



MULTI-DIMENSIONAL ANALYSIS OF SYNCHROMODAL LOGISTICS ON THE DEVELOPMENT OF SUSTAINABLE TRANSPORT CORRIDORS FROM THE PERSPECTIVE OF RECONFIGURING EUROPEAN-ASIAN SUPPLY CHAINS

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ABSTRACT. Background: The paper concerns the concept of synchromodal logistics. It has great economic and environmental potential in terms of optimizing cargo transportation using various modes and modes of transport. In the face of unexpected disruptions in the global economic system due to the COVID-19 pandemic, the shift paradigm may result in a thorough verification of numerous solutions in the operational activities of transport, shipping, and logistics companies.

The aim of the article is to evaluate the key indicators that influence the efficiency of synchromodality in logistics. Its implementation would allow the development of sustainable transport corridors from the perspective of the European-Asian supply chains reconfiguration.

Methods: The paper uses questionnaire research and interviews conducted among experts, as well as selected methods of artificial intelligence, to determine the weights of the essential indicators that influence the effectiveness of synchromodality in logistics. Moreover, descriptive methods were used as supporting methods.

Results: Basic indicators influencing the effectiveness of the synchromodal system were determined, which may favor the operationalization of the concept implementation process. These indicators can be one of the tools to assess the prospects for the development of synchromodal logistics.

Conclusions: The implementation of the synchromodal logistics concept offers opportunities to strengthen cooperation in Euro-Asian supply chains to promote the development of sustainable transport corridors in the field of the trans-European transport network. The synchronization of the multibranch network of transport connections, preceded by the flow of information and preferences of the supply chain participants, allows the selection of the most advantageous transport connection proposals in real time, taking into account the criterion of their availability. The main expectations concerning the development of synchromodality relate to the improvement of the level of transport and logistics services, modal shifts, use of the capacity of transport nodes, and reduction of CO₂ emissions.

Keywords: synchromodal logistics, transport corridors, sustainable development, synchromodal efficiency

INTRODUCTION

The contemporary world economy has entered the next stage of structural transformation. It is characterized by an intense penetration of products and services. A kind of binder in the process of structural changes is digital technologies and Big Data, which change the definition of a traditionally perceived product and service. This provides the basis for the implementation of an innovative concept of

synchromodal logistics, which allows for the innovative preparation and implementation of production processes of tangible goods and services, including those available in the virtual world [Giusti et al. 2019, Zhang and Pel 2016]. At the same time, the challenge for the leaders of synchromodal supply chains and their organizations is to work out new compromises for cooperation, that is, to replace competition with the idea of transparency and trust.

Synchromodal logistics can be interpreted as providing efficient, reliable, flexible, and sustainable logistics services through coordination of stakeholder cooperation and real-time synchronization of operations within one or more supply chains using ICT and ITS technologies [Guo et al. 2017]. It is characterized by great potential in terms of optimizing cargo transportation using various modes and modes of transport, in the economic, environmental and social dimensions [Adenso-Díaz et al. 2014, van Riessen et al. 2015].

In the face of unexpected disruptions in the global economic system due to the COVID-19 pandemic, the shift paradigm may result in a thorough verification of many solutions in the operational activities of transport, shipping, and logistics companies. Modern rail transport, due to its greater resistance to turbulence and crisis situations, shows a stable readiness to carry out the transport tasks of freight logistics, which may cause disruptions in the availability and capacity, as well as the competitiveness of logistics companies in EU member states, including Poland. At the same time, it is worth noting that the processes of concentration of freight flows are accompanied by limited possibilities of expanding linear and point-based transport and logistics infrastructure resources, therefore, the importance of efficient use of the already existing infrastructure resources is growing. The context of the negative impact on the environment and climate of modern cargo transport systems, dominated by truck transport, is also very important [Pan et al. 2019].

The implementation of the concept of the synchromodal logistics model offers opportunities to strengthen cooperation in the framework of Euro-Asian supply chains, on the basis of partnership, to promote the development of sustainable transport corridors in the field of the trans-European transport network [Nijole and Šakalys 2020]. The International Transport Forum estimates that by 2040 the volume of cargo transport between the EU and the Far East will increase 2.5 times, mainly due to China, whose position in the Asian bloc is very strong [Cosentino et al. 2018]. Furthermore, the forecasts indicate a gradual strengthening of the role of rail transport in Euro-Asian supply chains as a result of modal shifts.

The purpose of the article is to assess the key indicators that influence the effectiveness of synchromodality in logistics, whose implementation would allow the development of sustainable transport corridors from the perspective of the reconfiguration of European-Asian supply chains. In connection with the adopted goal, a research hypothesis was formulated, which is: the concept of synchromodal logistics affects the degree of sustainability in the development of transport corridors, and the strength of this impact can be measured using selected indicators that can be the basis for the operationalization of this concept.

MODEL OF FUNCTIONING OF SYNCHROMODAL LOGISTICS

Synchromodal logistics is an innovative approach to the flexible and sustainable use of various modes of transport at a higher level of process organization from the perspective of the supply chain. It is a concept that treats the issues of multimode transport, transport infrastructure and digital technologies, as well as environmental protection and climate change holistically [Aditjandra 2018]. Its goal is to increase the efficiency, flexibility, and implementation of the principles of sustainable development in the organization of logistics processes, thanks to the introduction of the 5PL service and technological solutions provider. The creation and operation of a virtual communication and logistics system changes the development perspective of the transport, forwarding, and logistics services market. The synchronization of the multibranch network of transport connections, preceded by the flow of information and preferences of the participants in the supply chain, allows the selection of the most advantageous transport connection proposals in real time, taking into account the criterion of their availability [Tavasszy et al. 2015, Miletić et al. 2017]. The main expectations related to the development of synchromodality within the European-Asian supply chains concern the improvement of the level of transport and logistics services, modal shifts, the use of the capacity of transport nodes, and the reduction of CO₂ emissions.

The synchromodal logistics was built with particular emphasis on the interdependencies between the critical factors in the development of synchromodal logistics (Figure 1). Theoretical identification of the operational aspects of the freight transport market within the European-Asian supply chains was carried out using the method of desk research as well as statistical

analysis and comparative analysis. The systematization of this output and knowledge created the basis for the application of selected methods of artificial intelligence. Thanks to these methods, it was possible to analyze the mutual relations in the economic (Ec), environmental (En), and social (So) dimensions, from the perspective of synchromodal logistics.

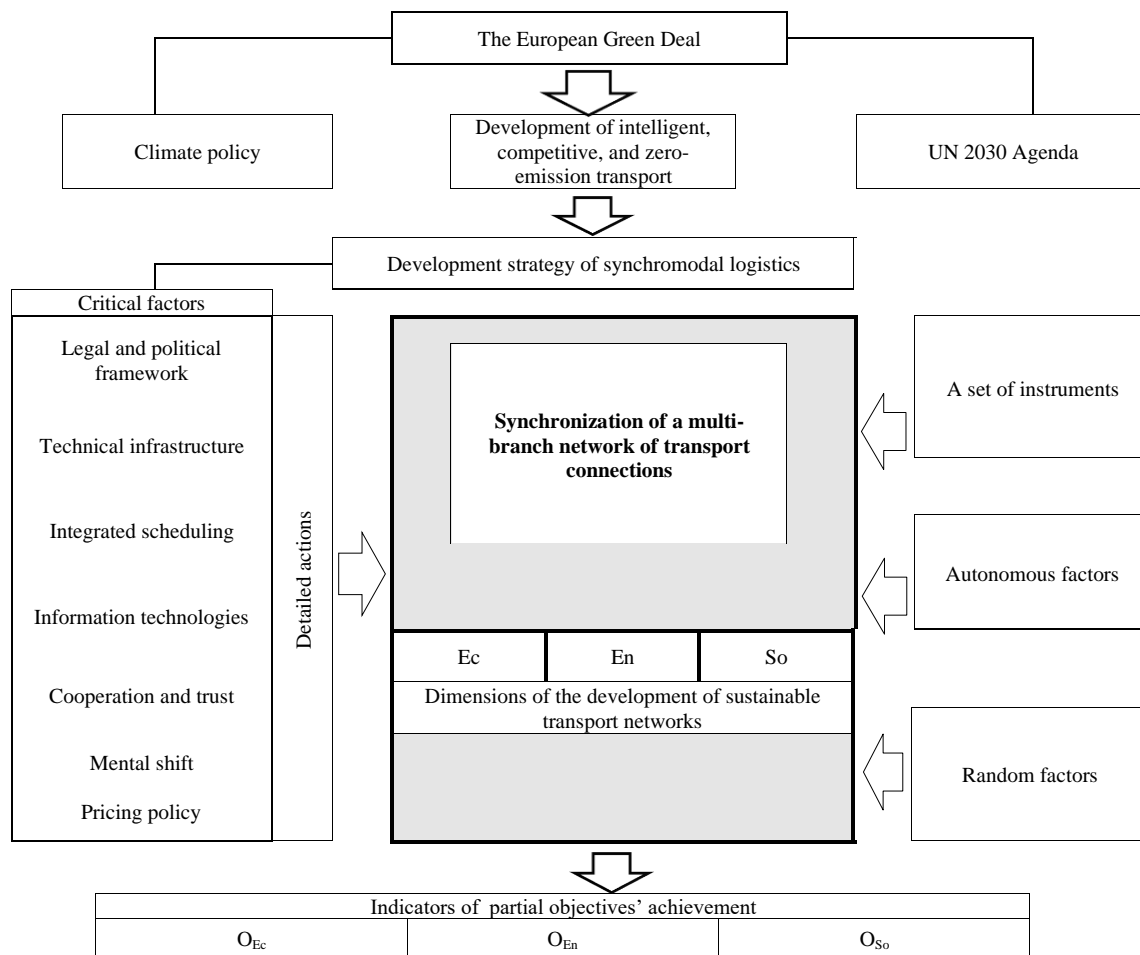


Fig. 1. The model of synchromodal logistics

Source: own study.

The development of synchromodal logistics is one of the future trends in the context of shaping innovative and sustainable logistics. Synchromodality is indicated as a necessary condition for optimal and sustainable transport in the future [Giusti et al. 2021]. This trend is supported, among others, by through the transport policy of the European Union, the European Green Deal strategy, the digital strategy and the UN 2030 Agenda. According to Dong et al. [2018], synchronization is a concept

that, in addition to transport, should also be extended to the entire supply chain, for example, inventory management or production planning.

The features of synchromodal logistics that allow the sustainable use of available resources are real-time information, flexibility, cooperation and coordination, and synchronization [Pfoser and Schauer 2016, Singh et al. 2016]. These characteristics are shaped by critical factors that condition the development of synchromodality (Table 1).

Table 1. Critical factors in the development of synchromodal logistics

Symbol	Critical factors	Detailed actions	Effects of activities
F ₁	Legal and political framework	Strengthening and coordination of the development strategy Research and development	Increased safety of transport Improving energy security Improving the state of the environment Climate protection
F ₂	Technical infrastructure	Development of intelligent transport nodes and corridors Development of the TEN-T network Terminal development	Reduction of infrastructure development and maintenance costs Improving the quality and availability of infrastructure Reduction of CO ₂ emissions
F ₃	Integrated scheduling	Planning at the network level	Improving operational efficiency Improving the state of the environment Improving the quality of process implementation Consolidation of volumes Optimal use of the time factor Modularization
F ₄	Information technologies	Big Data Automation Digitization	Development of monitoring technology Development of new business models Holistic goods network Flexible transport solutions
F ₅	Cooperation and trust	Network integration Horizontal and vertical cooperation	Service sharing Pushing instead of pulling
F ₆	Mental shift	Dissemination of synchromodal solutions in transport	Increasing the resilience and continuity of transport operations
F ₇	Pricing policy	Flexible pricing strategies	Improving the quality of services provided Dynamic integration and modification of services Cost reduction

Source: own study.

Analysis of research on synchromodal logistics [Pfoser et al. 2016, Manerba et al. 2019, Behdani et al. 2014] allowed us to recognize that the path to the development of this forward-looking concept leads through the implementation of seven basic groups of activities related to critical factors, which are listed in Table 1. The first includes activities to strengthen and coordinating the development strategy of synchromodal logistics, resulting from legal and political conditions. The second group consists of activities aimed at improving the organization of transport processes, mainly related to the development of technical infrastructure. The next two groups of activities, characterized by an innovative and innovative nature, are related to integrated planning and information technologies. A great potential for influencing the development of synchromodal logistics lies also in activities resulting from cooperation and trust, mental changes, and pricing policy. The implementation of the above-mentioned activities is to be possible thanks to the instruments, including legal, economic, technological, and information instruments. The final effects of these activities will also depend on the influence of external factors, including autonomous and random factors. They can

contribute to a marked acceleration or slowing of certain activities. Their importance and directions of impact on the functioning of global supply chains are confirmed by events accompanying, inter alia, the COVID-19 pandemic.

In the face of the slowdown in the growth of the world economy, countries are constantly looking for new economic ventures. In the era of globalization, they concern the phenomenon of competition not of individual enterprises, but of entire supply chains. Under such conditions, one for the key factors of competitive advantage is a properly organized supply chain, the fundamental element of which is the transport system [Norman et al. 2016, Veenstra et al. 2012]. Its main skeleton is the infrastructure system that determines the transport accessibility of the area, which is considered a factor determining the development of enterprises, regions, and countries. The accessibility of the transport infrastructure and the relationships that prevail in it determine the configuration of the logistics network, allowing for a coordinated and effective implementation of logistics processes [Dong et al. 2018, Intihar et al. 2017]. In their recently published analysis, K. Nübel et al. [2021] examined trends and

barriers in infrastructure planning and delivery. The main cause of the sector's problems is the prevalent fragmentation of the value chain and the lack of a long-term vision for infrastructure. To overcome these challenges, value chain integration is needed. The authors suggest that this could be achieved through use-case-based, visionary, and governance-driven creation of federated digital platforms for infrastructure projects. Digital platforms enable full-lifecycle and accountable governance guided by a shared infrastructure vision.

The reactivation of the New Silk Road, also known as the 'One Belt and One Road' initiative, is to be a source of additional value in the logistics network. The reconfiguration of the European-Asian supply chains, as part of the „One Belt and One Road” initiative, is to contribute to the improvement of trade flows within China and with the environment, mainly the countries of Europe, Asia, and Africa. From a synchromodal logistics perspective, this initiative has great potential for the development of sustainable transport corridors.

EFFECTS OF THE DEVELOPMENT OF SYNCHROMODAL LOGISTICS FROM THE PERSPECTIVE OF RECONFIGURING THE EUROPEAN-ASIAN SUPPLY CHAINS

The concept of synchromodal logistics and the measures for its implementation from the perspective of the reconfiguration of European-Asian supply chains are defined at the supranational level. However, the final set of planned measures and their weights are left to the discretion of individual states, which develop autonomous synchromodality development plans. These activities aim to strengthen and coordinating efforts to develop sustainable transport corridors [Aditjandra et al. 2016]. There are several arguments in favor of this approach. The main one is the growing role of transport in building the competitiveness of countries and strengthening their role on international markets. In the opinion of the World Bank, the costs of transport and trade are more important than trade policy in creating a competitive advantage for the national economy. This is because lowering transport costs by 10%

causes an increase in national income by about 2.5%, while a 10% increase in them contributes to an average of 20% decrease in the level of trade [Alonso Raposo et al. 2019].

To use the quantitative model of synchromodal logistics (Figure 1) to assess the effects of the development of sustainable transport corridors from the perspective of the reconfiguration of European-Asian supply chains, it was given quantitative characteristics. These characteristics are expressed in the assignment of point values to the critical factors F1, F2... F7, determining the values of the indicators of the partial activities Ec, En and So and the values of the indicators of the direction of their impact, which was obtained thanks to the results of the survey and the use of artificial intelligence methods (Table 2). The representative nature of the sample group of experts made it possible to obtain information of high cognitive value. 13 experts from Poland, who dealt with the studied issues, representing international companies from the transport-forwarding-logistics industry participated in the survey. The scope of the study covered the period from March to June 2021. The completion of the survey consisted of determining the preferred set of assumptions.

The point values assigned to the critical factors of synchromodal logistics, aimed at the development of sustainable transport corridors, made it possible to define the essence of these activities. It was assumed that the total number of points that evaluated the activities under the seven critical factors is 100. According to fuzzy set theory, the sum of the percentages for each of the activities is 100%. These values form a four-point scale of the effectiveness of the subactivities. The highest of these values indicates the most effective, and the lowest indicates the least effective partial effect. Indicators of direction of the impact of partial activities are the input variables of the model. They allow for the expression of the nature of the influence of subactivities on the achievement of sub-goals („1” favorable, „0” neutral, „-1” unfavorable). The indicators of the achievement of partial goals play the role of the output variables of the model. The value of the

main goal achievement index is the sum of the values of the partial goals achievement indexes.

Table 2. Averaged assessment of the critical factors of synchromodal logistics in terms of the development of sustainable transport corridors - results of the survey

Critical factors (symbol)	Value	Indicators of partial actions (%)			Indicators of the direction of partial actions impact*			Indicators of partial objectives' achievement		
		Ec	En	So	Ec	En	So	O _{Ec}	O _{En}	O _{So}
F ₁	15	47	38	13	1	1	0	6,98	5,69	0,00
F ₂	23	48	31	20	1	1	1	10,78	6,94	4,50
F ₃	17	43	31	25	1	1	1	7,26	5,29	4,16
F ₄	13	42	25	30	1	0	1	5,52	0,00	3,98
F ₅	12	47	18	34	1	0	1	5,45	0,00	3,91
F ₆	11	38	25	33	1	1	1	4,14	2,77	3,59
F ₇	10	41	23	32	1	1	0	4,13	2,25	0,00
Total	100	x	x	x	x	x	x	44,26	22,93	20,14
Main objective achievement indicator O								87,34		

*1 (favorable), 0 (neutral), -1 (unfavorable)

Source: own study.

The results obtained clearly show the high effectiveness of the critical factors of synchromodal logistics in the development of sustainable transport corridors, while ensuring the achievement of objectives in the economic, environmental, social and spatial dimensions (Table 2). The goal achievement index (O), representing the degree of effectiveness, is 87.34 points. Referring to the above description of the quantitative characteristics of the model to individual categories of activities, it can be concluded that assigning 23 points to activities in the field of technical infrastructure development (F₂), the study participants considered them to be the most important for the development of sustainable transport corridors, in line with the concept of synchromodal logistics. The partial activity indicators for factor F₁ indicate that it will be the most involved, i.e., 48% involved in the achievement of economic goals (Ec). Moreover, it was assumed that 31% of the value of activities related to the development of technical infrastructure will directly translate into the achievement of environmental goals and 20% to the implementation of social goals.

Indicators of the direction of the impact of partial activities inform about the beneficial impact of the F₂ factor on the implementation of all partial goals, i.e., economic, environmental

and social. Calculations made with the use of the model allowed for the scoring of these impacts. The positive contribution made by the activities of factor F₂ is: 10.78 points for economic goals, 6.94 points for environmental goals, and 4.50 points for the achievement of social goals. The distribution of indications regarding the next two critical factors, i.e. „Integrated planning” (17 points) and „Legal and political framework” (15 points), shows that these activities were found in the study to be relatively effective in the development of sustainable transport corridors. The greatest effects of these activities concern the partial goals of O_{Ec} and amount to 7.26 points (F₃) and 6.98 points (F₁).

The averaged values of the indicators to achieve the objectives of O_{Ec}, O_{En} and O_{So} show that the critical factors of synchromodal logistics will allow to achieve the highest level of effectiveness in the development of sustainable transport corridors in the economic and environmental dimensions (Figure 1). The values of the target achievement indicators are 44.26 points for economic aspects and 22.93 points for environmental effects. The results obtained with the use of the assumptions of experts 9, 4, 1 and 12 indicate a higher effectiveness in achieving the O_{Ec} goal, while the assumptions of experts for the O_{En} goal were more varied (Figure 2).

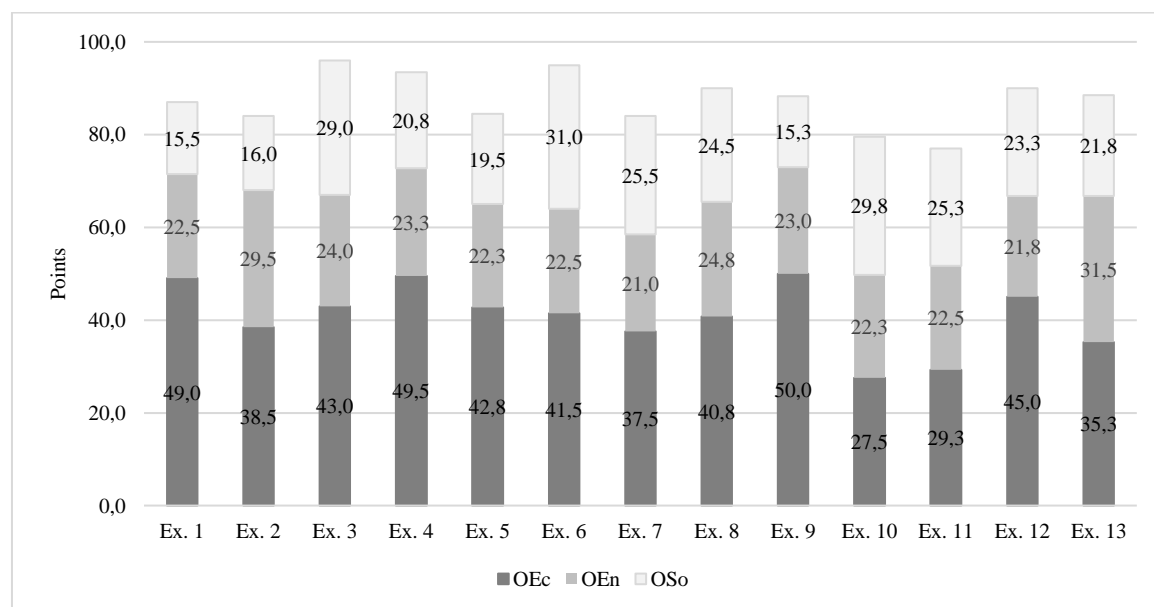


Fig. 2. Experts' indications regarding the impact of critical factors of synchromodal logistics on the effects of the development of sustainable transport corridors

Source: own study.

In all the variants of experts' responses presented in Figure 2, the determined values of the O_{Ec} , O_{En} and O_{So} objectives achievement indicators are relatively stable. The results obtained clearly indicate that the implementation of synchromodal solutions from the perspective of the reconfiguration of the European-Asian supply chains has great potential in the development of sustainable transport corridors.

CONCLUSIVE REMARKS

The research confirmed the possibility of achieving the assumed goal, according to which the implementation of the synchromodal logistics concept would allow the development of sustainable transport corridors from the perspective of reconfiguration of European-Asian supply chains. They also showed that the effectiveness of achieving this goal can be high if the effects of critical factors in the development of synchromodal logistics do not compensate for each other. It is also possible to achieve the sub-goals O_{Ec} , O_{En} and O_{So} .

The use of the model and the assumptions formulated by experts allows the conclusion that the main goal (O) can be achieved with an efficiency of 87.34%. The most important

critical factors determining the development of synchromodal logistics were the "Technical infrastructure" (F2), "Integrated planning" (F3) and "Legal and political framework" (F1). The highest efficiency (44.26%) was indicated for the implementation of measures in the economic dimension (O_{Ec}). The effectiveness of the implementation of the O_{En} and O_{So} objectives will be 22.93% and 20.14%. Thus, the results obtained from the study allowed for a positive verification of the research hypothesis.

Despite the convergent basic conclusions of the study, it seems appropriate to create a consultative platform to organize the achievements so far in this research area.

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