28%. This is a long way from the 90% reduction by 2050 that is needed from transport to achieve the overall 2050 climate neutrality. Despite the above shortcomings in road transport, it is the dominant and most favored mode of freight transport in the EU. The reasons are related to flexibility and reliability. Road transport can offer door-to-door service which is not the case with rail or barge transport. In this era of just-in-time supply chain, the reliability of transport service is of crucial importance to the shipper because any transport delay may quickly escalate into disruptions in the production process, leading to loss of production and subsequently loss of sales. Road transport also offers the flexibility to circumvent delays or disruptions in route, by taking alternate routes. This feature is difficult in rail or other modes.

Having said that, one of the key policy objectives of the EU policymakers has been to increase the modal share of rail and barge transport by shifting the freight from road transport. The key consideration behind this is the environmental footprint of road transport and the EU's target of climate neutrality of a 90% reduction in GHG from the transport sector by 2050. Other criteria that shippers consider important, depending on commodity types, regions, and markets are service quality, flexibility, security, sustainability, and marketing value. Service quality could refer to many attributes of the transport service, e.g., transparent communication, possibilities for tracking and tracing cargo, service help-desks, and guaranteed stable conditions for certain types of cargo, such as refrigerated cargo. The transport of high-value goods and dangerous goods requires more security – e.g., fewer accidents and lower lost cargo rates – that cannot always be guaranteed by all transport modes. In terms of sustainability, there is increasing pressure on firms, especially producers and sellers of consumer goods, to reduce the environmental and carbon footprint of their logistics supply chains. Carriers are also confronted with increased scrutiny of their environmental impacts, for example with regards to pollution, land use, and climate change.

1.3 FROM UNIMODAL TO INTERMODAL TRANSPORT

In order to deliver the products to the end customer in a reliable, safe, environmentally friendly, and economic manner, shippers use a variety of logistics systems. Ensuring a smooth transport process along all stages of a product is called supply chain management, a notion introduced in the late 1980s *(Houlihan, 1985; Jones and Riley, 1985 & Stevens, 1989)*. It is a well-established fact that as the distance between the point of origin (supplier) and the point of final consumption (customer) increases, it becomes more difficult to ensure uninterrupted delivery. This is mainly attributed to the uncertainty in the process which is random and cannot be predicted in advance. The truck used for transport may break down in between, there could be a road blockage, etc. If the sea or rail is chosen as the mode of transport, the "last mile" of the transport chain is almost invariably handled by road. This is likely to be the case regardless of the modal choice made because it is highly unlikely that the end point of consumption (e.g., a supermarket or a factory warehouse) is located right next to a rail siding or a barge terminal. This makes road transport an indispensablepart of the transport chain for "last-mile" and "first-mile" deliveries, if not for the whole chain. This transport between two stations can be carried out using one or multiple modes of transport as well as several different modes of transport *(Gudehus & Kotzab, 2012)*. Since the 1980 and 1990s, such logistics chains have been elaborated and defined as multimodal, intermodal, combined transport, co-modal, and even synchromodal transport *(Reis, 2015)*.

Multimodal transport was defined in 1980 by the UNCTAD and refers to a transport system where the carriage of goods is done by at least two different modes of transport based on a multimodal transport contract from a place in one country at which the goods are taken in charge by the multimodal transport operator to a designated place for delivery in a different country. This occurs, for example, when a good is transported by rail and then loaded onto a truck which transports it onwards by road.

Intermodal transport is considered to be a sub-form of multimodal transport, which Reis (2015) recognizes as a further development of multimodal transport. "Intermodal freight transport (IFT) is the concept of utilizing two or more 'suitable' modes, in combination, to form an integrated transport chain aimed at achieving operationally efficient and cost-effective delivery of goods in an environmentally sustainable manner from their point of origin to their final destination" *(Lowe, 2005)*. In this context, integration refers to the increased coordination between different modes of transport on a technological, contractual, or operational level and thus provides improved and reliable door-to-door transport. In terms of loading units, the same load unit is typically used throughout the transport process *(Bektas & Crainic, 2007)*. Thus, goods in transport change the modes or even the means of transport but not the container in the sense of a protective shell *(Gudehus & Kotzab, 2012)*. At this juncture it may be pertinent to highlight the fact that although this system is said to be utilizing two or more modes, in the majority of cases, efficient movements are invariably achieved by the use of just two modes: most commonly road haulage for the first and last mile, combined with a rail-freight trunk-haul journey, what is commonly known as 'combined road-rail' operation *(Lowe, 2005)*.

It is important to understand why there is a high level of focus on promoting intermodal freight transport and a shift away from road transport (modal shift) by the EU and other nations across the globe. The motivation behind the greater use of intermodal freight transport is the benefit it provides in terms of its environmental footprint. According to the European Environment Agency (2013), CO_2 emissions per tonne-kilometer from railways and inland waterways are about 3.5 and 5.0 times lower than those from road freight transport. This means that in light of the EU's climate neutrality 2050 goals and the broader objectives of the Paris agreement, promoting intermodal freight transport by moving the freight away from the road is a key objective to be achieved.

However, as highlighted in the modal split figures of the EU, despite all the efforts, the modal choice is still skewed heavily in favour of road transport. The reason for this bias towards road transport is that it is perceived to be far superior when considering lead time, reliability, and flexibility of service *(Lemmens et al., 2019)*. Vannieuwenhuyse et al. (2003) interviewed 500 practitioners and found out that flexibility is indeed one of the most important criteria in their freight transport decision making. Although trains and barges are cost-effective and environmentally sustainable when compared to road, they significantly lack flexibility in delivery quantity, frequency, and scheduling *(Meers et al., 2017)*. A truck can pick up and deliver the goods from locations that have no rail sidings or waterway quays for loading or unloading. A shift from road to trans and barges may lead to an adverse effect on the increased inventories or a reduced service level. As rail and barge services are generally slower than road and also less frequent, in-transit inventories and stock levels might be higher at both ends of the journey *(Dong et al., 2018*. Trains and barges also require larger and more stable shipment volumes due to their higher capacity compared to a truck to achieve economies of scale, thus making them a sub-optimal choice for flows that are subject to widely fluctuating demand. In addition, the regulations for rail transport between nations are widely varying and there is a lack of standardization which leads to cross-country movement of rail freight as a difficult task. Figure 4 provides a representation of the problems faced by cross-country rail freight within the EU. Due to these inefficiencies in rail and inland barge transport, both of these are not ideal for the customer in today's world of just-in-time deliveries. Thus, a combination of road freighting with either rail or inland barges may prove to be the most viable option, both economically and operationally, as it combines the benefits of both modes.

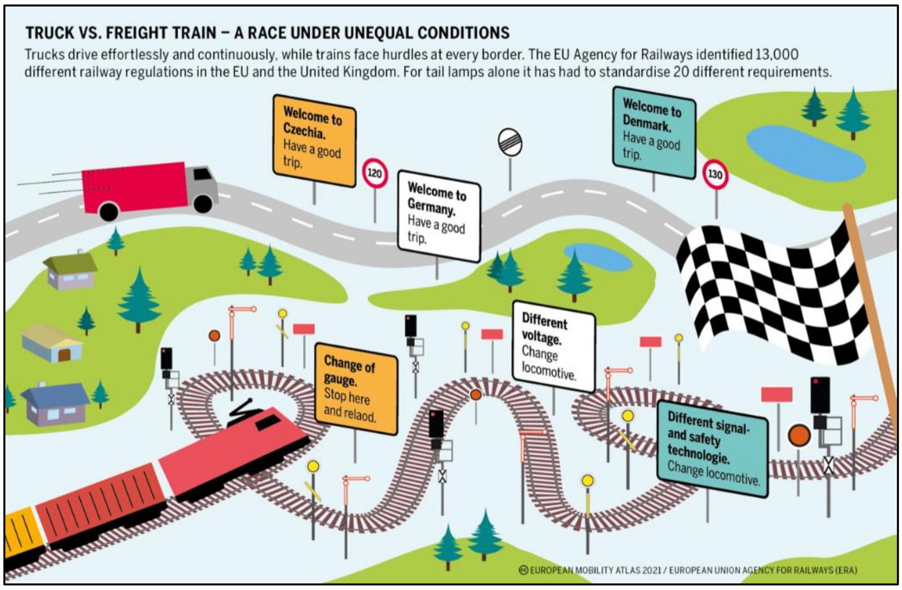

Figure 4: *Truck Vs Train Freight Transport*
Source: *European Mobility Atlas 2021, European Union Agency for Railways (ERA)*

As per the projections, total inland transport within the European Union is expected to grow by almost 50% from 2005 to 2030 *(Rich & Hansen, 2009)*. This is a significant increase in the freight flows, which combined with a push towards sustainable transport solutions worldwide, alternatives like rail and barge are expected to increase their role in the overall freight transport mix. However, as discussed above, rail and barge have significant inefficiencies when compared to road transport. Therefore, in general, intermodal transport is considered one of the most promising markets for rail and barge to regain their market share, as it combines the advantages of both barge and rail with truck transport *(Tavasszy et al., 2015)*. Intermodal transport allows access to large-scale modalities like inland barges and rail, from those areas that have only access to the road network. This is critical for unit load transport (i.e., a standard container) to allow bundling of freight flows from point of origin to the point of destination, thus reaching lower costs due to the economies of scale. In practice, transhipment from one mode to another can be done at a seaport or inland port ('dry port'), but in the later case introduces additional transhipment costs and handling time. Therefore, in the past, intermodal transport has mostly been successful in situations where.

➢ the transport costs could be kept extremely low (e.g., over very long distances or with double stack container movements in the USA),

➢ where natural or regulatory barriers were preventing road transport (e.g., regulations limiting permits for road transport across the Alps),

➢ or where transhipment costs had to be incurred anyway (e.g., at major gateway ports).

Due to these reasons, the share of intermodal transport across the entire freight transport market has remained low *(Tavasszy et al., 2015).*

Studies on the quality perception of shippers show that although intermodal transport offers lower prices (over long-distance transport), single road transport is perceived as a superior alternative when considering several other key decision criteria like lead time, reliability, and flexibility of service *(Cardebring at al., 2000; CER, 2013)*. In the past few decades, global supply chain management has gone through several trends – like just-in-time, lean and agile systems, and efficient consumer response, which requires a much faster, more reliable, and more flexible transportation service. The supply chain disruptions due to COVID-19, silicon chip shortages, vessels waiting outside LA/LB ports, and the most recent incidents of low water levels in the Rhine River are stark reminders of how important agility and flexibility for today's global supply chains are. The low water level in the Rhine River during August 2022 has the potential to severely disrupt the inland barge movement within Europe which again emphasizes the need to have flexibility and diversity of modes within the transport chains. To establish itself as a preferred modal choice in a fiercely competitive transport market, intermodal transport has to fulfill the growing consumers' needs and adapt to the changing business environment by becoming more flexible and presenting a more customized solution to the customer. This requires new models of operation and new arrangements that can improve the service levels and also achieve cost reductions in hinterland transport *(Tavasszy et al., 2015)*.

1.4 EVOLUTION FROM INTERMODAL TO SYNCHROMODAL TRANSPORT

As it is evident from the above discussions that the need to improve the efficiency and sustainability scores of the transport systems is of paramount importance and it is also clear that intermodal transport, in its current form, is inadequately designed to achieve these objectives. Therefore, during the start of the last decade, a new revolutionary concept was introduced by *Montreuil, B. (2011)* which is termed the Physical Internet (PI). By applying the concepts from Internet data transfer to real-world shipping processes, the PI exploits the concept of universal connectivity of logistics networks and services *(Montreuil et al., 2012)*. Still in its infancy in terms of real-world application, the concept can be interpreted by comparing data transfer in the digital world with freight transfer in the real world. In the Physical Internet freight is moved in a similar way as data is transferred in the digital internet: smart, seamless, and making use of the network of others. Smart replenishment models will ensure freight flows are combined and synchronized efficiently, resulting in higher vehicle fill rates, a shift towards more environmentally friendly transport modes, fewer trucks on the roads, and a significantly low carbon footprint of freight transport *(Lemmsns et al., 2019)*.

Within the European context, the European Technology Platform ALICE, Alliance for Logistics Innovation through Collaboration in Europe, was launched on June 11, 2013, and received official recognition from the European Commission in July 2013. ALICE has been set up to develop a comprehensive strategy for research, innovation, and market deployment of logistics and supply chain management innovation in Europe with the mission “to contribute to a 30% improvement of end-to-end logistics performance by 2030”. One of the key elements identified by ALICE to achieve this mission is the Physical Internet concept, as briefly explained above. “PI is pursuing an open global logistics system founded on physical, digital, and operational interconnectivity, through encapsulation, interfaces, and protocol design, aiming to move, store, realize, supply, and use physical objects throughout the world in a manner that is economically, environmentally and socially efficient and sustainable” *(ETP-Alice, 2018)*.

ALICE has identified five different areas that need to be specifically analysed and addressed in terms of future research and innovation needs to achieve its mission. These areas are:

- Sustainable, Safe, and Secure Supply Chains
- Corridors, Hubs, and Synchromodality
- Information Systems for Interconnected Logistics
- Global Supply Network Coordination and Collaboration
- Urban Logistics

One of the roadmaps of the PI initiative is the existence of co-modal transport services within a well-synchronized network, supported by corridors and hubs, providing optimal support to supply chains (Figure 5). The European vision of Co-modality is aimed at creating strong framework conditions for each mode of transport in its own right and, where possible, in cooperation with other modes (i.e., intermodal transport). This involves a significant divergence from the current individualistic transport system, where shippers and Logistics Service Providers (LSP) optimize their own networks and transport flows, towards the ultimate hyperconnected PI vision, synchronizing intermodal services between modes and with shippers. This concept, referred to as Synchromodality, aligns equipment and services on corridors and hubs and proposes a transition from small individual corridors and hubs towards one hyperconnected PI system *(ETP-Alice, 2018)*.

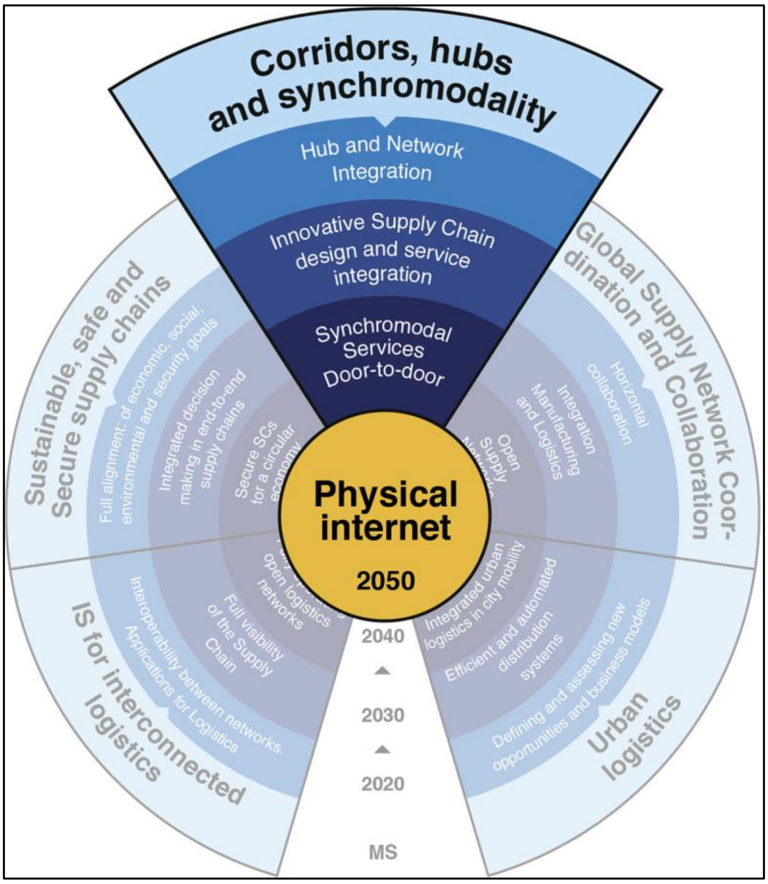

***Figure 5**: Synchromodality as one of the roadmaps of Physical Internet*
***Source:** ETP-ALICE (Corridors, Hubs and Synchromodality), 2018*

As synchromodality is a new concept in the world of logistics and is still in its infancy, a universal definition is yet to be established. As per ETP-Alice, "Synchromodality, or synchronized intermodality, can be defined as the service which, through informed and flexible planning, booking and management, allows to make mode and routing decisions at the individual shipment level, as late as possible in the transport planning process including the trip itself." The concept was first coined in 2011 and in one of the first explanations, *Verweij (2011)* characterized synchromodality as the ability to switch freely between transport modes at particular times while a consignment is in transit, also referred to as real-time mode switching *(Lemmsns et al., 2019)*.

According to Tavasszy et al. (2015), the cornerstone of this concept is an integrated view in the planning and management of different modalities to provide flexibility in handling freight transport demand. In Intermodal transport, due to the involvement of multiple modalities, integration of service has been a recurrent issue leading to inefficiencies. The main focus of the intermodal transport system is on the *vertical integration* of logistics services within one intermodal transport chain – including transport and transhipment services. An example of vertical integration could be the integration of hinterland transport operations and inland terminal processes in a dry port. However, the differentiating feature of a synchromodal freight transport system is its *horizontal integration* within a whole transport system (Figures 6 & 7).

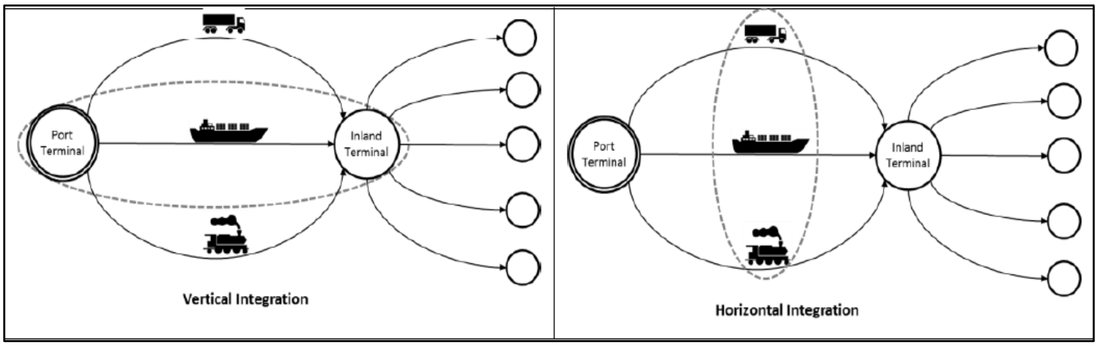

Figure 6. *Vertical vs. Horizontal integration in freight transport planning*
Source: *Behdani et al., 2014*

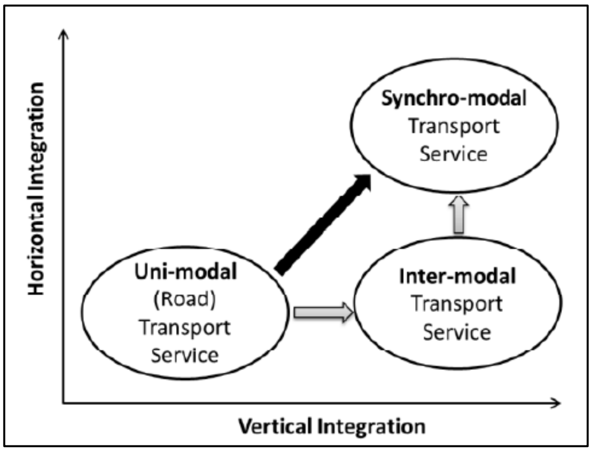

Figure 7. *Dual integration in a Synchromodal Freight Transport System*
Source: *Behdani et al., 2014*

It aims to integrate the transport services on different modalities into a "single transport service." This integration leads to a trade-off between the quality and cost parameters of different modalities. For example, inland waterways is extremely cost-effective as compared to other modes but it is less flexible compared to trucking. If we take rail as an example, it is even less flexible because of specific constraints like shared infrastructure with passenger trains which influences the timings of freight trains. By utilizing the complementary nature of various transport modes, a synchromodal freight transport system promises an integrated service that is no longer dependent on the type of modality that is used for the main haulage. The shipper specifies the service level parameters like the cost, time, and performance criteria, leaving the mode choice to the logistics service providers. This is referred to as ‘mode-free booking.’ The pricing approach is “service-based” rather than the traditional “mode-based” fare design (see Figure 8).

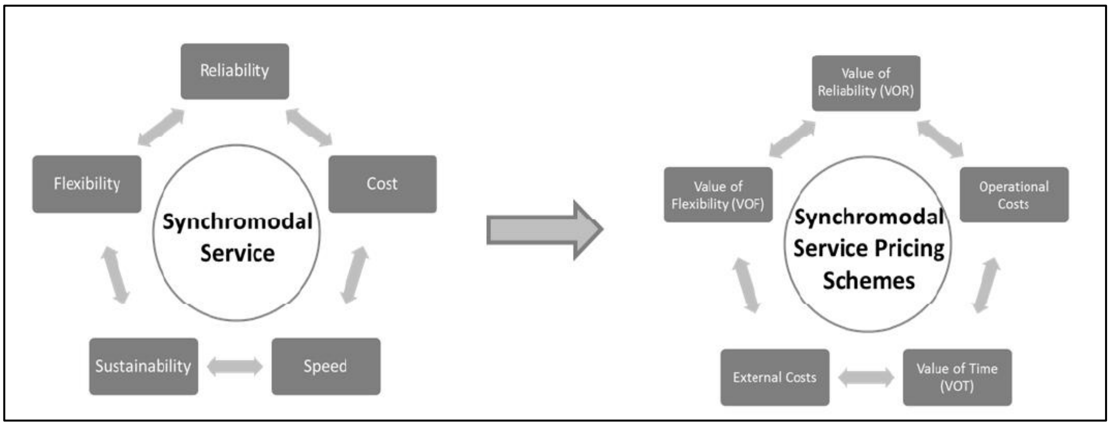

Figure 8*. Synchromodal Service definition and pricing*
Source: *Tavasszy et al. (2015)*

1.5 The current state of the synchromodal transport system

Although the concept of synchromodality seems complex concept, the rapid development in the information systems and digital capabilities within transport and logistics has led to its implementation much easier. Positive experiences with synchronized intermodal services exist in port-hinterland container transport, in proprietary transport chains of integrators (integrated logistics service providers), and hybrid (dual-mode) supply chains of certain shippers. However, despite these examples and practical application cases, the choice of mode and route is either fixed a long time ahead in the contracting process or is not made with the consideration of all the latest options. The network of modes is still decoupled at intermodal terminals, be it physically, financially, or administratively, and synchronization between modal operations is limited or absent *(ETP-Alice, 2018)*.

1.6 OBJECTIVE & RESEARCH QUESTIONS

Taking all of these concepts and developments into consideration, the author believes that synchromodality or physical internet is about the integration of the logistics and transport activities towards a broader, holistic realm of overall supply chain management and the papers published on this topic justify this argument. However, when one mentions the integration of logistics into the overall supply chain, it is not only about the hinterland transport to and from the port but also the ocean transport operations and management decisions within a port which play a major role in the logistics chain. Seaports are the junction where different modalities of transport converge and diverge (figure 9) along with an endless interaction between a diverse range of stakeholders, each with their own objectives and interests. So, it is natural to assume that seaports should occupy a central role in the operation and management of a synchromodal transportation system. However, the literature that is available on synchromodality and physical internet, although very limited, is mostly focussing on the hinterland transport operations to and from ports without much emphasis on the role of ocean transport operations within a seaport and the cross-country synchronization that is essential to achieve a globally integrated synchromodal transportation system. A true synchromodality is not just about the synchronization of hinterland transport operations to and from the port, rather it is about the synchronization of the whole supply chain which also includes the ocean transportation operations of the chain. Therefore, the author recognizes a need to identify the role of ocean transport operations and management within a seaport in a synchromodal transportation system. Furthermore, the author aims to develop a conceptual framework of reference which can be used to link the ocean transport operations and management within a port with the hinterland transport operations with reference to the synchromodal transportation system. When both the sides of a port, i.e., the ocean side and the hinterland side of transportation are connected as a single chain, true integration as conceived in the concept of the synchromodal transportation system, can be realized to its full potential.

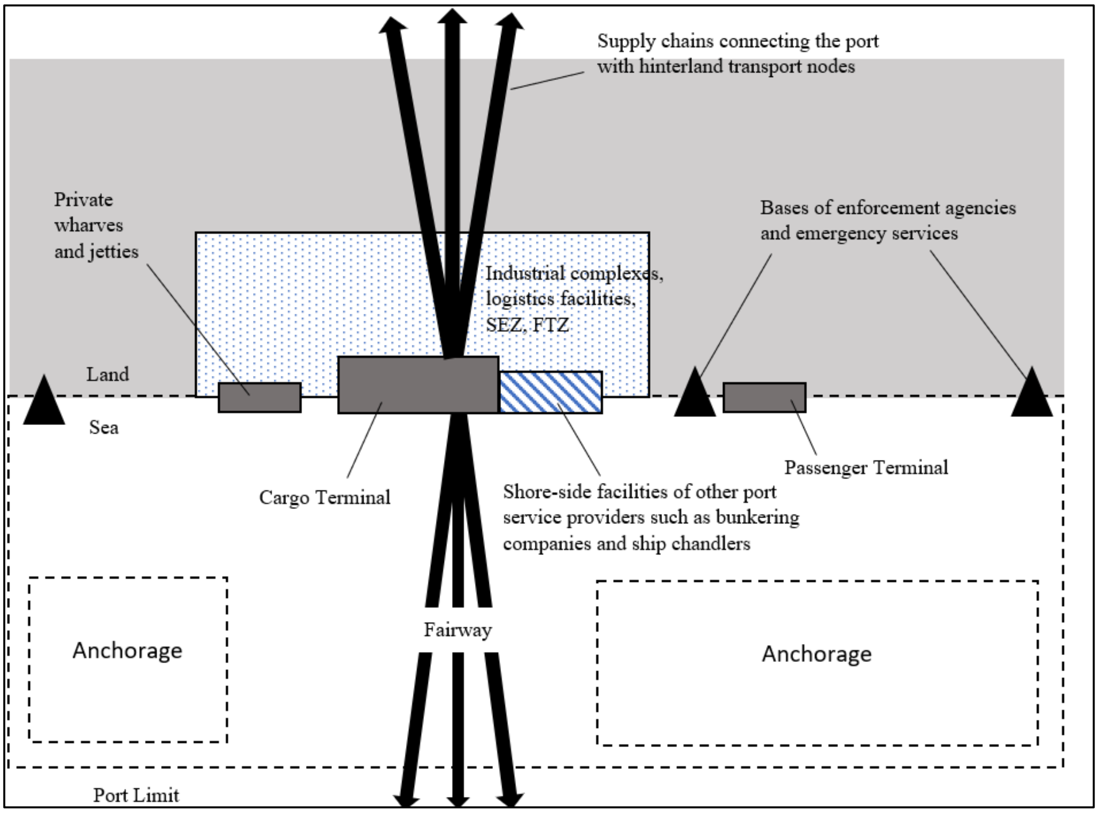

Figure 9*. Example of sea-land interface of a port*
Source: *Business and Economics of Port Management, An Insiders Perspective, Wei Yim Yap, 2021*

This is done using a systematic literature review and content analysis. In achieving these aims, this thesis answers the following research questions:

1) What are the main areas where the existing research on synchromodality is currently focussed upon?
2) What is the understanding and coverage in the existing literature about the marine side of port business (vessel-port) within the framework of a synchromodal transportation system?
3) What are the mechanisms which can link the marine side of operations in a port with its hinterland transport operations within the framework of a synchromodal transportation system?

As this is an emerging discipline within the field of transport engineering and logistics, it is important that an important link in the supply chain, i.e., ocean transportation operations, is not missed out when developing a new transport system. True integration, which is at the core of synchromodality, can never be achieved if ocean transportation is not included in it. The proposed contribution of this thesis to the body of knowledge on synchromodality is towards expanding the scope of synchromodality by including the ocean transport operations side of the logistics chain within the overall synchromodal transportation system, which to the best of the author's knowledge has largely been untouched so far in the literature.

The remainder of this thesis is structured as follows: Chapter 2 presents the methodological approach and data used for this study, Chapter 3 discusses the content analysis, systematic literature review, and their findings on the topic of synchromodality and physical internet, Chapter 4 discusses the conceptual framework which can be used to integrate the two sides of port operations, i.e., the port-to-hinterland side and the port-to-maritime transport side, and chapter 5 concludes the study along with future research recommendations.

2. CHAPTER 2: METHODOLOGY & DATA COLLECTION

2.1 METHODOLOGY

In this chapter, the detailed methodology adopted to answer the research questions and the data used for the analysis are explained.

To address the research objectives as outlined in chapter 1, this study deploys a mix of literature survey and content analysis of the existing literature. Literature reviews have often been used in logistics and supply chain research, especially when the research objective is to develop a conceptual framework or to offer insights into supply chain practice (Durach et al., 2017). A systematic literature review is a specific methodology that locates existing studies, selects, and evaluates contributions, analyses, synthesizes data, and reports the evidence in such a way that allows reasonably clear conclusions to be reached about what is and is not known. It is not the same as a traditional literature review, but a self-contained research methodology in itself that explores the literature with reference to a clearly defined research question. Systematic reviews have a clearly defined method section with each step of the systematic review rigorously reported. Justifications are given for all decisions taken by the reviewer. Only those studies that meet these inclusion and exclusion criteria are included in the review (Denyer & Tranfield, 2009). The overall goal is to achieve an organization and categorization of the intellectual territory of a certain field, its evaluation, and the further development of an existing body of knowledge (Pfoser, Kotzab, & Bäumler, 2022). There are four core principles traditionally applied to a standard systematic review process. As depicted in figure 10 below, systematic reviews are expected to be: replicable, exclusive, aggregative, and algorithmic (Denyer & Tranfield, 2009).

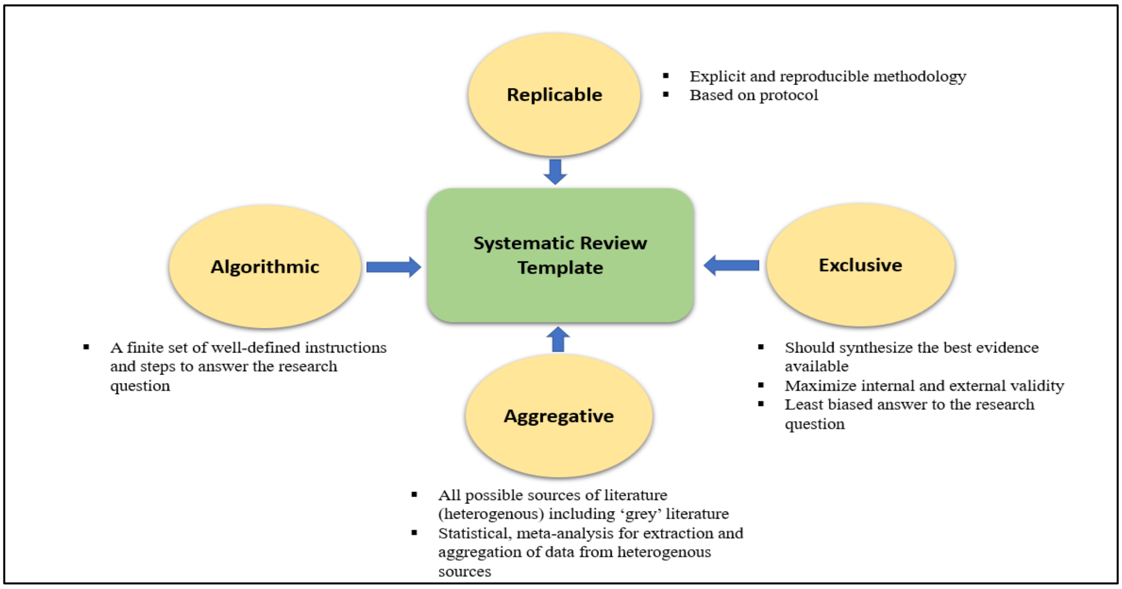

***Figure 10**. Core principles of a systematic review template adopted from Denyer & Tranfiled, 2009, modified by the author.*

In addition to the literature survey, this study also deploys the content analysis of the literature identified in the systematic review process. Content analysis is a class of methods within empirical social science that can be applied both quantitatively and qualitatively. According to Berelson (1952), one of the founders of this method, "content analysis is a research technique for the objective, systematic and quantitative description of the manifest content of communication"

The broad scope of content analysis can be translated into two levels of analysis. The first level analyses the manifest content of texts and documents by statistical methods and on the second level, the latent content of the text and documents is excavated requiring interpretation of the underlying meaning of terms and arguments. It is a specific strength of content analysis, differentiating it from other research methods, that this method can combine qualitative approaches retaining rich meaning with powerful quantitative (statistical) analyses, where required (Duriau, Reger, & Pfarrer, 2007). Referring to Mayring (2008), Seuring & Gold (2012) identify four main steps which together form the process model of qualitative content analysis (figure 11):

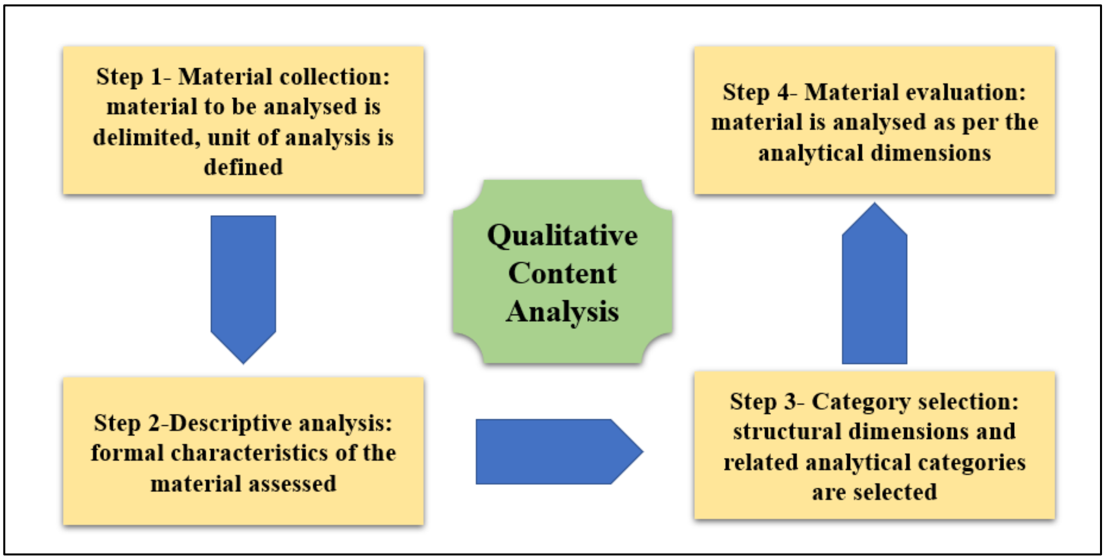

Figure 11. *Steps of a qualitative content-analysis, adapted from Seuring & Gold, 2012, modified by the author*

Denyer et al. (2008) suggest that systematic reviews of the existing literature base in the fields of management and organization science can help managers to develop their knowledge that can be used to design novel solutions in their fields and practice. According to Denyer & Tranfield (2009), there are five essential steps that define the systematic review process. These are presented below in figure 12.

Question formulation (step 1) is the most critical part of this process because the question acts as the lighthouse for the literature searches, inclusion, and exclusion criteria and thus helps to focus on the relevant literature only. Within the field of organization and management, a very common approach to question formulation is the CIMO approach. CIMO, which stands for Context, Intervention, Mechanism, and Outcome, was developed by Denyer et al. (2008). The CIMO approach, developed in reference to this study, is presented below.

CIMO Approach:

- C – Status of research on synchromodal transportation system including the application of physical internet in logistics.
- I – Application of existing models and approaches within the field of synchromodality and physical internet by the port operators.
- M – Mechanisms of utilizing synchromodal transportation system or physical internet concepts by the port operators.
- O – Possible benefits from the implementation of synchromodality in maritime and hinterland transport.

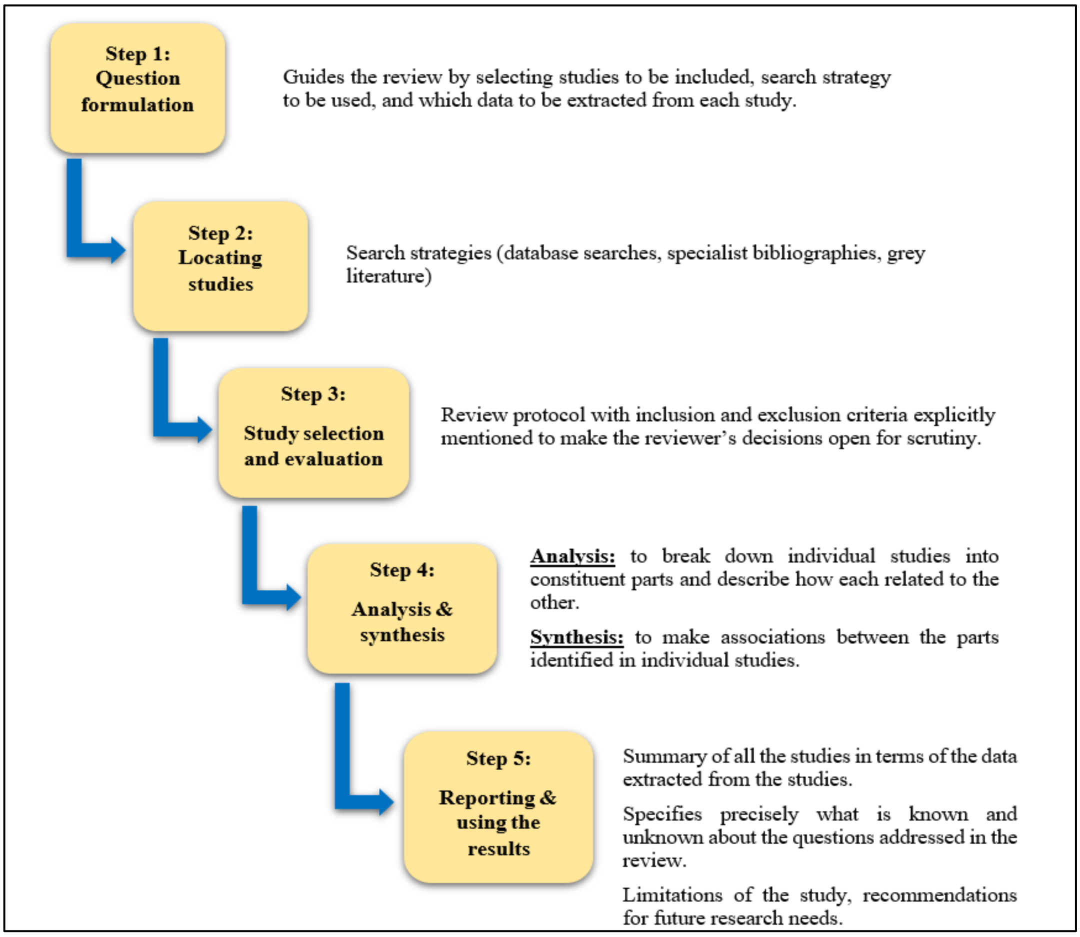

Figure 12. *Steps of a systematic review process, Denyer & Tranfiled, 2009, modified by the author.*

It may be pertinent to mention at this stage that as the field of synchromodal transportation system is a new concept and there is a lack of peer-reviewed quality journal articles, physical internet, which is closely linked to synchromodality, has been included in the CIMO approach to cover all the relevant literature in the field.

Based on the above CIMO approach, the following research questions were formulated:

1) What are the main areas where the existing research on synchromodality is currently focussed upon?

2) What is the understanding and coverage in the existing literature about the marine side of the port business (vessel-port) within the framework of a synchromodal transportation system?

3) What are the mechanisms which can link the marine side of operations in a port with its hinterland transport operations within the framework of a synchromodal transportation system?

Another important step in the systematic review process is protocol development. The primary aim of a systematic review is to identify, select, and review as much as possible of the relevant research in the field. This is done prior to a systematic review being undertaken and the purpose is to detail precisely how the review will be conducted. The protocol is analogous to and as crucial as a research design for an empirical study (Antman et al., 1992; Cook et al., 1997).

The approach used to accomplish this task (database selection, search strategies, inclusion, and exclusion criteria) need to be reported in detail to avoid any selection bias and to let others scrutinize the strategy of the reviewer. The protocol developed for this study is explained in detailed in the next sub-heading, i.e., data collection.

2.2 DATA COLLECTION

For the identification of relevant literature in the field, this study has considered all the relevant literature published on synchromodal transportation and the physical internet. Although this study is about port and maritime transport in the synchromodal transport system, the field of synchromodality is itself a very new concept, having been first coined in 2010, and restricting the literature search specific to port would severely restrict the review material. Therefore, to cover all the relevant studies in this field, the scope has been widened to include all literature on synchromodality, including the physical internet, which is a closely linked concept in the field of synchromodal transportation system. In addition to the inclusion of the physical internet in the literature search, grey literature (Master's and PhD thesis work) was also included to widen the scope and include all previous work done in this field. This criterion is unique to a systematic review and is different from the normal literature review. In a normal literature review, the attempt is to include only peer-reviewed work. However, in a systematic review, grey literature, like non-peer-reviewed work i.e., academic thesis work is also included.

The search strategy (search databases, search strings, and results) is presented below in table 1.

Sl. No.	Database	Search String used	No. of literature results
1	Science Direct	"synchromodal*"	104
		"synchromodal*" AND "Port"	74
		"synchromodal*" AND "Physical Internet"	26
2	Scopus	"synchromodal*"	114
		"synchromodal*" AND "Port"	15
		"synchromodal*" AND "Physical Internet"	6
Total publications using both sources			**339**
Removing the duplicate publications			
Total publications after removing duplicates			**221**
Evaluation with reference to inclusion and exclusion criteria filters			
Final number of publications for analysis			**116**

***Table 1**: Search strategy. Source by author*

The process flow for the data selection is presented in figure 13. First, extensive searches were performed in two popular databases, Scopus and Science Direct, using various search strings in title, keywords, and abstract as mentioned in Table 1. These databases were chosen as they cover a substantial portion of literature in this field and the grey literature is often not included in their results. In addition to these standard searches, Google Scholar was used to identify two master's thesis work on the topic of synchromodality.

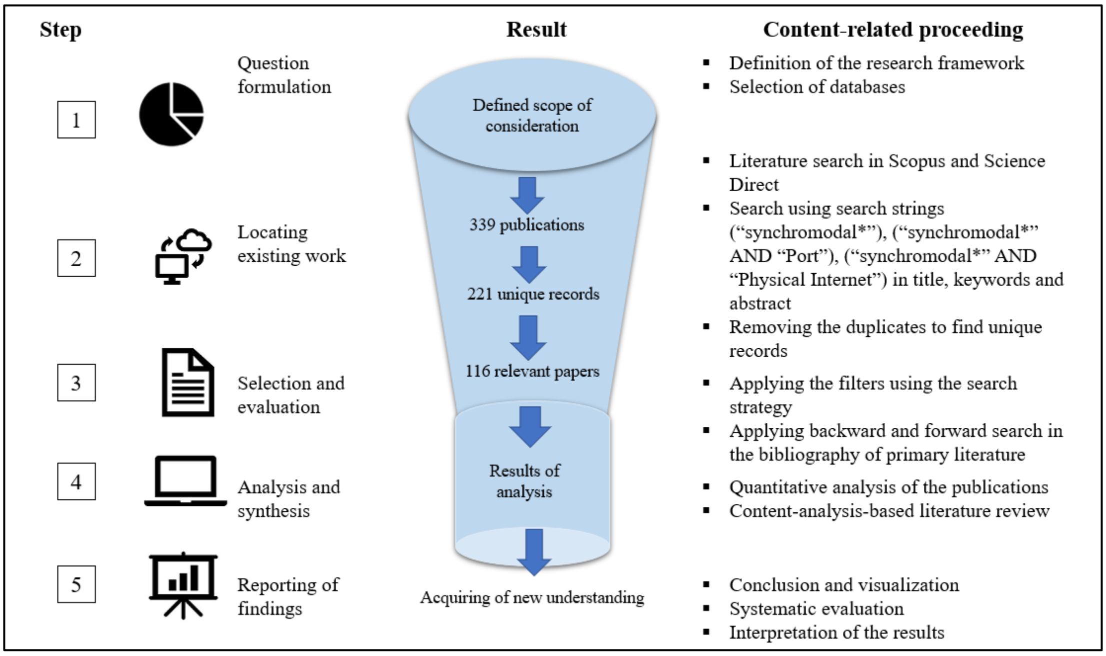

Figure 13. *Steps in identification & selection of literature on synchromodality as suggested by Pfoser et al. (2021), modified by author.*

There was no constraint put on the period of publication because this being a fairly new concept starting from 2010, any constraint on the year of publication will severely restrict the relevant papers for review. The language of publication was restricted to English and other languages were excluded. Using three different search strings for both databases, a total of 339 results were obtained. These results were exported to a citation manager software (RefWorks) and after the removal of all duplicate results, the total number of publications was limited to 221. These 221 publications were evaluated using the Rayyan tool for systematic review and the filters developed for this study. The filters developed for this study are to exclude those publications that are merely mentioning synchromodality once or twice without any further explanations of this concept or any of its key aspects like real-time mode switching, mode-free booking, etc. Each of the 221 publications was evaluated with the Rayyan tool for the presence of keywords "synchromodal", "synchromodality", "synchromodal transport", "physical internet", "intermodal transport", and "multi-modal transport". Intermodal and multimodal transport were included as keywords because there are many instances in the literature where these two concepts are used as a premise to explain synchromodality. Only the publications with these keywords in their abstract or title were included for analysis and others were excluded as non-relevant publications for this study. The filters also considered excluding the results that are dealing exclusively with the computer programming aspects of the physical internet, rather than its application in the field of logistics. Finally, the data set is reduced to 116 relevant publications, which also included the literature retrieved using backward and forward searches of the primary literature, to be analysed for their content (quantitative and qualitative) in the next chapter of this thesis. The list of these 116 records is included in appendix 1 at the end of this study.

3. CHAPTER 3: DATA ANALYSIS & FINDINGS

Once the appropriate data set of relevant literature is collected for review, the data analysis commences. The analysis of the 116 records, as selected in chapter 2, has been done using quantitative methods to see the geographical spread of the papers and the growth in the number of research over the years. Another type of analysis conducted in this section is the content-based qualitative analysis to dig deeper into the texts and themes of the existing literature to answer research questions 1 and 2.

It is important to highlight to the readers that the review and analysis are done for the 116 papers which are covering the overall field of synchromodality and physical internet, rather than just restricting the scope to synchromodality in port. The literature available on this subject is still very narrow and focuses mainly on the hinterland transport operations of the port business. The study could identify only one paper out of 116 that was specific to the application of synchromodality in ports which is not sufficient to perform any meaningful analysis. Therefore, to broaden the literature base, this study included the papers for all synchromodality related research in its search strategy.

3.1.Quantitative analysis:

Within the purview of quantitative analysis, the dataset of 116 records was analysed statistically to draw inferences regarding the number of publications over the years and their geographical distribution. Figure 14 below shows that synchromodal-related publications (in-line with our search strategy and review protocol, refer to chapter 2) are continuously increasing over the years. The earliest reference to the term synchromodality was first mentioned in a letter by the 'Strategisch Platform Logistiek,' an organization representing the Dutch logistics industry (Strategisch Platform Logistiek, 2010). In this letter, the organization advised the Netherlands' government regarding the development of the Dutch logistics sector and suggested synchromodal transport as a new sustainable and innovative transport concept (Strategisch Platform Logistiek, 2010). However, it took almost five years for the scientific community to show some serious interest in this new concept, as evidenced by the rise of academic publications on synchromodality from 2015 onwards.

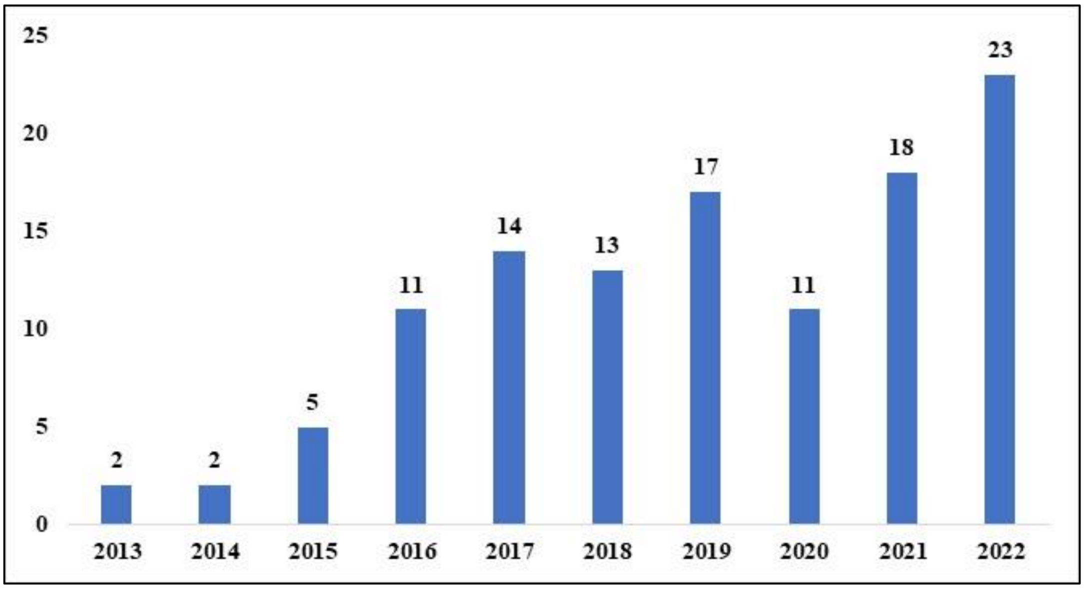

Figure 14. *Number of publications per year on synchromodality (including physical internet)*

Regarding the geographical adaptation and spread of the research on synchromodality, figures 15 & 16 below show the geographical spread of the research publications. It can be inferred that the concept of synchromodality has its origin in the Netherlands and the majority share of the publications is with Dutch researchers. However, gradually over time, publications from other countries are also appearing, although a much lesser share than the Dutch researchers. The concept is gaining attention across the globe with publications from all continents, the majority being from Europe.

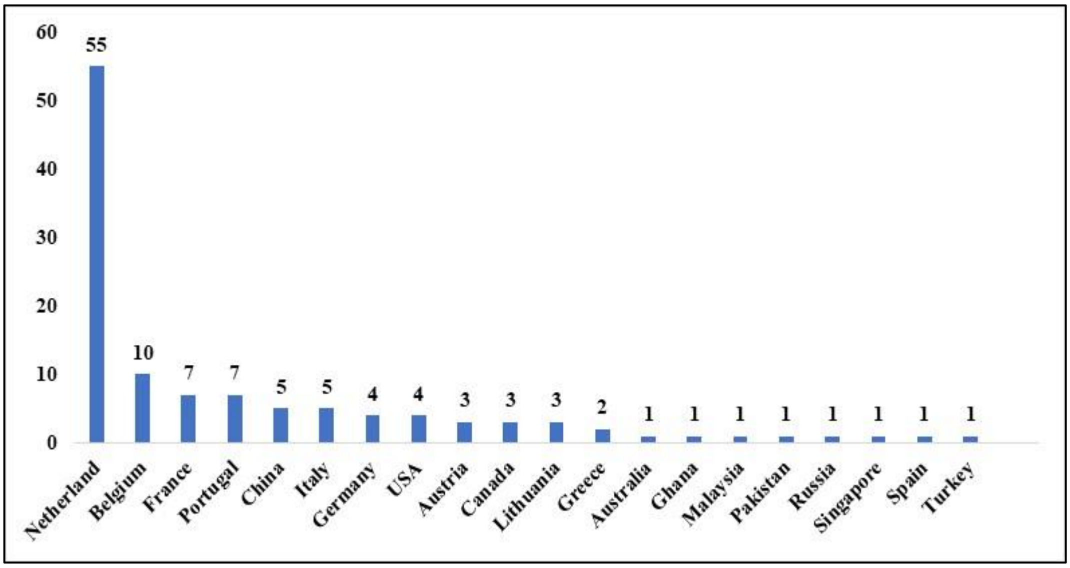

Figure 15. *Number of publications by country on synchromodality (including physical internet)*

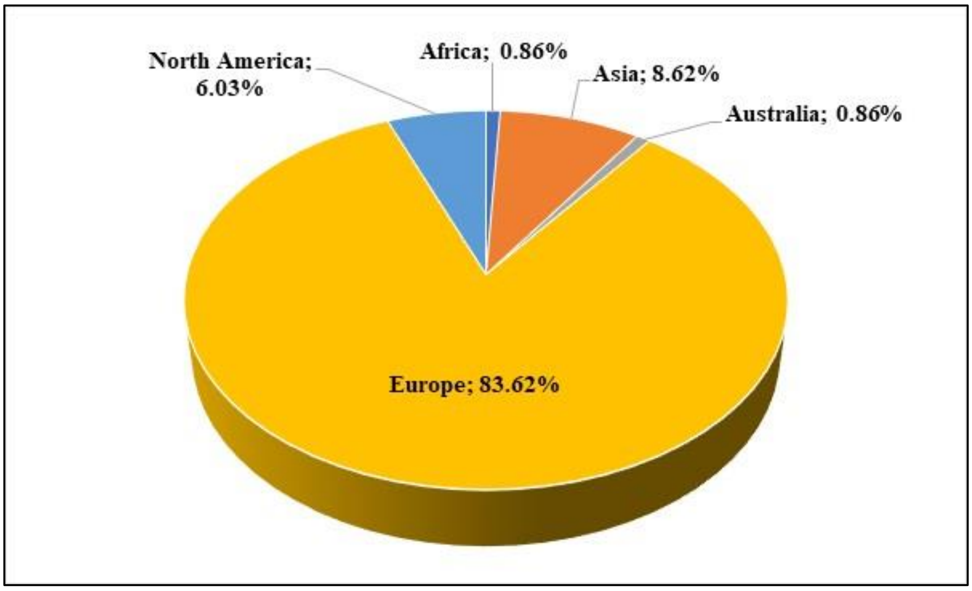

Figure 16. *Continental distribution of the publications on synchromodality (including physical internet)*

Another striking observation while looking at the geographical spread of research publications on synchromodality is that almost all the papers are from developed nations. There are very limited publications from the developing or the least-developed nations (figure 17). This may be due to the lack of technological and digital development in these nations' logistics infrastructure, which is a key enabler for the development of synchromodality.

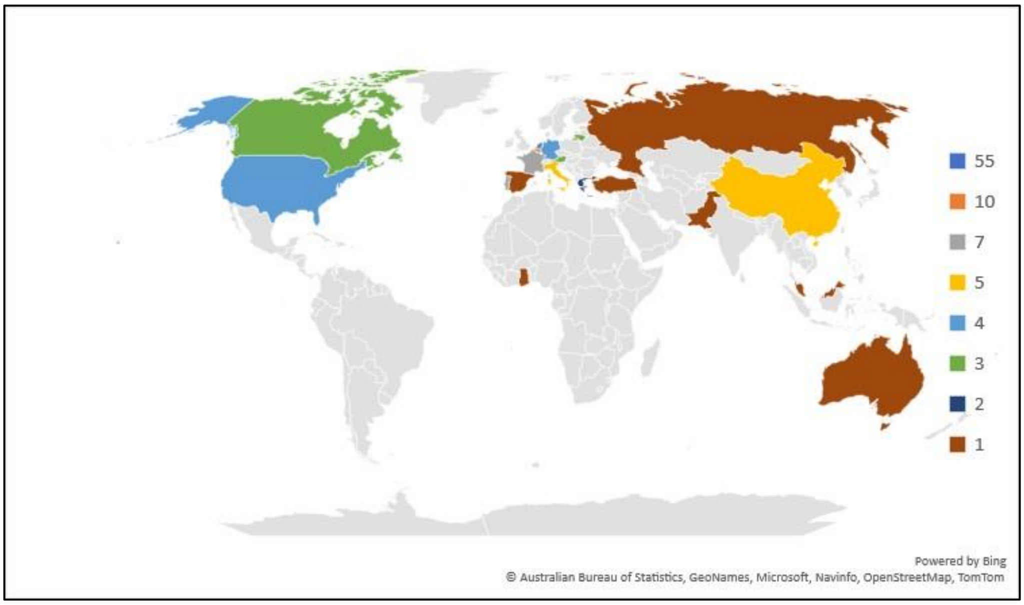

Figure 17*. Geographical coverage of research on synchromodality (including physical internet)*

3.2. Qualitative Content-Analysis:

The two approaches described in the literature regarding content analysis are analysis and synthesis. The aim of the analysis is to break down the individual studies into their constituent parts and attempting to find out any relationship between the parts. On the contrary, the aim of synthesis is to find out the relationship between the themes identified in the individual studies (Denyer & Tranfield, 2009). As the sample size for this study is small (*n* = 116), this review, is considered to be inductive, which is an accepted approach within this methodological domain (e.g., Björklund and Johansson, 2018 or Gosling et al., 2016). According to Agamez-Arias and Moyano-Fuentes (2017), the analysis and synthesis step of a systematic literature review requires a categorical grouping of the selected literature according to similarity and relationship in the themes. Accordingly, the dataset of 116 publications was evaluated and grouped into 6 different focus areas, 4 different broad subjects, and 20 different themes, the rationale for which are explained below in Table 2, Table 3, and Table 4.

Sl. No.	Main Focus Area	Description
1	Hinterland Transport	Main focus of the study is on hinterland transport; port-hinterland side of operations or logistics distribution from an inland terminal
2	Barge Transport	Main focus of the study is on inland waterways transportation through barges from port
3	Transshipment	Main focus of the study is on transshipment operations
4	Port-Maritime Transport	focus of the study is on maritime transport side of the port operation rather than the port-hinterland side.
5	Urban Transport	Main focus of the study is on urban transport and city logistics operations
6	Global transport	focus of the study is on global supply chain holistically within synchromodal transport system

Table 2*: Main focus area of the publications on synchromodality (including physical internet)*

Sl. No.	Main Theme Category	Field of Study
1	Inter-connection & interoperability of logistics systems	Computer engineering
2	Intermodal transport-decision support tool	System design
3	Intermodal transport-environment	Environment
4	Intermodal transport-implementation	Conceptual framework
5	Intermodal transport-modal choice	Modal choice/shift
6	Intermodal transport-robustness	System design
7	Physical internet, inter-connection & interoperability of logistics systems	Computer engineering
8	Physical Internet-decision support tool	System design
9	Physical Internet-digital twin & IoT	Computer engineering
10	Physical Internet-implementation	Conceptual framework
11	Physical Internet-Ports	System design
12	Physical Internet-system design	System design
13	Synchromodal transport-decision support tool	System design
14	Synchromodal transport-environment	Environment
15	Synchromodal transport-implementation	Conceptual framework
16	Synchromodal transport-information sharing	System design
17	Synchromodal transport-modal choice	Modal choice/shift
18	Synchromodal transport-system design	System design
19	Synchromodality & Physical Internet-Interaction	Conceptual framework
20	Synchromodal transport-maritime transport	Conceptual framework

Table 3*: Broad subjects of the publications on synchromodality (including physical internet)*

Sl. No.	Main Theme Category	Description
1	Inter-connection & interoperability of logistics systems	Study forcusses on inter-connection and interoperability in logistics, no mention of synchromodal or physical internet
2	Intermodal transport-decision support tool	relating to development of tools for decision making in intermodal/multimodal logsitics, no mention of synchromodal or physical internet
3	Intermodal transport-environment	relating to environmental aspects in intermodal/multimodal logsitics, no mention of synchromodal or physical internet
4	Intermodal transport-implementation	relating to the concepts, policy, success factors, enablers and challenges in implementation of intermodal/multimodal logistics, no mention of synchromodal or physical internet
5	Intermodal transport-modal choice	relating to factors affecting the choice of mode and modal shift in intermodal/multimodal logsitics, no mention of synchromodal or physical internet
6	Intermodal transport-robustness	relating to uncertainties/disturbances and system resilience in intermodal/multimodal logsitics, no mention of synchromodal or physical internet
7	Physical internet, inter-connection & interoperability of logistics systems	study related to the application of physical internet concept in inter-connectivity and interoperability of logistics systems
8	Physical Internet-decision support tool	relating to development of tools for decision making in physical internet based logistics system
9	Physical Internet-digital twin & IoT	study relating to development of application of digital twins and Internet of Things (IoT) in physical internet based logistics system
10	Physical Internet-implementation	relating to the concepts, policy, success factors, enablers and challenges in implementation of physical internet based logistics system
11	Physical Internet-Ports	study related to the application of physical internet concept in port operations and planning
12	Physical Internet-system design	study relating to development of protocols and prototypes for physical internet based logistics system
13	Synchromodal transport-decision support tool	relating to development of tools for decision making in synchromodal transportation system
14	Synchromodal transport-environment	relating to environmental aspects in synchromodal transportation system
15	Synchromodal transport-implementation	relating to the concepts, policy, success factors, enablers and challenges in implementation of synchromodal transportation system
16	Synchromodal transport-information sharing	relating to the flow of data and information between various stakeholders of synchromodal transportation system
17	Synchromodal transport-modal choice	relating to factors affecting the choice of mode and modal shift in synchromodal transportation system
18	Synchromodal transport-system design	study relating to development of mathematical models, protocols and prototypes for synchromodal transportation system
19	Synchromodality & Physical Internet-Interaction	study relating to correlation and similarities between synchromodality and physical internet concepts within the logistics field
20	Synchromodal transport-maritime transport	study related to the application of synchromodal transportation concepts in maritime transport side of port operations (slow steaming, smart steaming, virtual berthing of ships etc.)

Table 4*: Thematic categorization of the publications on synchromodality (including physical internet)*

Based on the above categories, the dataset of 116 publications was analysed by evaluating the abstract of each publication to gauge the main theme and focus area. The distribution of publications across themes and focus areas is presented below in table 5.

Sl. No.	Main Theme	Hinterland Transport	Barge Transport	Transshipment	Port-Maritime Transport	Urban Transport	Global transport
1	Inter-connection & interoperability of logistics systems	2					
2	Intermodal transport-decision support tool	11					
3	Intermodal transport-environment	2					
4	Intermodal transport-implementation	1	1		1		
5	Intermodal transport-modal choice	11					
6	Intermodal transport-robustness	1					
7	Physical internet, inter-connection & interoperability of logistics systems	1					
8	Physical Internet-decision support tool	1					
9	Physical Internet-digital twin & IoT					1	
10	Physical Internet-implementation	1					
11	Physical Internet-Ports				1		
12	Physical Internet-system design	1		1		1	
13	Synchromodal transport-decision support tool	19	2	1			
14	Synchromodal transport-environment	1					
15	Synchromodal transport-implementation	18					1
16	Synchromodal transport-information sharing	6	3				
17	Synchromodal transport-modal choice	5					
18	Synchromodal transport-system design	17				1	1
19	Synchromodality & Physical Internet-Interaction	2					
20	Synchromodal transport-maritime transport				1		

***Table 5**: distribution of publications on synchromodality (including physical internet) across themes and focus areas*

Further analysis reveals the distribution of publications as per their main themes as shown in figure 18. It is evident from this graph that most of the researchers have worked on the technical aspects of synchromodal, physical internet, and intermodal systems, i.e., the decision support tools, system-design, etc.

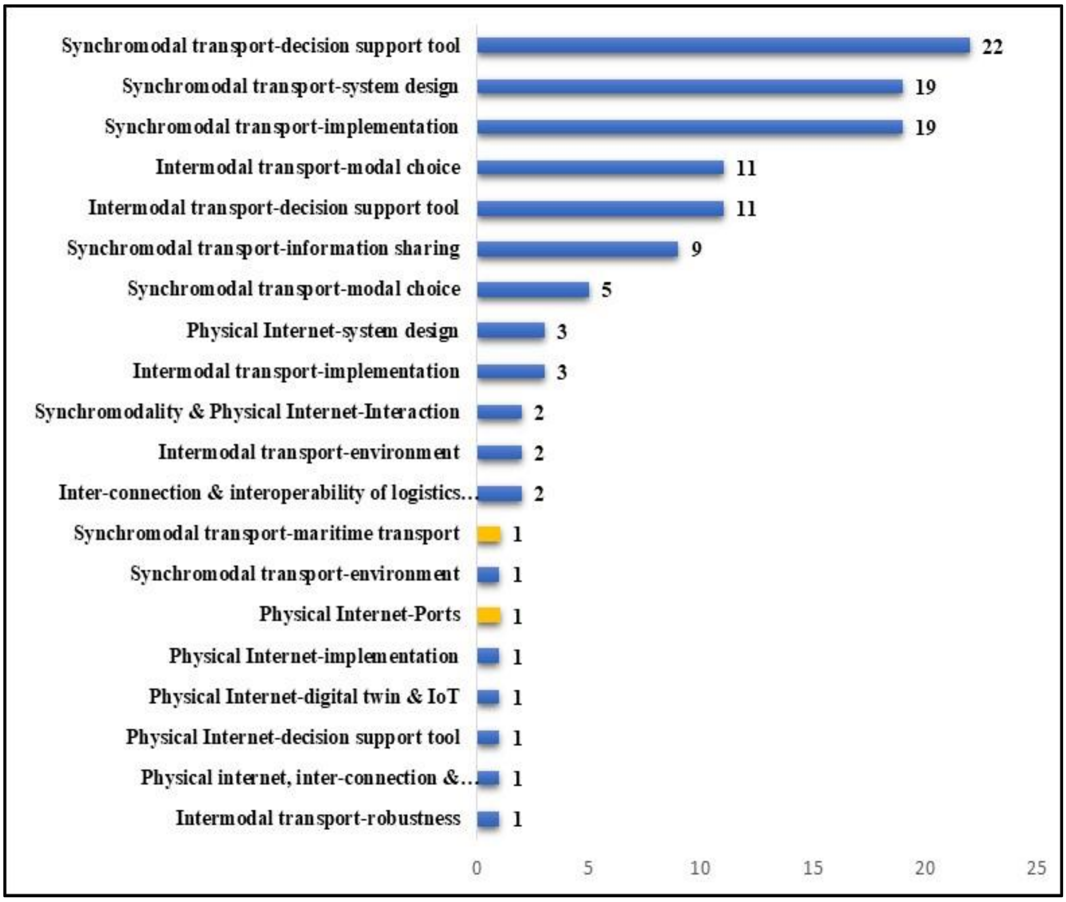

Figure 18. *Thematic distribution of publications on synchromodality (including physical internet)*

When the subject area within which the study has been conducted is analysed for all 116 records, an interesting insight is visible (Figure 19). The majority of the research has been done on the subjects of system designing and formulating conceptual frameworks (80.17%).

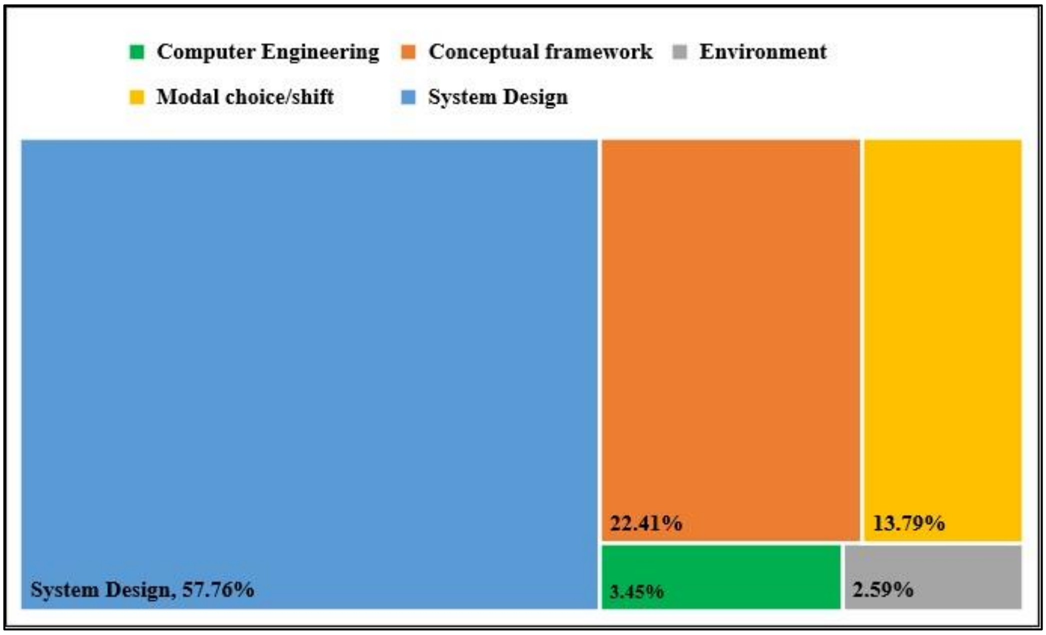

Figure 19. *Subjects within which research has been done on synchromodality*

However, within these two subjects, only 3.23% of the studies are focussing on port-maritime transport. If all five subjects are considered, the share of studies focussing on port-maritime transport is as low as 2.59% (Figure 20).

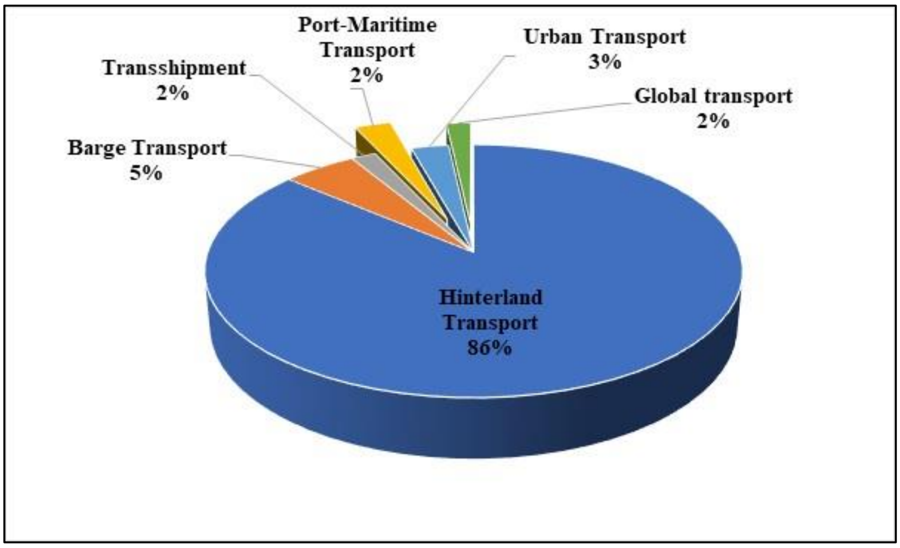

Figure 20. *Publications on synchromodality (including physical internet) based on focus area*

Another interesting insight is the coverage of research on the concept of physical internet which is closely linked to the concept of synchromodality. Out of 116 publications, only 5.17% were found to cover the physical internet. The research on synchromodality has been done only for a specific leg of the logistics chain, i.e., there is no sufficient literature where this concept has been explored as a holistic supply chain concept on a global level. Except for one publication (Guo W. et al., 2022), synchromodality has not been explored as a global supply chain concept. Almost all the publications (synchromodal, intermodal or physical internet) are mostly referring to hinterland logistics (86%) and research focusing on the maritime transport part of the port operations is almost absent. Although the port is a central theme in many of the publications, while evaluating the content closely, it was observed that in these studies only the port-to-hinterland aspect of port operations has been considered with reference to the application of synchromodality or physical internet. Out of 116 papers, this study could locate only one paper (Giusti et al., 2021) which is specifically addressing ocean transport operations with reference to a seaport for the implementation of a synchromodal transport system. This study has also focussed mainly on the concept of slow steaming and smart steaming and not much has been covered with reference to the management side of the port. A port is a system where various stakeholders with diverse objectives and interests are interacting. Management decisions within a port, which can balance the diverse interests of these stakeholders, are of crucial significance if a synchromodal transportation system is to be implemented because at the core of synchromodality is a highly efficient information exchange which cannot happen if the stakeholders' interests are not balanced.

Having analysed the content of all publications it is evident most of the research is focussed on the technical side of the field, i.e., model formulation, system design, conceptual framework, and modal shift/choices. The study identifies and categorises the areas within synchromodality that the researchers have mainly focussed upon so far. Also, it was observed that there is a research gap in the field of synchromodal transportation system with reference to the inclusion of the marine side of a port as most of the research is focussed on the hinterland side when discussing synchromodality. This analysis tries to answer research question number 1 and 2. In the next chapter, the author will answer research question number 3 by introducing a conceptual framework that can be used to integrate the two sides of port operations, i.e., the port-to-hinterland side and the port-to-maritime transport side.

4. CHAPTER 4: CONCEPTUAL FRAMEWORK FOR PORT

4.1 BACKGROUND

The analysis and findings presented in chapter 3 have highlighted the fact that there is very limited research about the role of maritime operations and management within a port when considering a synchromodal transport system. Due to the lack of evidence in existing literature, future researchers and industry practitioners will not be in a position to judge correctly which is the correct way to link the two sides of a port, i.e., the ocean transport side and the hinterland transport side. As the port is a system that connects the two sides together, it is of vital importance that there is a mechanism that can link the two sides together so that a real synchronization is feasible as far as the port is concerned. Therefore, this study will try to propose a framework that can be used by industry practitioners and future researchers for this purpose.

4.2 THE NATURE OF PORT BUSINESS

To understand and define the role of ocean transport operations in the overall port functioning and synchromodal transport operations, it is important to first define a concept called as ‘maritime transport chain.’ As defined by Schönknecht (2009), a transport chain is a sequence of various processes and relationships of a loading unit (e.g., a container) with the resources required for carrying out the transport. Transport chains that include the ocean as a mode of transport can be termed as maritime transport chains (Brümmerstedt et al., 2017). Figure 21 illustrates the general structure of such maritime transport chains.

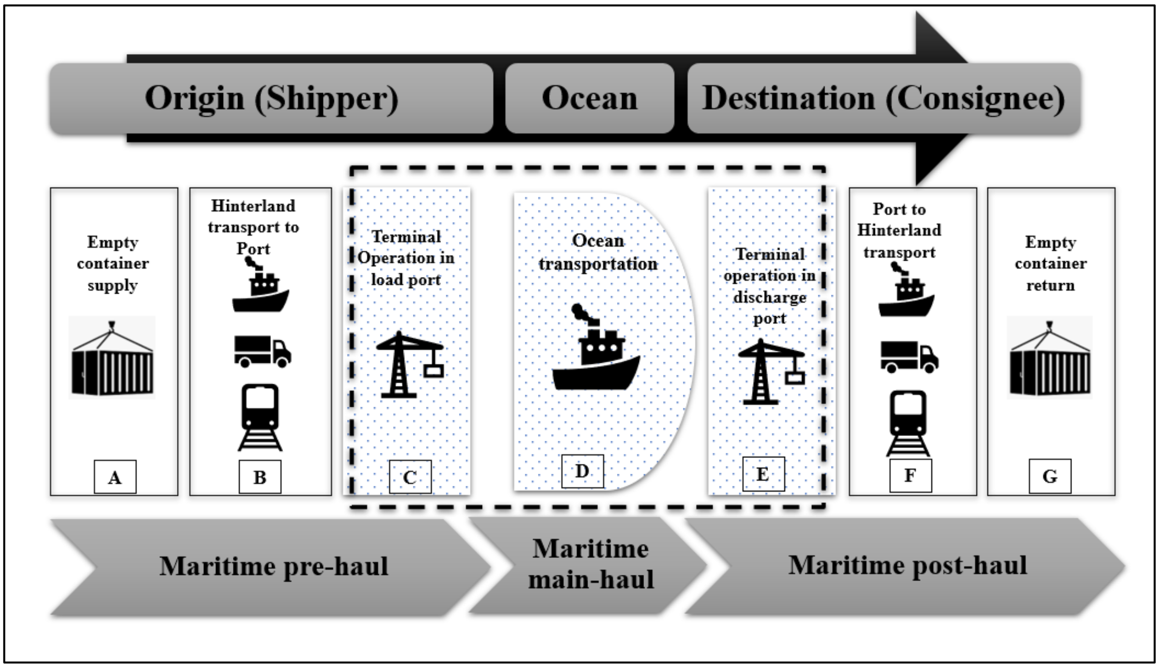

Figure 21. *Sections of a maritime transport chain, adapted from Brümmerstedt et al., (2017), modified by author*

As figure 21 illustrates, the maritime transport chain can be divided into three distinct parts.

a. Maritime pre-haul: A & B (supply of empty container by shipping line for loading, loading of the container at shipper's premises as well as its hinterland transport to the port by road, rail, or inland barges)
b. Maritime main-haul: C, D & E (handling of the container at load port, its ocean transportation, and handling of the container at discharge port)
c. Maritime post-haul: F & G (hinterland transport from the port by road, rail, or inland barges, unloading of the container at consignee's premises, and return of the empty container to the shipping line)

In this chain, the maritime pre-haul and maritime post-haul has been covered by the researchers in the existing literature on synchromodality as part of the hinterland transportation to and from the port. However, maritime main-haul is the part that has received little or no attention in the existing literature with reference to synchromodal transportation. It is evident from figure 21 that this part is the central node in the chain and truly integrated synchromodal transportation cannot be achieved if this node is not synchronized with the other two components of the chain.

The process of maritime main-haul is a complex combination of various sub-processes that are carried out inside a port and can be understood from the port production process. The Port production process is the way factor inputs (e.g., capital, labour, and land) are employed by port service providers to produce output which may be ships handled, cargo handled, or revenue earned among other things. There are three different perspectives through which the port production process can be seen: vessel, cargo, and the hinterland transport (Yap, 2021). All these three perspectives are linked together to form the overall port production process and it is the interlinking of these three different perspectives which is vital for the success of any synchromodal transportation system within a port. The three perspectives are illustrated in figures 22 to 24.

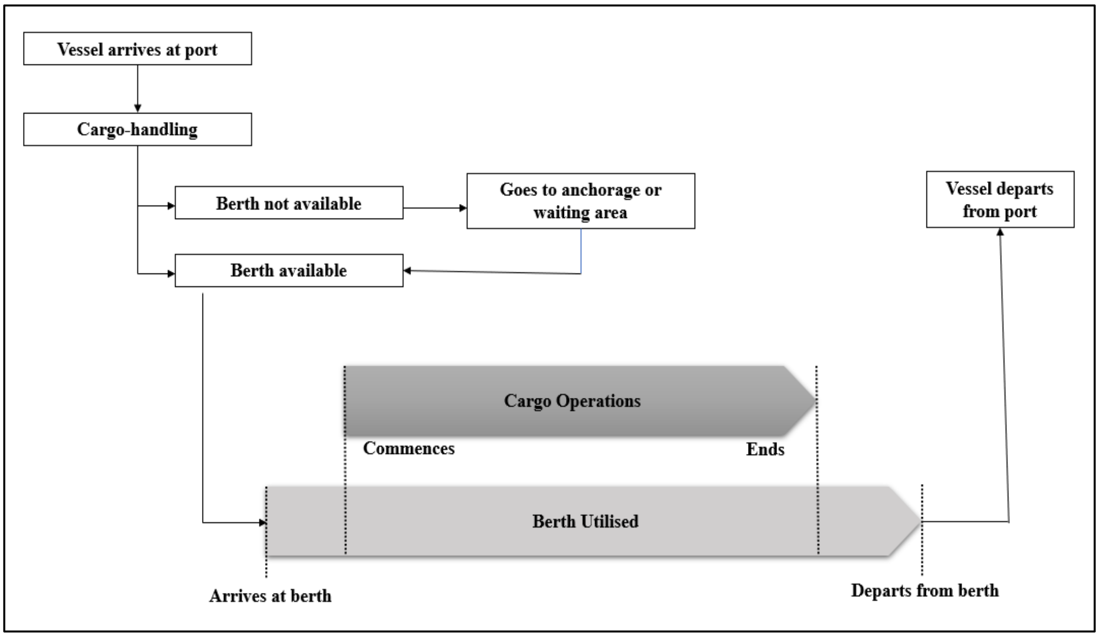

***Figure 22**. Port production process from the vessel perspective.*
***Source:** Business and Economics of Port Management, An Insiders Perspective, Wei Yim Yap, 2021*

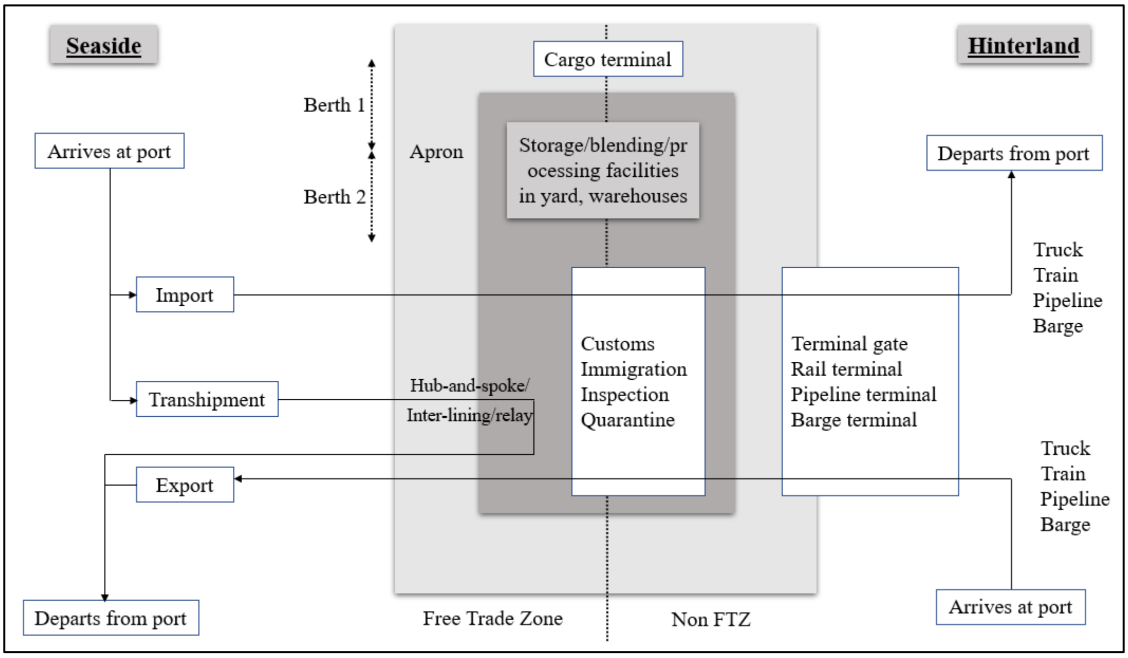

Figure 23. *Port production process from the cargo perspective.*
Source: *Business and Economics of Port Management, An Insiders Perspective, Wei Yim Yap, 2021*

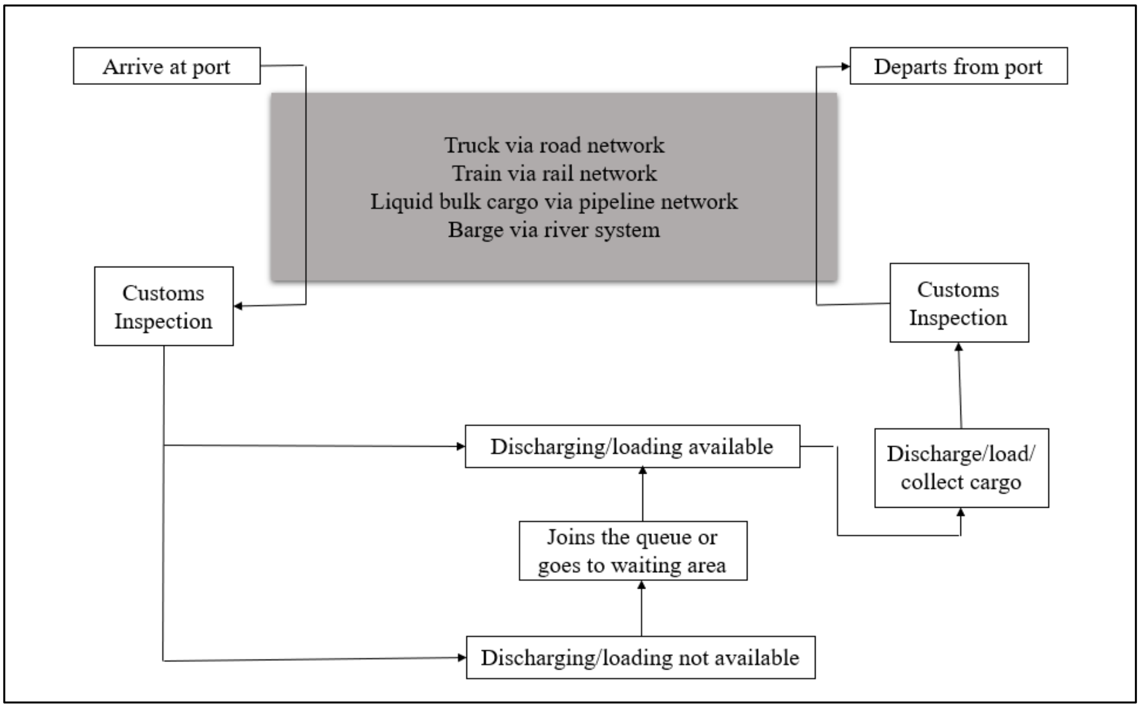

Figure 24. *Port production process from the hinterland perspective.*
Source: *Business and Economics of Port Management, An Insiders Perspective, Wei Yim Yap, 2021*

The purpose of reproducing the three perspectives, as suggested by Yap (2021), is to make the readers understand the complicated nature of the port business and the multiple layers of complexities involved. It is a known fact in business that whenever a process involves multiple layers of complexities and various stakeholders in the same system, there are possibilities of miscommunication due to incorrect information flows which may result in undesired inefficiencies in the system. Therefore, it is of vital importance that the three are linked and synchronized with each other. To achieve the inter-linking, technology plays a vital role as an enabler of improved productivity and efficiency, enhanced service levels, and reduction of costs for the port users (Yap, 2021). While discussing the three perspectives separately, it must be appreciated that in reality these processes happen simultaneously inside a port and each one is affecting the other. There are multiple stakeholders involved in the process and each one is having their own objectives and interests. Communication and information flow is of vital importance here for the success of the system. and it is further complicated by variations in traffic arrival patterns. Traffic arrival pattern is stochastic by nature and can vary substantially, especially between the peak and non-peak periods. For synchromodality to be successfully implemented in a port, an understanding of the traffic variations is essential as it profoundly affects the planning process. According to Wei Yim Yap (2021), there are two most significant causes of variations in port traffic; seasonal factors and economic events. Seasonality refers to fluctuations in traffic volumes related to particular events such as major holidays or weather-related occurrences like typhoon season, or even the working hours inside a port. For example, it is common to find morning and evening peaks in the arrival of cargo inside a port from the hinterland transport modes. Economic events can also severely disrupt the traffic arrival pattern in a port. A surge in demand, for example as a result of strong GDP growth, can lead to a shortage of berths or terminal capacity in a port. The resulting port congestion will cascade through the supply chain, particularly on hinterland transport modes with long queues of trucks outside the terminal gate and a large number of ships waiting at the anchorage for berthing. This situation was evident during major parts of 2021 in the port of Los Angeles/Long Beach in the USA where at the peak of congestion, almost 100 container ships were waiting at anchorage. There is an old saying in the shipping business, “A ship is earning only when she is sailing.” A vessel waiting at the anchorage is not beneficial to anyone.

The shipowner or the charterer of the vessel loses money due to idling and the environment around the port vicinity is adversely impacted due to exhaust from the vessels.

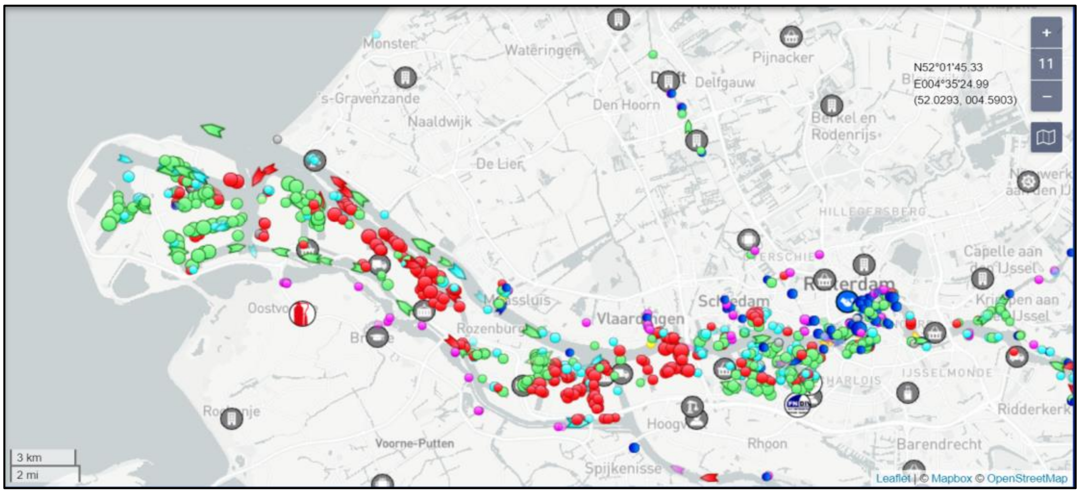

Figure 25*. Vessels waiting off Rotterdam as of 15 September 2018*.*
Source: *MarineTraffic.com*
**Circles indicate vessels at stationary*

In case of congestion, the vessel has to spend a longer time at the port and the vessel operator has to incur time costs. If the entire supply chain is considered as a single system, this increase in the time cost of the vessel will also reflect in an increase in the overall logistics cost which is a factor of the cost incurred towards vessel deployment, mobilisation of hinterland transport assets and diversions to alternative routings through other ports in case of severe congestion. This increase in the overall logistics cost brings down the logistics efficiency of a country and ultimately leads to uncompetitive exports and imports.

In addition to the seasonal and economic events leading to variations in traffic arrival for a port, non-adherence to the schedule, especially for the container vessels, also complicates the problem for the port. In this era of just-in-time production processes adopted by factories and the practice of keeping minimum inventories, vessels arriving too early or too late pose serious scheduling problems for the entire supply chain.

4.3 IMPACT OF MEGA CONTAINER VESSELS ON PORT BUSINESS

In addition to the various factors affecting the traffic arrival at a port, there is another factor that has become more prominent in the last few years and is expected to pose ever-increasing challenges for the port business. Over the last several years, there has been an increase in the adoption of ever-larger container vessels in the trade. Particularly significant in this regard is the rise of dimensionally largest ships in their class, the so-called Ultra Large Container Vessels that can no longer pass through the new locks of the Panama Canal. The term Ultra Large Container Vessel (ULCV) emerged in the early 2000s to describe model designs that were beyond the largest container ships of the time in terms of dimensions and capacity. At that time, Maersk C-class (Capacity 8650 TEU) was the largest container ship ever built (CRSL 2021). According to Jungen et al. (2021), although there are no clear and uniform criteria for when a container ship becomes a ULCV, the term is usually used for the largest ships into certain classes based on their nominal slot capacity in TEU. The various relevant thresholds for ULCVs are, for example, 14,500 TEU (Sahoo, 2021), 15,000 TEU (Lian et al., 2019), or even 18,000 TEU (Heaney et al., 2020). Figure 26 illustrates that post-2016, there is a clear trend towards an increase in the share of these larger vessels while the other smaller vessels are decreasing or flattening in their respective shares. The ever-increasing ship size has broken another record in 2022, with Taiwan-based Evergreen Line ordering multiple ships with a capacity of over 24,000 TEUs. The primary reason for the shipping lines to deploy ever larger vessels is the economies of scale that comes with an increase in the carrying capacity of the vessel, thus reducing the cost per TEU transported. These massive ships, although economical for the shipping lines, are a challenge to the ports where they call because of the requirement of resources to handle these ships and the pressure to increase terminal productivity.

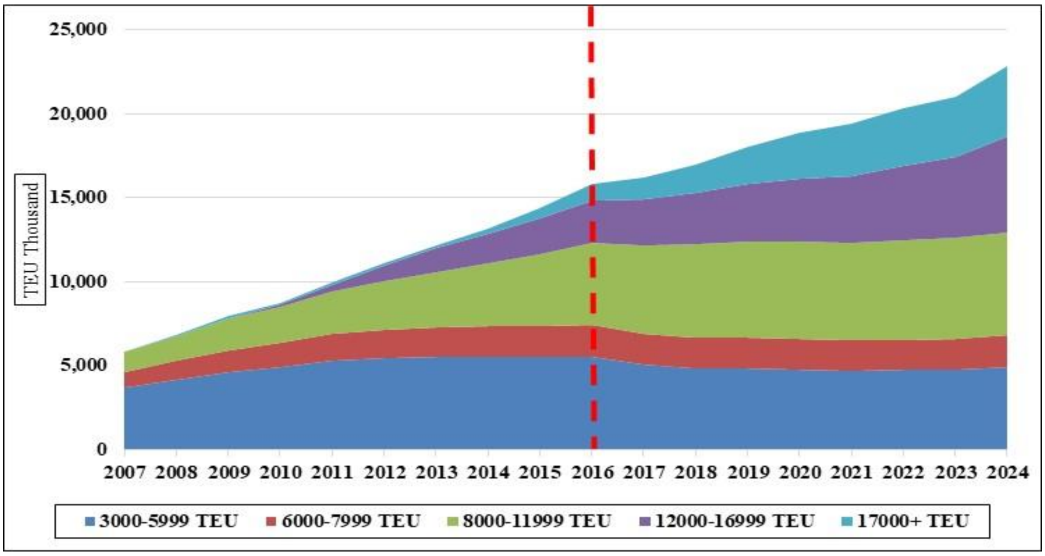

Figure 26*. Fleet development as per vessel size category (TEU Thousand)*
Source: *Clarkson Shipping Intelligence Network (SIN) database, 2022.*

Due to the very high capital intensity of these ULCVs paired with slow-steaming strategies, any non-productive port stay time risks the productivity of these vessels (Haralambides, et al., 2019, as cited by Jungen et al., 2021). As a result, there is increasing pressure on the terminal operators to improve their productivity and reduce the port call time while handling these mega vessels. The performance requirements given to the terminal operators by the shipping lines operating these mega vessels are becoming ever-challenging. For example, the shipping line 'Maersk' has stated a target of up to 5000-6000 moves per day which corresponds to 208-250 moves per hour for ULCV calls (WorldCargo News 2011, as cited by Jungen et al., 2021). Due to the high capacity and operational requirements for berthing space and crane capacity, it is extremely challenging for the terminals to ensure flexibility or even make up for delays.

The combination of ever-increasing call sizes and the ever-tightening productivity norms often lead to high peaks at the terminals during the handling of these ULCVs. Peaks occur when there is an intensified workload spread over a very short duration of working hours (Martin et al., 2015; Lane & Moret, 2014). As highlighted in the previous sub-sections, berthside terminal operations have a direct linkage with yardside operations and hinterland transport operations. Any delay in the berthside operation will invariably cascade down to the yard and the hinterland transport which affects the entire supply chain for the users. As the pressure to reduce port calls of these ULCVs is high, the containers which are to be loaded need to be provided in due time at berth, and the unloaded containers need to be transferred to the yard. For this to happen, storage operations at the yard need to be managed in order not to constraint the berth-side operations. It is reported that ULCV-induced peaks correlate with higher utilization in terminal yards (Merk et al., 2015), which puts pressure on the limited storage space.

These peaks also adversely affect the landside interfaces of the terminal, as incoming and outgoing containers are to be delivered and collected in temporal relation to the port call. Some researchers have found that there exists a relationship between call sizes and increased hinterland traffic volume, especially road transport (Merk et al., 2015). The ports which are having a high modal share of road transportation often show increased gate congestion with the handling of larger vessels (Ozbas et al., 2014).

As the negative effects of handling larger vessels in a port in terms of cost and efficiencies are mostly borne by the terminal operators and the users of port services, these negativities are still dealt with peripherally, and so it is primarily the cost effects of operating ULCVs from an isolated shipping lines perspective that dominated the discussion. The fact that the operation of ULCVs also involves costs and negative 'externalities' is often overlooked (Jungen et al., 2021). However, critical events like the accidents of CSCL Indian Ocean in 2016, CSCL Jupiter in 2017, the ONE Milano Bridge in 2020, and the six-day blockage of the Suez Canal in March 2021 have highlighted the challenges posed by these mega vessels and the undesirable impacts it can have on the global supply chains. At the root of the problems relating to the peaks and troughs in traffic arrival patterns and the impacts of handling ULCVs is the coordination and efficient operations between various stakeholders within a port production process. Therefore, it can be argued that the above factors play a crucial element in the success of a synchromodal transportation system within a port.

4.4 STATE OF SYNCHROMODALITY IN MAJOR EUROPEAN SEAPORTS

As highlighted in the previous section, the rising share of ULCVs in container shipping poses the risk of peaks and bottlenecks in the terminals. These bottlenecks and fluctuations have the potential to cascade down to the hinterland transport nodes. By intelligently combining and switching between different transport modes the concept of synchromodality could form a solution for improving hinterland transportation and easing of bottlenecks in a container terminal while handling the ULCVs (Tavasszy et al., 2015).

To achieve the objectives of synchromodality in maritime transport chains certain prerequisites are to be fulfilled which are categorized into seven categories by Putz et al. (2015). These seven categories can be summarized into four main categories due to their overlapping characteristics as illustrated in figure 27. There have been earlier studies to study the implementation of synchromodality in three major European seaports, i.e., Rotterdam, Antwerp, and Hamburg based on these four broad categories to see whether the whole concept of synchromodality or only single aspects are realized in these ports, as illustrated in table 6 (Brümmerstedt et al., 2017).

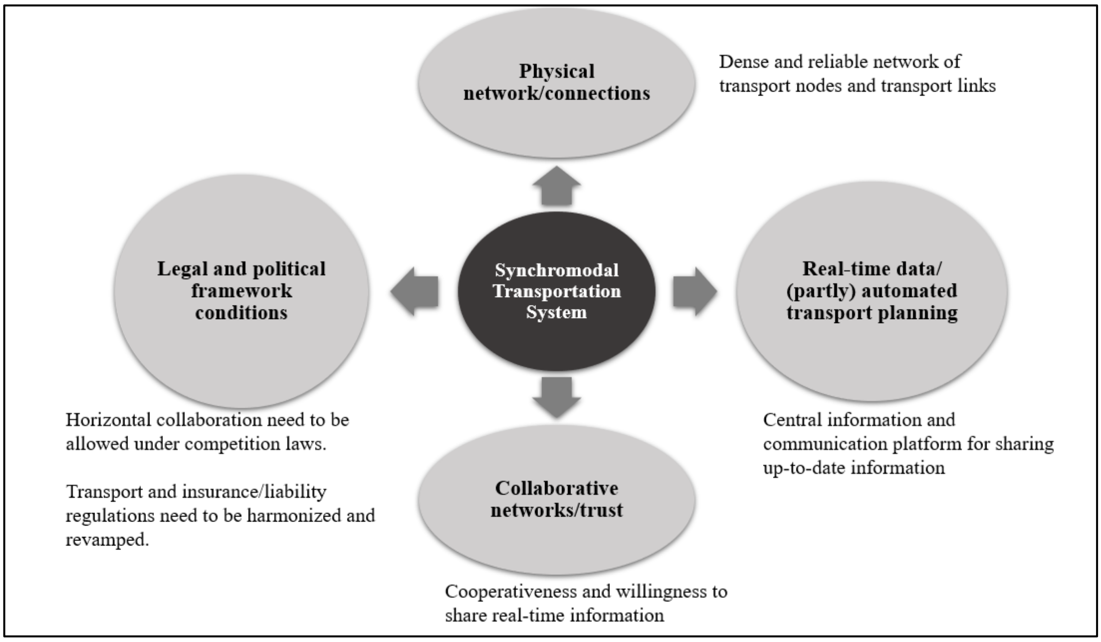

Figure 27*. Identified prerequisites for synchromodality, adapted from Brümmerstedt et al., (2017), modified by author*

Prerequisite for synchromodality	Rotterdam	Antwerp	Hamburg
Physical network/connections	→	→	→
Real-time data/(partly) automated transport planning	↑	→	→
Collaborative networks/trust	→	No data available	↓
Legal and political aspects	↑	↑	↑

Table 6*. Aspects of synchromodality in the major European container ports,* ***Source:*** *Brümmerstedt et al., (2017).*
Note: *green upward arrow: full compliance; yellow horizontal arrow: partial compliance, and red down arrow: no compliance.*

As per this study conducted and summarized in table 6, it is evident that none of the three ports are in full compliance with all the four essential prerequisites for synchromodality. Among these three ports, the Port of Rotterdam brands itself as a synchromodal port, as per ECT, where the hinterland transport is organized by European Gateway Services (EGS). Although the Port of Rotterdam brands itself as a synchromodal port, the network of Extended Gateway terminals is still too small. The complete underlying synchromodal network comprises of a total 25 terminals in six countries (ECT, as cited by Brümmerstedt et al., 2017) which means that not all hinterland transport can be organized in a synchromodal way. In addition to this aspect, another thing to be highlighted is that there has been no attempt in these ports to include the marine side of port operations within the realm of synchromodality. The focus, even in the Port of Rotterdam, has been on the hinterland side of operations. Synchromodality has the potential to provide a long-term solution for optimizing the hinterland transport of a seaport, reducing the container dwell-time in the Port of Hamburg, increasing the storage capacities of the container terminals within the Port of Hamburg, and by that increasing the reactiveness to peaks in berthside container handling due to ever-increasing size of container vessels. However, there is a lot of groundwork to be done in the Port of Hamburg to implement synchromodality. Port of Rotterdam has demonstrated that smaller-scale synchromodality concepts can be successfully implemented (Brümmerstedt et al., 2017). Even though synchromodality is a part of the broader Physical Internet roadmap until 2050 (ETP-Alice, refer to chapter 1, figure 5), the current state points towards a slow adoption and progress, and the focus on the inclusion of the marine side of port operations is lacking.

4.5 THE CONCEPTUAL FRAMEWORK

Based on the discussions so far in this chapter as well as the previous chapters, it is evident that there is a need to define the mechanisms through which the maritime transport operations side of the port business is synchronized with the hinterland operations. There have been multiple research and conceptual frameworks developed by previous researchers regarding the hinterland operations of a port. The area where there has been no attempt so far to devise a theoretical or conceptual framework is the maritime operations. As the concept of synchromodality is still in its infancy stage, there is no consensus and universal understanding is very limited in the sense of how to practically implement it and the ways in which organisations can be encouraged to adopt this idea. Therefore, in this sub-section, the author will try to devise a conceptual framework specifically for this part of the port business and explain how it can be synchronized with the already established hinterland synchromodality frameworks.

Before going into the details of the framework, it is important to define what a conceptual framework actually signifies. A conceptual framework is a synthesisation of interrelated components and variables which help in solving a real-world problem. It is the final lens used for viewing the deductive resolution of an identified issue (Imenda, 2014).

In the following sections, the study will identify certain operational and managerial antecedents which can be applied to the concept of synchromodality. The antecedents are the requirements and/or some challenges that need to be fulfilled and/or overcome to implement synchromodality. In hinterland operations, the synchronization aspect deals with multiple modes of transport that need to be in sync with each other. However, when considering the marine side of port operations, there is only one mode of transport involved, i.e., ocean transport, and all the synchronization problems are related to the synchronization of operations and management between the vessel and the port. According to the conceptual framework proposed by Pfoser et al. (2021), there are four key mechanisms identified for synchromodality, i.e., Real-time switching, Integrated network planning, horizontal collaboration, and mode-free booking. However, the author believes that this conceptual framework is primarily designed for hinterland operations and is not entirely applicable to the marine operations of a port. Reasons for this are the varying nature of the marine side from the hinterland side within a port, mainly related to the legal regime of vessels, the number of modes of transport, the international nature of the stakeholders, etc. Therefore, this study tries to extend the conceptual framework of Pfoser et al. (2021) to the marine side of the port business by adding certain mechanisms and dimensions which are unique to this part of the port business. The author would also like to propose a new term for this part of the synchromodal system 'Synchro-Marine,' to highlight the fact that there is only one mode with multiple synchronization challenges. This conceptual framework is illustrated in figure 28 and explained in the following sections of this chapter.

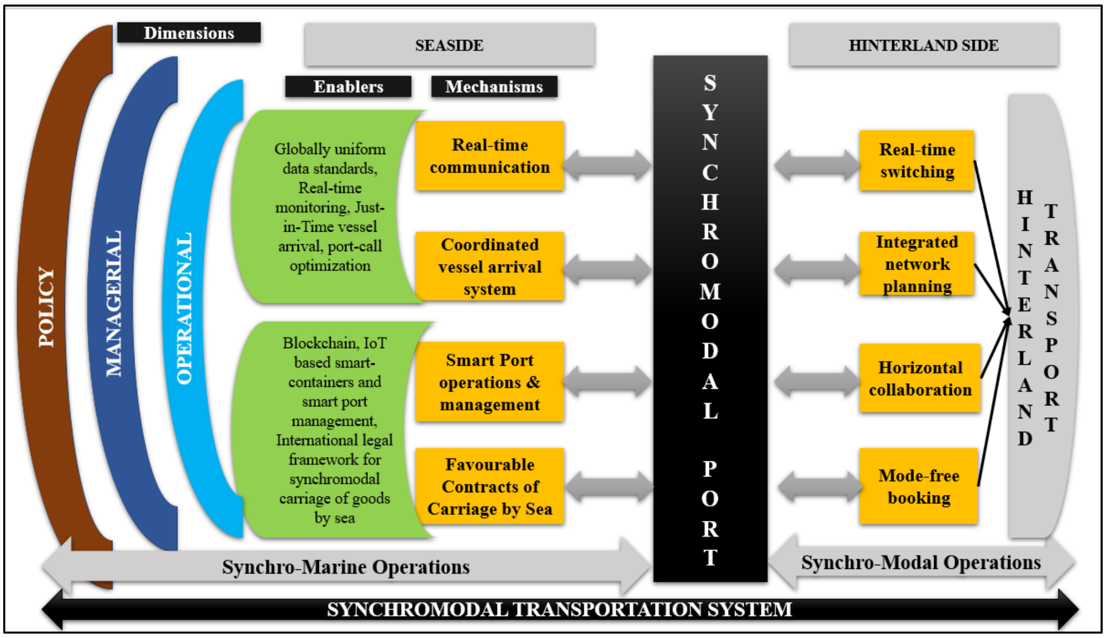

Figure 28. *A conceptual framework for Synchro-Marine Operations in a Synchromodal Port*

The above framework focusses on the marine side of the port business in a synchromodal port, which was defined in the preceding chapters as ‘synchro-marine.’ The hinterland side of the framework is taken from the model proposed by Pfoser et al. (2021). The proposed framework is divided into four mechanisms and three dimensions. Various enablers, not an exhaustive list, are identified for each of the mechanisms. This synchro-marine part of the port will link to the synchro-modal part, i.e., the hinterland operations, to form an integrated synchromodal transportation system. The three dimensions identified in this framework are; operational, managerial, and policy dimensions. All these three dimensions cut across the four mechanisms for a successful implementation of the synchro-marine system. Since the port is in the centre of such a system, it is in the best position to act as the integrator and balancer between the two sides of the port business. These are the building blocks of this framework which are explained in the following sub-sections of this chapter.

4.5.1: Real-time communication

The success of a synchronized system depends upon effective and smooth communication between the different stakeholders. Just as there are multiple parties on the hinterland side of the port business, here are multiple stakeholders involved in the marine side of the port business too. For example; Ship owners, charterers, vessel crew, nautical service providers (towing, pilotage, navigational aids, etc), shipping agents, stevedores, customs and immigration authorities, coast guard, etc. to name a few. To ensure a smooth flow of information exchange and data sharing, it is necessary that these stakeholders follow a certain uniformity either through operating under a common data platform or through adopting universally accepted data standards which is equally adaptable to different data platforms. It is important to recognise here that these stakeholders are having different interests and objectives and may not be willing to share the information with each other because of the confidential nature of the information. For instance, a charterer may not be willing to share its inventory position on an open data platform for the fear of losing its bargaining power in the hands of a competitor or a ship-owner. In this scenario, it becomes imperative that there exists a certain mechanism that can ensure data integrity and security, at the same time not compromising on the uninterrupted exchange of information.

4.5.2: Coordinated vessel arrival system

The information shared by the hinterland side of stakeholders (for example the Beneficial Cargo Owners, BCOs) can be aggregated and analysed by the port and passed on to the incoming vessel or vessel operator. In this reference, there are two concepts worth discussing here. One is the smart steaming approach and the other one is the Just-in-Time (JIT) arrival of vessels in a port.

Smart-steaming is the real-time synchronization of the operations by considering the possibility of slowing down or speeding up vessels, according to real-time information and a more comprehensive view of the network with a multi-stakeholder approach. It is the practice of coordinating stakeholders and synchronizing logistics operations through re-planning procedures based on the adjustment of the vessel's traveling speed. The new paradigm aims to globally optimize the efficiency and sustainability of the entire logistics network (Giusti et al., 2021).

Under the European Horizon 2020 (EU Framework Programme for Research and Innovation) project called "SYNCHRO-NET: Synchromodal supply chain eco-NET" smart steaming was appointed for the first time to propose a sophisticated approach covering the end-to-end integration of the global supply chain network. The project was led by DHL but to the best of the author's knowledge, there was no practical implementation of the concept after its formulation in 2018. According to Giusti et al., (2021), the central idea behind the speed adjustment in the smart steaming approach is that with an adequate fleet with a mix of ships sailing at low and high speeds, the ships sailing at a lower speed can compensate for the costs and emissions derived by the ships sailing at higher speed. Compared to different modes, ships have more flexibility to adjust their speed as they are not constrained by congested roads, but could end up waiting longer time in ports if the speed adjustment is not coordinated by the port. Therefore, ports have a central role, as real-time coordinator and communicator, when planning the arrival and departure schedules and handling operations in the terminal. On the other hand, vessels should also communicate with the port, in real-time, when their schedules change for any reason. Therefore, efficient real-time communication between the port and the vessel is the first critical step towards synchro-marine operations.

A closely-linked concept in this regard is the Just-in-Time (JIT) arrival of ships in a port. With the adoption of IMO resolution MEPC.323 (74), in May 2019, IMO invites the Member States to facilitate, among others, actions that support the industry's collective efforts to improve the quality and availability of data and develop necessary global digital data standards that would allow reliable and efficient data exchange between ship and shore as well as enhanced slot allocation policies thereby optimising voyages and port calls and facilitating Just-in-Time (JIT) Arrival of ships (IMO, 2020).

According to the Just In Time arrival guide published by the GloMEEP project coordination unit of the IMO, the concept of JIT Arrival of ships allows for ships to optimize their speed during the voyage to arrive at the Pilot Boarding Place (PBP) when the availability of berth, fairway and nautical services is ensured by the port. A prerequisite for the JIT arrival is the optimization of the port call which generally is not optimized. Ships may steam at an above-optimal speed to the next port only to find that they have to wait at the anchorage. There could be many reasons for this waiting, some of which are; the berth is occupied with other vessels, cargo is not available for loading, Storage yard is full because the hinterland transport connections are congested leading to non-evacuation of stored cargo from the port. The effects of congestion in a port were explained in the previous sub-sections of this chapter. This "hurry up and wait" approach of port calls needs to be optimized for better economic performance which can only be possible when there is a real-time, uninterrupted information exchange between vessel and port, with the port acting as a central coordinator, for the simple reason that port is having control over more decision variables in the system than a vessel or any other stakeholders in the port production process.

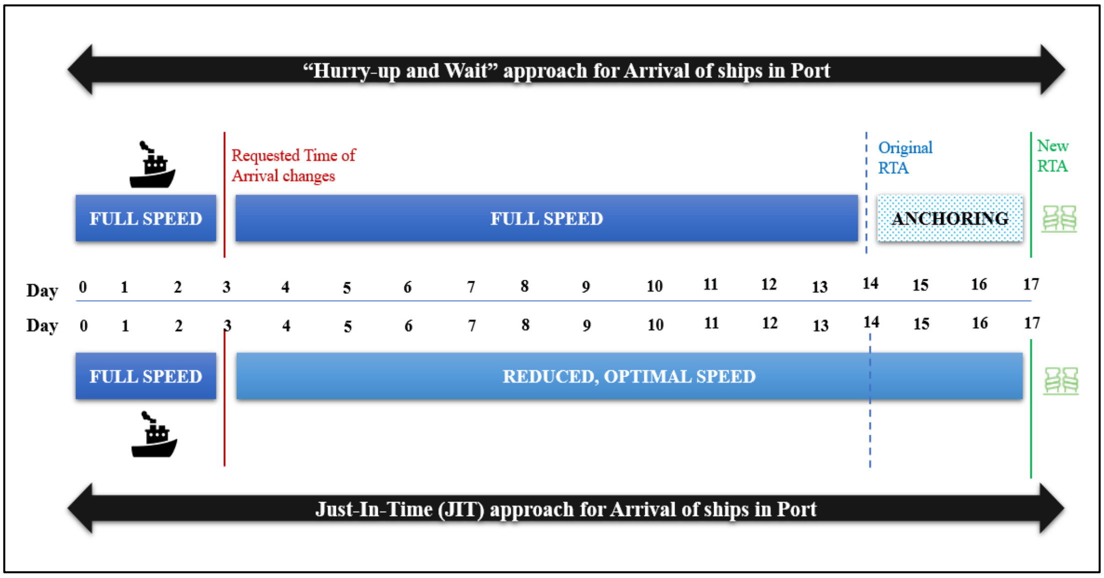

Figure 29*. Today's approach for port call Vs JIT Arrival approach, source: IMO, 2020*

Figure 29 illustrates that in contrast to this "hurry up and wait" approach, JIT Arrival of ships slows a ship to maintain the optimal ship operating speed to arrive at the Pilot Boarding Place when the availability of: 1. Berth; 2. Fairway; and 3. Nautical services (pilots, tugs, and linesman) is ensured (IMO, 2021). This arrival time, calculated on the basis of the availability of these three aspects, is called the Requested Time of Arrival (RTA). In addition to these three requirements for the Requested Time of Arrival to the Pilot Boarding Place (RTA PBP), the author suggests the inclusion of additional aspects like cargo readiness and hinterland connections readiness to arrive at the RTA PBP. In a JIT scenario, RTA PBP is communicated frequently to the ship while it is under voyage, thereby enabling the Master to decide on the optimisation of ship's speed. RTA PBP is calculated by the Port Authority, taking into account:

- Maximum sizes and conditions of the ship
- Availability of berth, fairway, and nautical services
- Clearance of other authorities e.g., customs, immigration, etc.

As highlighted in the explanation of the port production process (refer to figures 22-24), there are multiple stakeholders involved in a port call, thus making the JIT arrival challenging to implement. It requires close collaboration and effective data exchange between ships, shipping agents, port authorities, terminal operators, nautical services (e.g., tugs, pilots, etc.), and vessel services (e.g., bunker barges and waste collectors).

Port production business is an inherently complicated system and to operate effectively and efficiently in such a system, all stakeholders require visibility of the vessels and the ports they are calling. Stakeholders across the supply chain need to share up-to-date, reliable information about each vessel's location, its speed, and the shipment it carries-as well as data on the terminals and locations where the shipments may be collected (or delivered) in order to efficiently connect maritime vessels with other modes of transport such as road, rail, or inland barges. Terminal operators, barge operators, freight forwarders, road transporters as well as rail operators will be able to improve their operations when their activities are synchronized (Just In Time) with the operations of the vessel that carries the shipments that are relevant to them (IMO, 2020). This requires the discussion of emerging concepts referred to as "smart port" and "smart containers," which will be discussed in the next sub-section.

4.5.3: Smart Port Operations & Management

The concept of a "smart" port is not new. According to Wei Yim Yap (2021), the idea of "smart" in the sense of technology applied to the port business encompasses the elements of analytics, predictive abilities, and intelligent systems which can learn and adapt automatically in accordance with evolving roles and changing requirements of entities in the port community. These self-learning systems are often referred to as Artificial Intelligence (AI). Advances in information capture, diagnostic capabilities, analytical capacity, and process execution are seeing AI play a greater role, especially with regard to the information and operation related dimensions of the port business. AI is defined as the "theory and development of computer systems able to perform tasks normally requiring human intelligence, such as visual perception, speech recognition, decision-making, and translation between languages" (Yap, 2021). There are many areas where AI can be applied within the context of port business. These include aiding real-time decision-making, intelligence augmentation, predictive analysis, problem solutioning, and strategic optimization among other applications. As highlighted by Yap (2021), the scope of AI applications in a port community is underscored by the intricate web of information and transaction linkages which encompasses the communities of shippers, shipping lines, supply chain operators, terminal operators, port service providers, and trade facilitators as well as other government agencies including tax authorities and R&D agencies. AI allows knowledge and competencies to be harnessed across an entire port community instead of just a few companies and organisations previously. This aspect of a “smart” port is at the core when it comes to enabling the synchro-marine system within a synchromodal port. New technological possibilities are offered by emerging concepts like blockchain-based transactions which allow verification of port community transactions to be done electronically and autonomously. Blockchain technology has the potential as a key enabler of real-time information exchange within the context of synchromodality in port by allowing different entities to work through different platforms without the need to migrate to one single system.

Similar to the concept of a “smart” port is the emergence of “smart” containers with situational awareness capabilities which is changing the way containers were seen before. According to Becha et al. (2020), situational awareness can be defined as “knowing what is going on around us”, or – more technically – as “the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future”.

When the door-to-door transportation of goods is considered in the context of the global supply chain, goods are transported by several modes of transport and through multiple transhipment hubs. There is a huge number of players involved in the transportation chain but none of them have a full visibility of the trip execution. Smart containers provide the necessary data streams to allow for the status of the goods and carrier operations.

Smart containers are traditionally intermodal containers – with added electronic devices like Internet of Things (IoT), enabling them to sense, interact, and communicate with the data platform. The added electronics enable tracking and monitoring of a container trip and the conditions under which the container and its cargo have been transported. Such a container can be designed to share near real-time physical data such as location to the users of the transportation system (Becha et Al., 2020). This helps in enabling a near real-time visibility between various stakeholders across the supply chain during the container's entire journey.

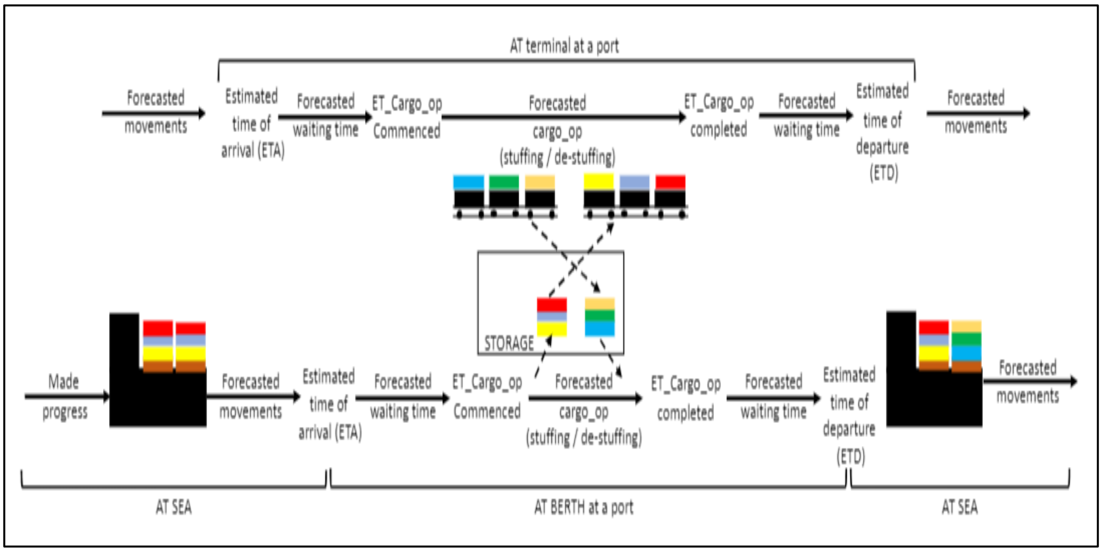

***Figure 30**. Movement of containers by ships and trains (as example of carriers) movements with visits to transshipment hubs (ET = Estimated time), **Source**: Becha et al., 2020)*

Figure 30 illustrates movements and an intermodal shift at a transshipment hub involving two means of transport. It is critical for the Beneficial Cargo Owners (BCO) to get insights into the movement of the goods along the intermodal transport chain to plan their processes efficiently. As a foundation, the smart container would have the capability to communicate location progress and by combining this data with data on plans/forecasts associated with the movement and operations of containers, it would be possible to predict goods' time-of-arrival at the final destination with high precision. BCO can use this information to optimize its inventory levels (Becha et al., 2020). This effectively means that the process of container transport and handling in a terminal can be synchronized with the process of inventory planning and production processes.

Another key development regarding the smart port concept is the "digital twin". Port of Antwerp, where this technology is now implemented, defines it as the digital copy of the entire port area (including equipment, superstructures, and infrastructures), with real-time information. The position of ships, containers, equipment, and vehicles can be visualised in the computer system and planned in advance. Smart containers in itself are not an indispensable part of a smart port but utilising the real-time location of smart containers while they are in-transit to the port (laden as well as empty boxes), coupled with the concepts of AI, intelligent machines, blockchain platforms, and digital twins, a port can plan their resource utilization and move towards the journey of synchromodality in a much better way.

4.5.4: Favourable Contracts of Carriage by Sea

The final mechanism in the proposed framework for the synchro-marine system is the enablement of a favourable legal regime for synchromodal transportation. As highlighted before in this study, the majority of studies on synchromodality are focussed on hinterland transportation. The author can identify one of the possible reasons for not venturing into ocean transport operations when researching synchromodal transportation as its international nature. When the scope of synchromodality extends from hinterland transport to maritime transport (main-haul, refer to maritime transport chain, figure 21), it includes an international legal regime through Contracts of carriage by sea, e.g., Carriage of Goods by Sea Act (COGSA), the Hague-Visby rules, etc. which define and govern the execution of charter party clauses for merchant shipping. When merchant shipping is included in the synchro-marine system, the legal regime needs to support this system. For example, if we take the JIT arrival of ships or the smart steaming approach, under the existing charter party clauses, many charterers or operators are obliged to bring the vessel to port during a certain period (laycan) which is not in sync with the RTA. Similarly, under the charter party clauses, vessel operators are not allowed to reduce the speed below a certain speed which is guaranteed in the charter party clauses. Another issue may arise concerning the insurance and liability regimes. Vessels are governed by the international carriage conventions and the insurance & liability provided by the Protection & Indemnity (P&I) clubs as well as the Hull & Machinery (H&M) insurance is subject to international regulations. These legalities need to be in sync with the emerging concepts of JIT arrival, smart steaming, and other approaches to enable synchromodality.

In summary, it can be concluded that all these four mechanisms and their enabling tools are components of a broader framework that involves the operational, managerial, and policy decisions from the port's side. Port has to play a central role that ties together all these elements of the framework to work in tandem for the functioning of the "synchro-marine" as well as the "synchro-modal" part of the overall synchromodal transportation system. The Port is in a better position to take over this responsibility compared to other stakeholders because it is the port production process where all the stakeholders converge and diverge. As these enabling mechanisms are still in their infancy and concept stage, a lot needs to be done regarding a truly integrated synchromodal system. The mechanisms as considered in the existing literature are not sufficient to achieve a full synchronization because ocean transport needs to be dealt with differently from hinterland transport because of its global nature and jurisdictions.

In the next and final chapter, this study will highlight some of the limitations of this research and future research recommendations.

5. CHAPTER 5: RECOMMENDATION & CONCLUSION

This study has tried to summarise the existing literature in the evolving field of synchromodal transportation system through a literature review process. In the process, the study has tried to contribute towards a better understanding of the current state of research on synchromodality by identifying the existing focus areas and themes where the researchers have mostly focussed (=research question 1). This was achieved based on the analysis of a total of 116 relevant publications related to the field of synchromodality, physical internet, and intermodal transport were selected after defining the search strategy and filtering criteria.

In addition to this aspect, the study has also tried to highlight the lack of research on maritime transport operations within a port when considering synchromodality in transport and provided evidence that the research is biased towards the hinterland side of operations. This was achieved using quantitative and qualitative content analysis of the existing literature in this field to establish that there is a lack of sufficient research on the understanding of the marine side of the port business under a synchromodal transportation system (=research question 2). The study could identify only one research out of 116 records that were specifically dealing with the marine side of the port under a synchromodal transportation system.

Furthermore, the study has tried to construct a conceptual framework by identifying the mechanisms, enablers, and dimensions, that can be used to include the maritime transport operations side of the port business into the overall synchromodal transport system (=research question 3). In this attempt, the author has proposed a new term “synchro-marine” for the maritime transport part of the port business, when referred to within the context of synchromodality. This was done to differentiate this side of the port with only the ocean as a mode of transport from the hinterland operations where multiple modes of transport are involved. The study tried to highlight and emphasize the significance of emerging digital tools which can be used to achieve the objective of synchromodal port. The author believes the proposed conceptual framework will add to the understanding of the maritime transport side of a port business in its inclusion into the synchromodal transport system, which was non-existent in the existing research.

5.1: Limitations of this study & future research recommendations

As the field of synchromodality in transport is still in its early stage of research and the practical application is very limited or non-existent in the industry, there is a lack of field-level data and case-studies related to its practical application in the industry. There have been a few pilot projects but except for the port of Rotterdam, there is no evidence of this concept being used in any other place. Although there is a growing interest in research in this field across different countries, the literature available on the subject is still very narrow and focuses mainly on the hinterland transport operations of the port business. To broaden the literature base, this study included intermodal transport in its search strategy because the literature covering synchromodality and physical internet was not sufficient to perform any meaningful analysis.

Based on the challenges identified in this study and the conceptual framework proposed, the author identifies certain specific areas within the maritime transport operations of a port business that future researchers in the field of synchromodality can focus upon. These are elaborated below:

a. Legal framework for synchromodality in maritime transport:
   As highlighted in the conceptual framework, the international nature of maritime transport makes it challenging to include in the synchromodality. Future researchers need to explore the interactions and modalities in which the international legal regime, especially the carriage conventions and charter party clauses, affects synchromodal transport with respect to the ships. Further research is also required to explore the role of insurance and liability regimes under a synchromodal maritime operations scenario.

b. Study based on the type of shipper: LCL Vs FCL
   Another interesting comparison can be made to identify any similarities or differences when adopting a synchromodal transportation system by the type of shipper, whether it is a Less than Container Load (LCL) or Full Container Load (FCL). These two shippers are fundamentally different in their transport requirements in terms of price and time sensitivity, and it will be useful to see the effect of adopting synchromodal transport from their perspective.

c. Pricing mechanisms in synchromodal transportation system

As the research on synchromodality is gaining popularity and practical applications are also beginning to appear, although extremely limited, future researchers can focus on studying the pricing aspects within a synchromodal system. In a synchromodal system, the idea is to de-link the price with the mode of transport and link it with the service levels agreed between the logistics service provider and the user of the service. It needs to be studied and explored how such pricing will be decided and by whom? Since the transport sector, particularly road transport, is highly fragmented and unorganized, a shift from mode-based pricing to service-based pricing can be challenging to implement.

d. Global end-to-end synchromodality & the role of port:

Future researchers may also focus on studying the role of a port in synchromodal systems which are synchronized end-to-end globally on a cross-country basis (from the shipper's factory in one country to the consignee's factory in another country). Whether the port will play a role in such a system, or it will be controlled mostly by the shipping lines and large multi-national integrated logistics service providers is an area worth studying.

For any field of knowledge that is emerging and in the infant stage, it is natural that there will be multiple areas within the field which are yet to be explored and studied. Synchromodality and Physical Internet is a multi-disciplinary field of knowledge involving researchers from business, computer engineering, transport engineering, law, policy, and economics. Each of the three dimensions, as mentioned in the proposed framework (operational, managerial, and policy), provides an opportunity for research in itself and open further sub-dimensions for study. It will be enriching for the research community to see some more practical applications of this concept across industries and geographies to test the theory in practical situations. The concept is gaining popularity among researchers from different countries, although the numbers are still biased towards Europe. Going forward, it will be interesting to see how this concept picks up in the less developed countries which are poorly equipped with the necessary digital infrastructure required for synchromodality.

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APPENDIX 1

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