Synchromodality in Transportation: A Comprehensive Literature Review on the use of Data-Driven Approaches and Real-Time Management

Full paper

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Abstract

In recent years there have been numerous challenges for global logistics. One of the concepts that can be utilized to address these challenges is synchromodality. However, it seems that there does not exist a well-defined framework to structure and guide its research and its implementation. Considering the high dependence of this concept on data-driven methods and technologies (as its main enablers), there is a need to address this gap from this point of view. In this research, backed by the literature in the field of logistics and also data-driven methods, a fourth level of management (i.e. real-time) is added to the classic three (Strategic, Tactic, and Operational) to address this relationship between data- driven methods and synchromodality. Using this four-level framework, the literature of synchromodality is analyzed. Further on, using another framework the use of different data-driven technologies in the different stages of decision making in the field of synchromodal transport is discussed. In light of the result of these analyses, authors hope that future researches and implementations of the concept of synchromodality will become facilitated.

Keywords: Logistics; Synchromodality; Data-Driven; Multimodality; Intermodality

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Abstract
In recent years there have been numerous challenges for global logistics. One of the concepts that can be utilized to address these challenges is synchromodality. However, it seems that there does not exist a well-defined framework to structure and guide its research and its implementation. Considering the high dependence of this concept on data-driven methods and technologies (as its main enablers), there is a need to address this gap from this point of view. In this research, backed by the literature in the field of logistics and also data-driven methods, a fourth level of management (i.e. real-time) is added to the classic three (Strategic, Tactic, and Operational) to address this relationship between data-driven methods and synchromodality. Using this four-level framework, the literature of synchromodality is analyzed. Further on, using another framework the use of different data-driven technologies in the different stages of decision making in the field of synchromodal transport is discussed. In light of the result of these analyses, authors hope that future researches and implementations of the concept of synchromodality will become facilitated.

KEYWORDS
Logistics; Synchromodality; Data-Driven; Multimodality; Intermodality

1. Introduction

1.1. General Context

The need for logistics operations has gone through an evolution from mostly local needs into an international level. When talking about logistics, one would think of the means of transport immediately. Using several modes of transport in international trade, i.e. multimodality, has been a common practice throughout the history, however, the official definition and coinage of the term, dates back to 1980, where multimodality was defined as the use of at least two means of transport in a transportation service (United Nations. 1980). In 20th century, and in search of more efficiency, the concept of a standard transportation unit, standard containers, the concept of intermodality was put forth, where handling in transshipment points would become minimized and in turn, the efficiency increases (Pfoser, S., Kotzab, H., and Baumler, I. 2021). Cranes, trucks, and storage areas were designed and built to follow suit.

So far, more or less, this is the concept of intermodality and multimodality that is being implemented all over the world. Two other concepts, namely co-modality and combined transport were also recently introduced to promote more efficiency and sustainability (Reis, V. 2015; Pfoser, S., Kotzab, H., and Baumler, I. 2021), however, they are basically about setting improved goals for multimodality and intermodality. The concept of synchromodality has been introduced in the recent years as an attempt to reach further timeliness, resilience, reliability and sustainability in freight transport. Synchromodality involves switching the mode of transport and conducting real-time re-planning and rescheduling, to ensure further resilience and efficiency of the logistic chain in case of a contingency : shipment no longer wanted in the destination or a change in the requirements of its delivery, or a simply a disruption in one or several modes of transport.

This added resilience and reliability has become more important in the recent years through different challenges and crises. The effects of the COVID19 crisis are still affecting international logistics and it showed us how vulnerable this system is to disruption. Political issues also can always create unpredicted disturbances in the logistics chain. The war in Ukraine, the political tensions and the trade war between the United States and China, the tumultuous Middle East, and even tensions among different parties (globalists vs nationalists) can also degrade the quality of the service in the domain of logistics. The pollutions caused by freight transportation also remain a very serious side effect of global trade.

1.2. Challenges

The efficiency of international transport system is one of the most important subjects addressed by countries and unions, notably European Union (to name a few: (European Commission. 2006, 2011, 2019). Every year numerous projects are funded extensively to tackle problems in this field. Nonetheless, there are still numerous problems in today's logistics systems.

The low resilience and reliability of international logistics still wastes much time and energy and causes extravagant costs. According to Sea-intelligence.com the reliability of schedules are still between 30-40% (Murphy, A. 2022). even with all the robust planning and mathematical optimizations in place. It is clear that logistics and supply chain actors must increase the level of their collaboration to face such risks. This can start with more flexibility on the subject of data-sharing. In the case of COVID19 crisis the management of supply and logistics chain in the US, faced a high level of unclarity and lack of visibility, despite some collaborations of major private companies (Ngo, C. N., and Dang, H. 2022).

The emissions of transportation remain a very serious side effect of global trade. However, emission change significantly across different modes of transport. Therefore, there is a necessity to facilitate switching to modes with lower emissions. Furthermore, the introduction of the concept of slow-steaming indicates that simple and accessible actions can change the level of emissions significantly. Thus, the importance of every possible action to reduce the emissions. This environmental problem is still a global challenge despite all the international resolutions (from the Kyoto agreement to the Glasgow's) and despite efforts on part of European Commission (European Commission. 2006, 2011) and the international private or public companies (The Climate Pledge group. 2023).

However, it is not only emissions that subdue sustainability; the need for ever- growing size of ships and warehouses and ports change ecosystems and the quality of life drastically for humans and wild life (Nefs, M., Zonneveld, W., and Gerretsen, P. 2022). The working condition in these big structures sometimes hit the titles; strikes are a common risk in ports and in big logistics companies such as Amazon, in which annual turnover of employees can exceed 100% (Kantor, J., Weise, K., and Ashford, G. 2021).

Furthermore, political issues can always create unpredicted disturbances in the logistics chain. The war in Ukraine and sanctions on Russia, the political tensions and trade war between the United States and China, the tumultuous Middle East, and even tensions among different parties (globalists vs nationalists) and results of elections can change the fate of a seamless efficient logistics chain. Just days after the start of the war between Russia and Ukraine, car industry in Germany was hit hard and damages were felt by the steel industry in Japan (The Wall Street Journal. 2022). In the meantime, there is an increasing interest in short supply chains that supports local products and it is gaining momentum with the changing attitudes of consumers. This can potentially change the fate of many big projects.

Finally, the Last but not least, the congestion of roads (causing 40-70% more pollution in trucks (Holguín-Veras, J., Sanchez-Díaz, I., and Browne, M. 2016)) and the decreasing number of truck drivers, the limited capacity of rail networks, and the long waiting of ocean going carriers in ports, call for a better utilization of logistics capacities.

These are all today's problems which can be alleviated through further research and development and implementation of new ideas.

1.3. Synchromodality and Data-Driven Methods

One of these new ideas is the concept of Synchromodality which seems promising in creating a leap in the evolution of transport. The definition of this concept based on the literature is as follows: the ability to switch among modes of transport and re-plan and re-route cargo in a real-time manner during the course of transport (Acero, B., Saenz, M. J., and Luzzini, D. 2022; Giusti, R. et al. 2019; Khakdaman, M., Rezaei, J., and Tavasszy, L. A. 2020; Pfoser, S., Treiblmaier, H., and Schauer, O. 2016; Pfoser, S., Kotzab, H., and Baumler, I. 2021). This concept joint with data-driven methods can eventually be capable of solving many of these problems. Of course, its implementation remains a big challenge. However, this has not and should not discourage researchers and practitioners to step up and collaborate to implement this concept.

At the same time, it is safe to say that the quality of a decision is highly dependent on the ability of obtaining data and information in high quantity and quality. The story of data in supply and logistics chains started with tracing using the data of merchandise gathered using RFID, and has continued with recent advents in the field of Internet of Things (IoT), with which the data of equipment can also be traced and monitored. Data-driven methods have provided this ability. Data-driven methods in logistics and supply chain management are defined as the use of data in these fields for practices such as prediction, tracking, scheduling and re-scheduling, and resource allocation (Nguyen, D. T. et al. 2022; Srinivasan, R., and Swink, M. 2018; Williams, B. D. et al. 2013). There is a high potential for the use of data-driven methods in logistics in regards with swift and appropriate reactive and proactive actions within the aforementioned context. Numerous studies have proven that data-driven methods, if configured correctly, can provide optimal or near optimal solutions, far better than classic notions of mathematical programming and simulation (Alrobaie, A., and Krarti,

M. 2022; Bousdekis, A. et al. 2021; Maheshwari, S., Gautam, P., and Jaggi, C. K. 2021). In addition, these methods can be coupled with classic optimization and simulation in certain cases especially in prescriptive analysis and in relation with vehicle routing, scheduling, and inventory (Maheshwari, S., Gautam, P., and Jaggi, C. K. 2021).

The needs and timeliness of this literature review is very well justified; synchromodality is a new concept which needs to be understood, structured and used in dealing with the numerous problems of the logistics system of the world (Pfoser, S., Kotzab, H., and Baumler, I. 2021).In addition, now is the time to tie it with the concept of data-driven methods, as the fire power of data science and computer science is exceeding expectations day by day. Furthermore, the concepts of data science and especially Big Data Analysis is now capable of handling an integrated, constant, big flow of data.

1.4. Questions of the Research

Based on the aforementioned challenges of today's transportation networks, it is necessary to research best strategies and practices to manage such a new concept as syncrhomodality; all levels of management must be researched and double checked to see why problems of unreliability persists to different extents. Afterward, given the bulk of studies conducted in these areas, it would be fruitful to research and filter out promising technologies and methodologies. Finally, given the important role of data-driven methods in dealing with real-time problems, the relationship between advancements in data-driven methods and the different challenges of implementation of synchromodality must be researched. Therefore, the Authors in this article will try to answer the following questions:

(1) How can the concept of synchromodality be managed in all levels of management?
(2) In the world of transportation of today, which type of methodologies must be used to tackle synchromodality problematics?
(3) How are data-driven methods used to solve synchromodality problematics and how should they be used and organized?

It is clear that conducting a systematic literature review on the concept of synchromodality while keeping an open eye to detect similar concepts and also the most fruitful methodologies can very well respond to these questions. Thus the purpose of this research.

1.5. Structure of the Article

Based on this introduction, in this article, authors conduct a systematic literature review on synchromodality and data-driven methods used in logistics and based on this review, gaps in the literature and some suggestions in regards with future researches are delineated. This article is structured as follows: in section 2, the methodology of the research and steps of a Systematic Literature Review are explained. In section 3, the literature review is conducted step by step. In section 4, results of the implementation of the methodology on the literature is discussed, and finally in section 5, the conclusion of this study is put forth.

2. Methodology: Systematic Literature Review

In order to achieve the objectives of this research, and pinpoint the role of datadriven methods in synchromodality, there is need to conduct a Systematic Literature Review (SLR) on the academic research in this area. Furthermore, the authors draw on their interviews and their experience in several projects in connection with the transportation industry. Any method used to conduct a SLR need to be structured and scientifically proven or the results will lack any credibility. These methods are used repeatedly and have been modified for different disciplines of knowledge (Durach, C. F., Kembro, J., and Wieland, A. 2017). Here, the SLR used is a variation of the one explained by Durach et al. and Vosooghidizaji et al. (Durach, C. F., Kembro, J., and Wieland, A. 2017; Vosooghidizaji, M., Taghipour, A., and Canel-Depitre, B. 2020). In this research, this method has been improved to have the study of the previous literature reviews as one of the main steps to unravel keywords and key concepts in a specific field. Therefore, the steps of this literature review are as follows:

(1) Step one: Previous literature reviews are studied and keywords, classifications, characteristics, frameworks and key concepts are determined.
(2) Step two: Keywords and key concepts are used to search in databases to find the most pertinent works.
(3) Step three: The preliminary sample of researches found in step two are filtered based

on the degree of their relevance to the purposes of this research using the key concepts discovered in step one.

(4) Step four: After a first round of analysis, based on the characteristics of the proposed approaches, a framework of analysis is developed and the literature review is synthesized using this framework.

(5) Step five: The result of the conducted literature review is presented.

3. Implementation of Systematic Literature Review

3.1. Step One: Previous Literature Reviews

In this step, the previous literature reviews conducted in the field of synchromodality and also in the field of data-driven methods in logistic and supply chain are discussed. There have been several literature reviews conducted in these domains and in order to continue and enrich the work they have begun, they must be studied thoroughly. This step is necessary for providing a foundation of knowledge on the topic and also for differentiating this work from these other studies. Furthermore, by referring to these studies, trends of the subject matter can be traced back to the origins of the topic, and appropriate keywords are identified. Reviewing these works also help to direct and guide future studies, without ignoring the valuable knowledge already found.

This review is in line with the past efforts and an attempt to improve their findings. Researchers have already conducted literature reviews in these domains from time to time and they have created a foundation for accelerating and guiding further research and forming substantial understanding of different fields through their contributions.

3.1.1. Synchromodality

In the field of synchromodality, to the best of our knowledge there still has not been a literature review study in regards with its data-driven nature. However, as it is yet another attempt to increase the efficiency of logistic operations following intermodality and multimodality, there is much to be adapted. In this regard, literature reviews on these subjects must be carefully studied to form a better understanding of the concept.

The necessity of management of a logistic chain in the Strategic, Tactical and operational is well understood and reaffirmed by researchers (Slats, P. A. et al. 1995; Archetti, C., Peirano, L., and Speranza, M. G. 2022; Chargui, T. et al. 2022; Delbart, T. et al. 2021; Larsen, R. B., Atasoy, B., and Negenborn, R. R. 2021; Qu, W. et al. 2019; SteadieSeifi, M. et al. 2014). One of the main themes of the reviews in these fields are usually to discuss the general forms of problems and possible solutions in each level of management, and also indicating the aspects already explored or to be explored. Many of such problematics discussed within the context of intermodality and multimodality must be studied in-depth as these subjects are highly connected to the concept of synchromodality.

In one of the highly cited references in the field of intermodality and multimodality, SteadieSeifi et al. have conducted a thorough analysis of the literature (SteadieSeifi, M. et al. 2014). The models discussed in this article forms a structured view that should be noted while implementing synchromodality. Basically, they have classified researches based on the three levels of management. In the strategic level, topological settings are discussed which include formation of logistic corridors and hub-and-spoke systems. Network flow planning and service cutwork design categories of problems are classified as tactical problems and different types of models and solutions are indicated. In the operational level also, resource management and itinerary scheduling, replanning and disturbance management is identified. It must be noted that in this research the question of real-time replanning has also been discussed however, there is no sign of any paper in the field of synchromodality, i.e. modal switch and choice of transportation mode, has not been discussed. It is also noted that they have not found any solid literature for co-modal and synchromodal studies. They have considered these criteria to identify the body of literature: Mode, multicommodity, allocation, direct shipment, capacity, transshipment, scheduling issues, uncertainty issues, decentralized decision making, and additional objective components.

In addition to the three levels of management, Archetti et al. have also classified mathematical problems and studies based on the modalities of transport i.e. road, rail, maritime and air (Archetti, C., Peirano, L., and Speranza, M. G. 2022). They have also provided general forms of mathematical formulations for typical problems in these fields. Uncertainty has also been addressed in this context; Delbart et al. have studied uncertainty in intermodal and synchromodal transportation in the three levels of management (Delbart, T. et al. 2021).

Another note not to be missed about synchromodality is dynamism and the ability to switch mode in real time. Thus, the scientific importance of considering the studies in regards with dynamism. Dynamism of the mathematical formulation have been reviewed by Elbert et al., (Elbert, R., Müller, J. P., and Rentschler, J. 2020). They classified researches based on their dynamic or non-dynamic, and deterministic or stochastic approaches.

Testing and implementations in the gigantic scales of today's logistics is a very delicate matter. Therefore, simulation has been widely used. The application of simulation in intermodality and its limitation have been reviewed by Crainic et al. (Crainic, T. G., Perboli, G., and Rosano, M. 2018).

Of course, innovations continue to appear and they must be studied and explored, and there have been some reviews on the most recent innovations in the field of logistics. For example Ambra et al., discuss synchromodality in relationship with physical internet (Ambra, T., Caris, A., and Macharis, C. 2019b). However, in this paper sustainability is referred to as the reason for synchromodality, however benefits and needs for synchromodality exceeds ensuring only sustainability. Also, in regards with the connection between physical internet and synchromodality, although these two concepts may eventually enable better implementation of each other, no direct connection can be assumed. We must keep in mind that the concepts of physical internet is about standardization of the equipment and operations of logistic, which only if coupled with real-time data on a interoperable network of actors, can contribute to synchromodal needs. On the other hand, data-driven methods as suitable methodologies for solving problematics arising from synchromodality and dealing with data should be thoroughly studied. However in regards with synchromodality or similar subjects such as real-time modal shift no reviews have been conducted in regards with its implementation using these approaches.

Synchromodality is a concept with which we aspire to solve the shortcomings of intermodality and multimodality. Thus aside from its critical success factors (Pfoser, S., Treiblmaier, H., and Schauer, O. 2016) and the uncertainty (Delbart, T. et al. 2021), one must depict a wholistic picture of the setting in which it must be applied. In an attempt by Pfoser et al., they have studied the mechanisms and antecedents (i.e. requirements) as pre-requisites for implementing synchromodality (Pfoser, S., Kotzab, H., and Baumler, I. 2021). These mechanisms are: real-time switching, mode-free booking, horizontal collaboration, and integrated network planning (Pfoser, S., Kotzab, H., and Baumler, I. 2021). However, in this research, this classification and that of antecedents of each of these mechanisms is highly debatable. Nonetheless, in this article, a breadth of well-organized factors and elements are presented.

In a recent research, Acero et al. try to introduce the concept of synchromodality and find out how it can be useful in solving supply chain and even production problems (Acero, B., Saenz, M. J., and Luzzini, D. 2022). That said, still the connection between synchromodality and production seems very weak. Logistics do involve supply chain operations, however synchromodality is highly concentrated on logistic.

Furthermore, it must also be noted that in most cases the interviewed experts discuss their needs rather than understanding the concept and limiting their expectations to it. In an open interview conducted by the authors of this research with practitioners and industry leaders of intermodality and multimodality in the Normandy, France, in 2022, nearly 90% did not provide a proper definition of synchromodality if any. One must pay attention not to involve other expectations into the definition of such a newly coined term.

3.1.2. Data-Driven Methods in Logistics and Supply Chain

In order to have a well-organized understanding of the status of the research in the field of data-driven methods, related to the concept of synchromodality, literature reviews in this field specially in the context of logistic and supply chain, must be studied. It must be noted that a research and a method is considered data-driven, when analysis of data have been used intensively to facilitate obtaining results.

In this regard, in one of the very well-organized recent reviews, Koot et. al indicate that data-driven methods (such as jointing IoT with Big Data Analytics (BDA)) can be used to detect and predict deviation, empowering timely responses to risk factors (Koot, M., Mes, M. R. K., and Iacob, M. E. 2021) which is, in turn, one of the main purposes of synchromodality. IoT can be easily integrated within logistics as the concept of track-and-trace has been already used in this context (Koot, M., Mes, M. R. K., and Iacob, M. E. 2021). Furthermore,in this paper, the four main types of data-driven analysis (i.e. descriptive, explanatory or diagnostic, predictive, and prescriptive) (Koot, M., Mes, M. R. K., and Iacob, M. E. 2021; Maheshwari, S., Gautam, P., and Jaggi, C. K. 2021) and also four levels of management (i.e. strategic, tactical, operational(offline), and operational (online)) has been used to categorize studies.This four-level classification is a new attitude and at the same time it is in line with prominent research in the field of integrated planning in logistics where Turner and Slats et al. consider strategic, tactic, operational and real-time as four levels of management (Turner, J. R. 1993; Slats, P. A. et al. 1995).

In another prominent research by Filom et. al, the use of data-driven methods used in ports, as the orchestrators of logistic and supply chain, is studied (Filom, S., Amiri, A. M., and Razavi, S. 2022). In this work it is noted that between predictive analysis and decision making there is a gap which is filled by prescriptive analysis and these methods of analysis can be statistical, operation research, simulation and also machine learning. The superiority of machine learning methods is also discussed in comparison with operational research methodologies. In this regard types of machine learning are also discussed: supervised learning, unsupervised learning, reinforced learning and deep learning (which can be a sub-method of the other machine learning types). In this paper, lack of data is declared as the main hurdle in the use of data-driven methods in ports.

Based on these studies, predictive analysis (training a system using historical data to predict the future state of the system) is only the prerequisites for implementing data-driven decision making in logistics. The decision making is made easier when prescriptive analysis is conducted. Logistics operations can benefit from prescriptive analysis (such as association and clustering) to become more flexible and faster especially in regards with decision making (Koot, M., Mes, M. R. K., and Iacob, M. E. 2021). Data-driven methods are crucial when talking about real-time action as they outperform greatly the traditional supply and logistic chain management methods in helping swift decision making (Maheshwari, S., Gautam, P., and Jaggi, C. K. 2021).

The role of data-driven methods in ensuring resilience of logistic and supply chain has also been studied (Zamani, E. D. et al. 2022; Talwar, S. et al. 2021); authors indicate that in order to ensure the appropriate actions (i.e. proactive, reactive, or a combination of the two) in different phases of resilience/risk management (i.e. readiness, response, recovery, adaptability), there is a need for monitoring the environment, and then flexible responsive capacity to reconfigure and re-plan (Zamani, E. D. et al. 2022). They also suggest that data-driven methods such as BDA is suitable for scheduling, predicting and resource allocation in real-time (Zamani, E. D. et al. 2022; Conboy, K. et al. 2020).

However, data is not only used in analytics in the field of logistics and supply chain management. Digital Twins is also a concept which can use data to produce a simulated environment to conduct simulations with higher precision and details (Bousdekis, A. et al. 2021). Therefore, it seems logical to consider these other technologies which are data-driven and help the implementation of real-time operations.

3.2. Step Two: Search in Scientific Research Databases

In the second step, required characteristics of the preliminary sample of studies are determined. Here, based on the analysis in step one, there is an understanding of the key concepts of synchromodality and also data-driven methods. As per implementation of synchromodality, based on the literature, there are three levels of management (i.e. strategic, tactic, and operational) to consider. Thus, primary studies must address these levels of management and fall into the main themes of synchromodality, i.e. mode switch and real-time re-planning.

However, as this concept has been introduced recently, there does not exist much pertinent research. Therefore, one must consider the background of synchromodality and the history of its development in collecting the preliminary sample studies. In this regard, those researches in the field of multimodality and intermodality in logistics in which one or more characteristics of synchromodality is considered (i.e. dynamic re-planning and re-routing) are also included. This also eliminate any possibility of neglecting a study, in case of absence of the keywords.

Using the insight gained in step one, several possible trends and keywords are chosen to be searched in databases and a preliminary sample of articles are selected. The keywords used in this step are first ”synchromodality” and ”synchromodal transport” in the field of logistic or supply chain management. Further on, several secondary keywords such as ”re-planning”, ”re-routing”, and ”dynamic intermodality” were also used to inspected and make sure no related studies are neglected. This search was conducted in well-known English peer-reviewed journals within SCOPUS and Web of Science databases. Forward and backward citations were also probed to ensure no relevant research is neglected.

3.3. Step Three: Filtering Search Results

In the third step, based on the pertinence of the articles in the preliminary sample, a handpicked subset of them is created carefully. We must also pay attention not to get deep into computer science as this research is about management and implementation of synchromodality. Other than this, the keyword “synchromodal” has been used in the domain of education also. Therefore these researches are omitted from the subset . In this study this subset includes 78 researches.

3.4. Step Four: Literature Synthesis

In the fourth step, a thorough analysis is conducted on the final sample. Firstly, descriptive analysis based on the criteria and the research frameworks chosen from the literature review is carried out and then a content analysis is presented. Thus, results of this analysis is presented in two forms: 1) descriptive results (in which general statistics on number of papers per year, country and authors are discussed) and 2) content analysis results (in which based on a new framework, pertinence and the quality of responses given to the problematic of synchromodal transportation are discussed).

3.4.1. Descriptive Results

After a thorough analysis of the literature, it can be easily discovered that there is not a great number of papers in the field of synchromodal transportation. And in fact this number is on the rise (Figure 1).

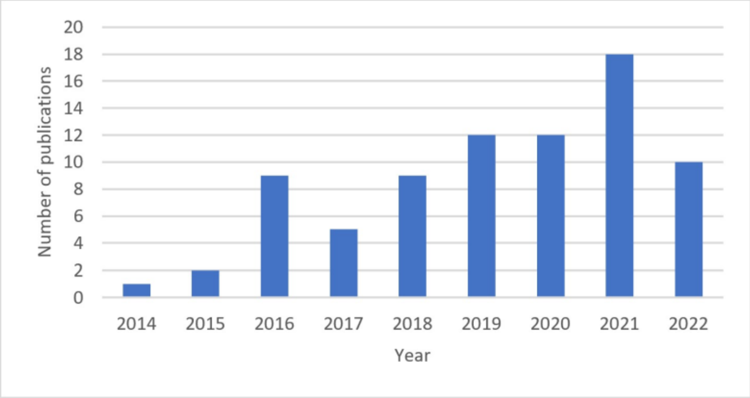

Figure 1.: number of published articles per year in the selected sample

Furthermore, this subject is growing interest among researchers year by year, yet its complex nature limits the number of high quality researches in this domain. Based on our analysis the journal with the highest number of articles in the field of synchromodality is Transportation Research Part E: Logistics and Transportation Review followed closely by European Journal of Operational Research. It must be noted the highest overall number of articles belongs to Transportation Research Procedia which publishes conference proceedings(Table 1).

In regards with the number of publication per country, Netherlands is far ahead with 26 articles followed by France with 9 articles (Figure 2). The reason for this focus of Netherlands on this subject is their policy of turning Netherlands into the “Gateway to Europe” which has resulted in high investment in transportation and research in transportation (Nefs, M., Zonneveld, W., and Gerretsen, P. 2022). Accordingly, the authors with the highest number of papers in this domain are from Netherlands (Table 2). It must be noted that authors with one paper are not included in this table.

Table 1.: Number of published articles per journal in the domain of synchromodal transportation.

Journals	Number of selected publication
Transportation Research Procedia	8
Transportation Research Part E	7
European Journal of Operational Research	5
Sustainability	4
International Journal of Production Research	3
Transport Reviews	3
Computers & Industrial Engineering	2
Omega	2
Journal of Transport Geography	2
Decision Support Systems	2
Research in Transportation Business & Management	2
Cogent Engineering	2
Flexible Services and Manufacturing Journal	2
IFAC-PapersOnLine	2
International Journal of Production Economics	2
Journal of Cleaner Production	2
Others	28

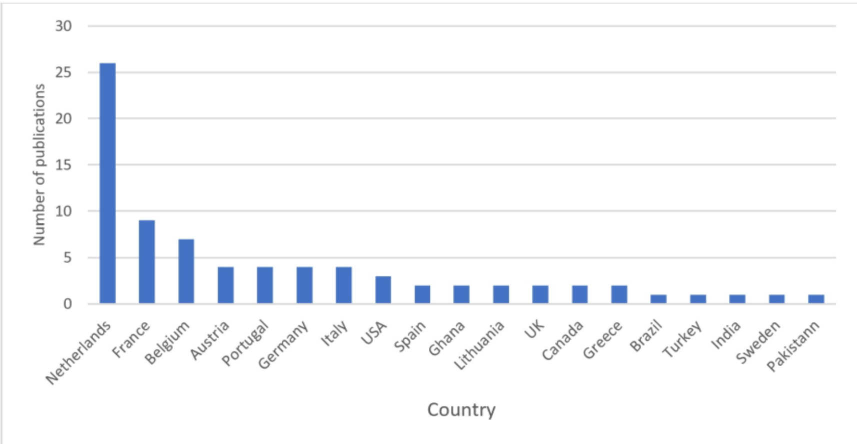

Figure 2.: Number of published articles per country

Table 2.: Number of published articles per author

Author	Number of pertinent publication
Negenborn, Rudy R.	10
Tavasszy, Lorant	6
Atasoy, Bilge	5
Tadei, Roberto	4
Trentesaux, Damien	4
Manerba, Daniele	4
Giusti, Riccardo	3
Macharis, Cathy	3
Lukosch, Heide	3
Boute, Robert	3
Verbraeck, Alexander	3
Reis, Vasco	3
Pan, Shenle	3
Caris, An	3
Rezaei, Jafar	3
Pfoser, Sarah	2
Guo, Wenjing	2
Chargui, Tarik	2
Bekrar, Abdelghani	2
Pan, Shenle	2
Fazi, Stefano	2
Dekker, Rommert	2
Kurapati, Shalini	2
Rosano, Mariangela	2
Ambra, Tomas	2
Gijsbrechts, Joren	2
Crainic, Teodor Gabriel	2
Huang, George Q.	2
Ballot, Eric	2
Kourounioti, Ioanna	2
Blokland, Wouter Beelaerts van	2
Larsen, Rie B.	2
Woensel, Tom Van	2
Crainic, Teodor Gabriel	2
Agbo, Aaron Agbenyegah	2
Perboli, Guido	2

3.4.2. Research Framework and Content Analysis

After a first round of in-depth analysis on the articles in the chosen subset, in order to discuss the main trends and the uses of data-driven methods and technologies in synchromodality, a framework is developed. This framework is developed based on the literature and the understanding of the researchers of the field and it can help classify problematics and sub-fields of this particular subject. By doing so, future research subjects are determined more easily and expression of needs in a specific domain will be facilitated.

One of the main classifications in the literature of logistics and supply chain management has been the different levels of management which are used to give a general insight and facilitate the understanding of the purposes and problematics addressed by actors involved in different levels of management. In almost all the pertinent liter- ature of synchromodal logistics three levels of strategic, tactic and operational levels have been considered (Archetti, C., Peirano, L., and Speranza, M. G. 2022; Chargui, T. et al. 2022; Delbart, T. et al. 2021; Larsen, R. B., Atasoy, B., and Negenborn, R. R. 2021; Qu, W. et al. 2019; SteadieSeifi, M. et al. 2014). However, when we review the literature of integrated planning and data-driven methods, and based on the need for fast real-time decision making in synchromodal transportation, we can divide operational level into offline and online(real-time) levels (Koot, M., Mes, M. R. K., and Iacob, M. E. 2021), or consider a fourth level (Turner, J. R. 1993) (Table
3). The addition of this level seems more logical based on the necessity of real-time planning and re-planning of synchromodality in a faster way beyond the conventional methodologies already used in operational management level, since the fastest results in these methods will need several hours of computation. Furthermore, the dynamism that is addressed in several papers in this field, is usually about solving operational research mathematical models considering a rolling planning horizon. In this regard, when we talk about dynamic decision making in operational level, it is more or less a slower decision making which inherits a delay, thus the need for differentiating real-time planning from operational level dynamic planning. Adding this fourth level (real-time level management -aka online operational management), will attract attentions of researchers to the point that faster adaption to change and faster re-planning is greatly required in the industry.

Table 3.: Levels of management with their planning horizon

Level of Management	Planning horizon
Strategic	Several months to several years
Tactic	Several days to several weeks
Operational	Several hours to several days
Real-time	Real-time to several hours

On the other hand, the one thing that makes a synchromodal system real-time is situational awareness (Hofman, W. et al. 2016) and it stems from the data collected on the status quo of the logistic actor and its environment in real-time. This situational awareness is only possible through efficient interoperability connections and instant share of data and/or information which is inherently different from the rest of problematics addressed in operational level.

Having such a four-level classification in mind and the special real-time needs of the fourth level, in a nutshell the process of ensuring such reactivity is as follows. In order to convert this vision of synchromodality into reality, an agreement between companies and entities in regards with collaboration with the purpose of data exchange and integrated planning is necessary. This agreement can be strategic or tactic; it can be strategic because this can involve long-term contracts and considerable investments in providing the infrastructure and preparing a seamless flow of data, and it can be tactic because these collaborations might only involve mid-term cooperations, conducted on a infrastructure already present. After establishing such links, and achieving data interoperability and collaborations with trustworthy partners in regards with shared data flows, efficient methods must be implemented to use these flows of data to take better decisions. Data-driven approaches (i.e. descriptive, diagnostic, predictive and prescriptive) have already been used more or less to facilitate the process of decision making in all levels by providing concise and precise analysis of the present situation (descriptive and diagnostic methods) and highly reliable predictions in the future (predictive methods). They can even automate decision making in cases where the decision making algorithms allow it (prescriptive methods); day by day examples of autonomous machines which can learn and act are on the rise and this will reduce the time of decision making significantly. Based on this analysis and literature, the conceptual framework of this study is developed (Figure 3).

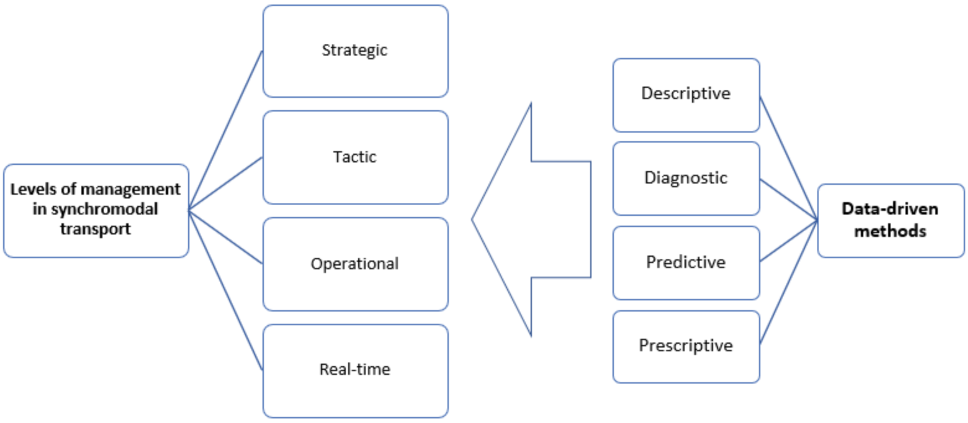

Figure 3.: Conceptual model of different levels of management in regards with the use of datadriven methods in implementing Synchromodality

In order to reach this level of data usage and facilitate data-driven decision making, several technologies must be put in place in regards with these data driven methods and also the step by step nature of data management (i.e. capture, storage, retieval, and exchange of data) (Ambra, T., Caris, A., and Macharis, C. 2019a). Using these technologies analysis of data and the use of the information and/or knowledge obtained will be possible. It must be noted that fast decision making (usually powered by prescriptive analysis) is the most important criterion for choosing these technologies, and it is primordial in order to minimize the unwanted effects of a sub-optimized logistic operation. In other words, speed of the decision-making process, limits the number of methods which can be used in regards with real-time nature of synchromodality. Such reactivity with the goal of implementing synchromodality using data-driven methods, draws on many subjects that were coined along with the concepts of Industry 4.0.

Thus, based on the study of the literature and pertinent frameworks, the use of the following technologies were chosen as classifiers in our framework: Big Data Analysis (BDA), Machine Learning (ML), Blockchain, Digital Twin (DT), Physical Internet (PI), Internet of Things (IoT), ”Real-time simulation”, ”Real-time Optimization”, and Security. Moreover, levels of management, research approach, type of optimization problem (if any), types of planning (centralized or decentralized), and types of data used(simulated or real) are considered in this framework (Table 4).

Table 4.: Framework of the content analysis - conducted on a total number of 78 articles (numbers are in percentage and fields are not mutually exclusive.)

Levels of management				Approach		Types of planning		Data used		Technologies and concepts											
Strategic	Tactic	Operational	Real-time	Qualitative	Quantitative	Data-driven	Non-Data-driven	Centralized	Decentralized	Simulated data	Real data	Big Data Analysis (BDA)	Machine Learning (ML)	Cloud-computing	Blockchain	Digital Twin (DT)	Physical Internet (PI)	Internet of Things (IoT)	Real-time Simulation	Real-time Optimization	Security of data-sharing
54	41	31	17	58	47	18	27	33	1	17	13	1	0	1	0	4	8	0	0	5	1

3.5. Step Five: Results of the analyses

Finally, in the fifth step of this literature review, results of the analysis are reported and the extracted insights, trends and future needs are delineated. The results show that the real-time level has received very little attention on part of researchers so far. Only 13 papers have discussed the real-time nature of the problems of synchromodal transportation, of which only 2 have developed adapted quantitative solutions. One of which is the work of Qu et al. in which using a centralized approach and metaheuristics, results of a re-routing and re-scheduling problem can be obtained within seconds (Qu, W. et al. 2019). The other is the work of Hrušovský et al. in which using real-time simulation and ”real-time optimization” they develop a quick Decision Support System (DSS) for real-time decision making regarding re-planning and rescheduling (their approach also is centralized) (Hrušovský, M. et al. 2021). It must be noted that in several papers, several levels of management have been considered and also in some papers both qualitative and quantitative methods have been used.

In regards with optimization problems, 14 papers have used data-driven methods in regards with synchromodality and of these 14 papers, 10 have used real-world data in their models. Moreover, of the 14 articles discussing optimization in relation with synchromodality, only 4 have considered the fast speed of the execution of their models (Hrušovský, M. et al. 2021; Qu, W. et al. 2019; Riessen, B. v., Negenborn, R. R., and Dekker, R. 2016; Zhang, Y. et al. 2022).

In regards with centralization of planning, only 3 papers have considered decentralized planning (Pan, S. 2019; Larsen, R. B. et al. 2021; Kurapati, S. et al. 2017), of which two are qualitative (literature review and simulation game) and the other one is about secure exchange of data in a truck-barge transportation system (Larsen, R. B. et al. 2021). This is the only paper developing a solution for the question of security and privacy of data exchange within a synchromodal logistic chain.

Simulation in the literature of the concept of synchromodality has been used mostly to show the efficiency of the optimization methods or to have a feedback loop for the optimization problem. In some other cases, simulations are used to produce numerical examples as artificial data feed for data-driven optimization models. The simulation that is usually used in this case is discrete event simulation. More information on the use of simulation in transportation can be found in the work of Crainic et al.'s work (Crainic, T.

G., Perboli, G., and Rosano, M. 2018). Apart from classic simulation, Digital Twin has also been attended in three qualitative works (Ambra, T., and Macharis, C. 2020; Carvalho, A. et al. 2020; Leung, E. K. H., Lee, C. K. H., and Ouyang, Z. 2022).

Big data analysis is only pointed out in a qualitative work on importance of semantics in optimization (Hofman, W. et al. 2016). The semantics is of importance as before pipelining the flows of big data, clear and unambiguous use of semantics is necessary to connect and cross-reference data bases.

Cloud-computing also have only been indicated in one article (Tsertou, A. et al. 2016). The role of cloud-computing and its scalability feature is crucial for data management and processing power.

Finally, of all the solutions and technologies that can contribute in real-time level management, Physical Internet has received the most attention on part of researchers (Ambra, T., Caris, A., and Macharis, C. 2019b; Chargui, T. et al. 2020; Lemmens, N., Gijsbrechts, J., and Boute, R. 2019; Leung, E. K. H., Lee, C. K. H., and Ouyang, Z. 2022; Pan, S. 2019). However, Machine Learning, Real-time simulation, Blockchain technology and Internet of Things have not received any attention yet on part of researchers in the domain of synchromodal transportation.

4. Discussion

Based on the analysis conducted in the past section, the traces of the use of datadriven methods in solving problematics in the domain of Synchromodality are now extracted and clarified. As we can see in the provided framework (Table 4), in regards with the technologies and concepts which can be used in Synchromodality, there is still a vast opportunity for researchers. It is necessary to remind the readers that these technologies and concepts were used here as they are highly useful (if not crucial) in implementing a sound management of data and conducting data-driven methods in synchromodality. In other words, there already exist track and tracing systems and some basic interoperabilities (for example in case of Automatic Identification System (AIS) data and Satelite-AIS data), however, in order to up the game and consume the generated data to excel logistic operations, there is a need for the sharing of more data and more in-depth analyses. In this section, we try to delineate and discuss some of the main results of the conducted analyses.

4.1. Levels of Logistic Management

As discussed in previous sections in addition to the three management levels usually considered in intermodal and multimodal transportation, in order to attract the attention of the researchers and emphsize on the needs of synchromodal transportation we need a fourth level of management: real-time management level. However, this does not mean that synchromodal transportation problems are the same in strategic, tactical and operational level as intermodal transportation; creating digital interoperability among logistic actors, is most of all a matter of strategic alliance.

In the strategic level, in a few articles, a paradigm under the name of 5th Party Logistic Service Providers (5PL) is discussed (Giusti, R. et al. 2019; Pan, S. 2019) as the orchestrator of these digital inter-operations. In some other attempts to couple synchromodality and physical internet, a whole new system of pi-concepts (including pi-container, pi-movers, pi-hubs, pi-cross-docking) is discussed which mostly fall into strategic and tactic areas (Ambra, T., Caris, A., and Macharis, C. 2019b). Physical Internet helps the implementation of synchromodality mostly by standardization of the methods by which cargo is handled in logistic operations. It is clear that such concept still requires adoption and implementation of ICT technologies to be useful. In addition, a more seamless synchromodal transportation requires higher numbers of transshipment centers in order to change mode and re-plan transportation as soon as a disruption occurs (Crainic, T. G. et al. 2021; Giusti, R., Manerba, D., and Tadei, R. 2021). The shippers' preferences in regards with delegation of choosing the mode of transport is also a strategic matter (Khakdaman, M., Rezaei, J., and Tavasszy, L. A. 2020). Furthermore, the question of resilience against uncertainty and disruption is at the core of the concept of synchromodal transportation. When re-planning and re-routing is discussed, it automatically embeds uncertainty and risks of disruption in the logistic chain.

In tactic level also, problematics in the domain of Service Network Design (SND) including selection and scheduling of services, types of terminal operations, routing of freight, and Network Flow Planning benefit from the access to real-time data and trends of logistic flows in different periods of time.

Of course, operational level problematics such as routing problems and allocation of resources can also benefit from data-driven methods. However, where data integration and interoperability shines the most is in real-time planning level in which IoT devices and computing units can interact and update the status of the system in real-time, so that no time is wasted; neither for describing the present (descriptive and diagnostic methods) and predicting the future (predictive methods), nor for decision making and prescribing solutions and acting on them (prescriptive methods).

4.2. Technologies and Solutions

As mentioned earlier, the indicated technologies and concepts make data management and data consumption easier and more efficient, and this will in turn increase the speed of reactions to any disturbance or contingency during a synchromodal freight transport. Thus the biggest advantage is the time which is spared during data management and processing.

Big Data management and analysis is one of the pivotal technologies in this regard. While classic data management technologies such as SQL and no-SQL methods fail to manage big bulk of data in a timely manner, Big Data analysis comes in handy (using technologies such as Apache Hadoop) rendering data analysis possible and feasible. In synchromodal transportation terms, this means faster access to the results of analyzed data (from traffic, weather, etc.) in regards with descriptive and diagnostic analysis. Furthermore, using this technology, live flow of considerable amount of data can be analyzed (example: analysis of AIS data locating other ships and vessels in ports and anchorage areas). This technology can be easily coupled with different forms of Machine Learning to provide real-time predictive and prescriptive analyses. It can be also be used coupled with Cloud-computing for faster and cheaper scalability.

In regards with Machine Learning, as a reminder to the reader, there are three main types of learning which can be utilised in logistics: supervised learning (learning from labelled data), unsupervised learning (clustering or labelling unlabelled data), and reinforced learning (learning from exploration and from trial and error). With the abundance of data from sensors, actuators and IoTs in the world of logistics, and the ability to store them in high quantity, there is a high potential for applying these learning methods. Specially deep learning which is basically the use of Artificial Neural Networks (ANNs) in Machine Learning to form models out of multi-sourced data of various natures. As indicated before, coupling these learning methods with BDA would facilitate working with high volumes. Furthermore, using the scalable power of cloud computing technologies would increase speed and efficiency (as used in Amazon.com). In addition, especially supervised learning can be used instead of probability functions in discrete event simulations to generate instances. Thus, the use of these technologies together can form an axe of research.

As aforementioned, cloud-computing has enabled access to scalable computing power in a matter of clicks. This power can be easily joined with resource intensive programs, be it detailed and big optimization models, repeated iterations of simulation, or fitting data to a multi-layered neural network. Further, to help lowering the computation load of the central cloud servers, edge computing (preliminary processing of raw data in the field) and fog computing (processing data in local servers) can be utilised. The architecture of such systems remains a field of exploration for computer scientists. However, coupling this computational power with complicated modeling in synchromodality can be an axe of research in this domain.

In regard with blockchain technology, it is tightly related to the matter of security of data sharing. That is why many researchers and practitioners are working on the concept of smart contracts and secure exchange of data are interested in blockchain technology. Eventually the use of standard formats of documents and data strings along with blockchain technology can ensure both security and speed (since there will no longer be a need to verify authenticity several times specially because of decentralised storage of data).

As discussed earlier, Digital Twin can be considered as a form of simulation, in which a digital copy of the reality can be used to create scenarios, and this can also utilise and produce live flow of data. Integrated with Big Data Analysis it can provide a representation of the physical world in virtual world. This is essential for testing scenarios and action plans at the beginning of transportation planning and also after any kind of contingency (for example a need of mode switch in synchromodal transportation) or disruption (for example protest in one of the modes of transport). Digital Twin can highly benefit from a well implemented IoT in terms of inward flow of data, and it can highly benefit from cloud computing and BDA for implementation and outward information flow. In addition, coupling digital twin with reinforced learning which requires trial and errors and exploration can be highly fruitful in evaluating new scenarios.

Finally, ”real-time optimization” here is a term to address an optimization model which is detailed enough to be a good representation of synchromodal system and which can lead to a result in matter of seconds (mostly using meta-heuristics). ”realtime simulation” is also about conducting numerous iterations of simulation within seconds to double check scenarios and results of optimization models. There exist a considerable amount of research in regards with pairing optimization and simulation and it is safe to say that this can be considered as the classic approach to deal with problematics in the field of synchromodality. The emphasis on ”real-time” here, however, attracts researchers' attentions to the necessity of working on feasible solutions in synchromodality where speed is of high importance.

The aforementioned combinations are some of the potential configurations which can be researched to gain more insight in the efficiency of their usage. As discussed earlier and from the framework of the research, these technologies have been rarely attended in the literature in regards with the synchromodal transportation. Therefore, based on the analyses above, and the necessity to respond to the requirements of synchromodality in real-time level, we propose several axes of research for future studies, and also future efforts by practitioners (Figure 4). These axes are partly based on the four pillars of data management (i.e. capture, storage, retrieval, and exchange of data), the DIKW pyramid (i.e. Data, Information, Knowledge, Wisdom) and the logical needs of decision making.

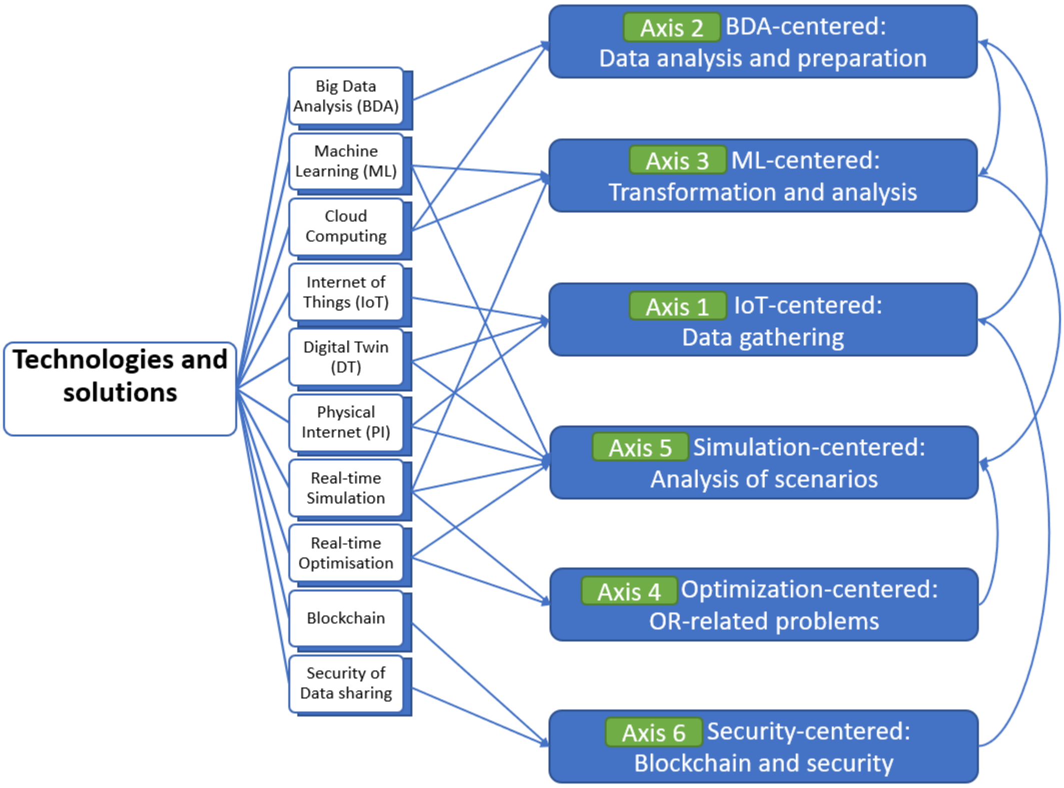

Figure 4.: Technologies and solutions and axes of research in regards with Data-driven methods and Synchromodality

As explained above, the technologies covered in this paper can be used selectively in providing solutions in different steps of implementation of a data-driven synchromodality including data gathering, data analysis, transformation of data and prescription of action plans, and finally simulation and testing. Arrows in the model in Figure 4 represent relation between technologies and axes and also among axes. Surely, more relations can be envisioned with each update of these technologies and based on needs of the field.

4.3. Trends, Barriers and Prospects

Based on the results of descriptive and content analysis of the literature, it is clear that there is a need for more researches in the field of synchromodal transportation. Data exchange and data-driven methods are at the heart of a new era of interoperability in the industry, and it has been very well understood by companies; the high level of recruitment of data analysts can show that companies are getting ready to take this leap toward full implementation of data driven methods in their businesses. Surely business models must change to accommodate not only new recruits but also new paradigms of doing business (Tavasszy, L. A. 2020). It must also be noted that the shift toward extensive data exchange among actors of supply chain will have more favorable results than only synchromodal transportation; adaptive process planning, inventory policies, purchasing, marketing, transport synchronization and many other fields will be affected (Urciuoli, L. 2018).

Implementation of ICT innovations in regards with synchromodal transportation has several barriers which can be classified in three strategic categories: user-related, policy-related, technology-related (Harris, I., Wang, Y., and Wang, H. 2015).

User-related barriers are about the fact that managers are not aware of benefits of such exchange. This is why there is a serious need for researches to showcase benefits. In this regard, in one research, and in a limited scale and a centralized manner, it is shown that (Los, J. et al. 2020) sharing route plan is always a profitable action. They also show that at least 50% of the logistic actors need to share full plan information so that the overall operation would be profitable for all actors. However, it is not researched that how the proportion of profit changes before and after sharing full plan information by carriers.

Therefore, in this area researchers should still continue their endeavors to justify the concept of synchromodality for high level managers and stakeholders. Fortunately, many businesses are engaging in sustainable actions (The Climate Pledge group. 2023). However, these engagements must take more serious forms.

In regards with policy related barriers, several papers have tried to address pertinent issues (Crainic, T. G., Perboli, G., and Rosano, M. 2018; Nefs, M., Zonneveld, W., and Gerretsen, P. 2022; Tavasszy, L. A. 2020). It has been indicated that political leaders and policy makers must take note of the trends in transportation and guide the public awareness toward issues caused by world-wide transportation services. They should also provide solutions to ensure sustainability in logistics. Thus, policies must encourage logistic actors to collaborate in regards with data sharing and implementing concepts such as synchromodality.

Policy makers and public sector must also try to provide sufficient infrastructure to streamline transportation in a much more sustainable way. Currently, at the foundation of data gathering, sensors and actuators are sufficient to capture data and information of the field agents, however, in the next level, the need for high bandwidth for transferring raw data between (for example) the field IoT unit, its edge computing unit, fog computing unit and eventually cloud computing unit is still present and this requires substantial investment in technologies such as 5G. Specially, if the data format is of heavy nature (for example: picture or video), higher bandwidth is required. However, implementation of these infrastructure requires a high level of commitment on part of policy makers and logistic actors.

Task forces such as International Taskforce of Port Call Optimization (Port Call Optimization, 2022)-that promotes data sharing among ports and reduce waiting times in anchorage areas-also must increase, as standardization of data formats and means of of sharing it would help digital interoperability substantially.

In regards with technology related barriers, we can point out the different levels of implementation of data-driven methods in companies. Such factors make vertical and horizontal real-time integration impossible. Therefore, easy to use, inexpensive and available platforms must be developed so that all actors can have access and contribute to shared data-bases. Hopefully, cloud services such as Infrastructure as a Service (IaaS), Plateform as a Service (PaaS), and Software as a Service (SaaS) can help and facilitate access to prerequisites of the data-driven technologies.

4.4. Centralized vs Decentralized

In most of the research in the field of synchromodality, decision making happens in a central unit which knows all and has all the information and data of the system. Some of the advocates of such decision making, talk about 5th Party Logistic service providers (5PLs) as entities capable of doing such orchestration (Giusti, R. et al. 2019; Pan, S. 2019). Others think that ports as public entities can serve as intermediary among logistic actors and are capable in orchestrating efforts such as synchromodality (Langenus, M. et al. 2022; Filom, S., Amiri, A. M., and Razavi, S. 2022). In practice, in some cases, powerful entities in the logistic chain, have the ability to convince other actors to share their data with them so that a central decision making is conducted (such as the relationship between Amazon and contractual trucking companies).

On the other hand, Blockchain is a promising concept in regards with decentralized data sharing. However, no researcher has worked on developing such decentralized synchromodal transportation based on Blockchain.

5. Conclusion

It is obvious that the concept of synchromodality is attracting attentions and the number of papers in this domain is increasing every year. However, it seems that the community of researchers and industry practitioners are still hesitant on the concept; very few authors are paying attention to the real-time side of this concept and most researchers are still continuing the same path of intermodality to tackle the real-time nature of synchromodal transportation. In regards with the classic axis of research (optimization and simulation), it is true that with the increasing processing power of computers, complicated mathematical models can be solved much faster, however, this speed is still not enough to provide real-time optimized results. Meta-heuristics have different shortcomings in obtaining optimal results. On the other hand, there are numerous technologies and solutions which can fill a part of this gap in an efficient way. BDA, ML, Cloud-computing, Digital Twin, PI, IoT and Blockchain are among some of them. Specifically, the joint use of BDA and ML have proven useful and superior in providing optimal result in many cases.

In order to ensure the utility of such methods, research project team leaders are invited to create interdisciplinary groups made of computer science, mathematics and management researchers in order to better address these problems.

Companies and enterprises are also invited to share data under binding contracts with such research groups so that, in a respectful and reciprocal environment (in terms of privacy and ownership of data), research on the topic could progress. Collaborations make use of a well-configured infrastructure including sensors and actuators to fast and safe high-bandwidth networks to share the data generated through different steps of the logistic operation and also the adept professionals in pertinent domains who employ data-driven technologies and methodologies to make sense out of the data. It must be stressed that data-driven methods cannot be conducted without professional analysts in the field. In addition, it is crucial for an analyst to keep a self-interrogative and self-critical mindset, while being courageous to confront the so-called logical common sense, should needs be. The culture of logistic chain members must also be open to the unknown and very much willing to test and forgiving toward brief unfavorable results.

From system engineering point of view, we are still in the stage of conceptualization (concept exploration) of synchromodality; we still need to define what we expect from it and we must verify if it is feasible or not. Thus, there is a need for researches to show this feasibility and its financial tangible benefits.

In this paper, through a systematic analysis of the literature, the concept of synchromodality and its real-time features were analyzed and discussed. Data-driven methods and technologies were used in a framework to conduct content analysis on the literature of synchromodality transport and based on that, trends were delineated and future suggestions were made.

In regards with limitations of this research, we are well aware that regardless of our efforts in our search for articles and references, there might still be some papers and some conferences which might merit a closer look. However, to the best of our knowledge, well-known reliable sources and data bases are indeed included. Apart from that, in this research, sadly we were limited to the research written in English.

The results of this research can help researchers decide which parts of the study of synchromodality in regards with data-driven methods require more scrutiny. This paper can also be helpful to practitioners and managers and policy makers in regards with decisions on investments and policy making.

Data Availability Statement (DAS)

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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