TRANSPORT
ISSN 1648-4142 / eISSN 1648-3480
2019 Volume 34 Issue 3: 300–311
https://doi.org/10.3846/transport.2019.9718

INVESTIGATION AND EVALUATION OF MAIN INDICATORS IMPACTING SYNCHROMODALITY USING ARTIW AND AHP METHODS

Raimondas ŠAKALYS[1], Henrikas SIVILEVIČIUS[2*], Laima MILIAUSKAITĖ[3#], Algirdas ŠAKALYS[4]

[1]*Dept of Logistics and Transport Management, Vilnius Gediminas Technical University, Lithuania*
[2, 3, 4]*Transport and Logistics Competence Centre, Vilnius Gediminas Technical University, Lithuania*

Received 20 April 2018; revised 25 October 2018, 20 December 2018; accepted 16 January 2019

Abstract. The East-West Transport Corridor (EWTC) in the Southern part of the Baltic Sea Region (BSR) has been chosen as a practical area for implementation of a novel transportation concept called synchromodality. The main expectations in developing synchromodal transport system are related to the improvement of the transport service level, modal shift and capacities utilization of transport hubs along this corridor. However, in the absence of identification of major factors influencing synchromodal system it is difficult to evaluate a potential benefit of implementation of this new transport concept. Our main goal in this paper was, on the basis of a review and using a specific questionnaire, to determine the main indicators impacting effectiveness of the synchromodal system. Compatibility of experts' opinions was verified by using Multiple-Criteria Decision-Making (MCDM) method. The paper will be useful for transport and logistics companies interested in moving towards synchromodal transport, as well as for future researchers. In the course of the research – using the Average Rank Transformation Into Weight (ARTIW) and Analytic Hierarchy Process (AHP) methods – it was determined that the normalized subjective weights of the five main criteria impacting synchromodality distributed in the following order: service quality, efficiency, infrastructure sufficiency, technical properties of terminals and interaction of technologies. In accordance with the Kendall's concordance coefficient and consistency ratio values, expert opinions are consistent, which enabled the rankings of expert group averages and the eigenvector to take as a result of the task solution. The outcomes of the research presented in the paper have shown that service quality (transport time, service and waiting time, handling time, working hours, reliability and flexibility) is the most important indicator (criterion) impacting synchromodality. At the same time it is a big challenge for transport researchers because it requires to design and apply a qualitatively new mathematical models facilitating an establishment of an optimal synchromodal network and services along chosen transport corridor.

Keywords: synchromodality, transport corridor, indicator, rank correlation, ARTIW, AHP, MCDM.

Introduction

Globalization of the world economy created tremendous challenges for trade development and transnational transport services. A fresh look at the construction of new transport routes in the Baltic Sea Region (BSR) could be one of the most important factors for the establishment of more efficient transport links better served to support rapid growth of the international trade. The expansion of the EU and the related impact on a rapid growth of economies in the Baltic States requires a balanced and modern transport network development, not as traditionally with focus on the Northern part of the BSR, but in the entire BSR.

The link between and integration of various hubs in the East-West Transport Corridor (EWTC) in the Southern part of BSR is the main feature in the drive to fully capitalise on the potential they have in the global transport market, and to steer the region towards sustainable transport solutions. The eastern part of the corridor is a gateway to and from the BSR connecting it with Russia, Kazakhstan and China to the East and Belarus, Ukraine and Turkey to the South-East. The EWTC with the Black sea link going to Georgia, Armenia and Azerbaijan connects this route with Kazakhstan and Far East (EWTCA 2018). The EWTC future perspectives are related to the increasing transportation flows along Asia–Europe transport links.

In order to ensure efficient transportation process of intermodal freight along the EWTC, it is necessary to ob-

*Corresponding author. E-mail: *henrikas.sivilevicius@vgtu.lt*
#Corresponding author. E-mail: *l.miliauskaite@vgtu.lt*

tain compatibility of the existing infrastructure capacity, as well as coordinate operations of infrastructure managers and operators (Šakalys, Batarlienė 2017).

The aim of the paper is to determine the main indicators impacting synchromodality (based on specific questionnaire and knowledge of transport and logistics experts (operating along EWTC) and authors of this paper) and by using Multiple-Criteria Decision-Making (MCDM) method it was determined the normalized subjective weights of the main criteria impacting synchromodality.

The research, results of which were used in preparing the article, was executed with an applied approach including: the extended literature study; a specific thematic study; interviews with stakeholders and transport experts from the BSR – both performed in the framework of TENTacle (2019) project of the BSR INTERREG (2019) programme – and use of MCDM method to rank and weight the results of the research. A comprehensive literature review was performed to obtain the knowledge on how the subject of synchromodality is developed in the academic literature. The new knowledge gained from this review served as a basis of further research. The outcomes of the TENTacle (2019) thematic study (qualitative analysis), together with the results of the academic literature review, provide the information needed for identification of main indicators impacting synchromodality, and were used as the basis in preparing questionnaire for stakeholders and transport experts. Research results (including questionnaire) were ranked by using Average Rank Transformation Into Weight (ARTIW) and Analytic Hierarchy Process (AHP) methods.

1. Literature review

Starting from the adoption of multimodal concepts, stakeholders also developed intermodal solutions, nowadays striving for more flexible, reliable, sustainable, cost efficient synchromodal concepts ideas (Muller 1999). According to the Oxford dictionary (*https://www.oxforddictionaries.com*), synchronisation (noun) described as the fact of happening at the same time or moving at the same speed as something else and synchronise (verb) it is a cause to occur or operate at the same time or rate. The meaning of 'synchro' in synchromodality needs to be broadened from the synchronization of the different transportation modes towards the synchronization of transportation with other supply chain activities such as inventory management and the setting of service levels. Although the term "synchronization" has been used before in literature concerning freight transport, for example indicating a seamless supply chain (Rodrigue 1999) or an integrated information material flow (Hauge *et al.* 2011).

Synchromodal services require an integrative network strategy for multimodal freight transport within Europe. Network integration involves a close fit of corridors and hubs into a holistic EU freight network. Hubs need to be nominated, equipped and connected by corridors in a consistent way, from Trans-European Transport Network (TEN-T level) to last-mile level, in order to allow services to achieve the economies of scale and the integration scope of multimodal networks (ALICE 2015; Buiel *et al.* 2015). The concept of synchromodal transport is an important constituent of the physical internet. The physical internet necessitates the synchronization of intermodal services between modes and with shippers – referred to as synchromodality – aligning equipment plus services on corridors as well as hubs thus integrating them into networks (Putz *et al.* 2015). Synchromodality uses an integrated network of various transport modes available in parallel to provide flexible transport solution with great optimality (Zhang, Pei 2016).

According Aditjandra (2018) the modal shift and intermodalism have been replaced by "smart", "green", and "integrated" themes, alongside economic competitiveness and growth. The objective of the chapter in the book Aditjandra *et al.* (2016) is to illustrate the current state of European rail freight research and how this can improve rail freight to support green and sustainable transport, as promoted by the governments of the EU. Zunder *et al.* (2013) analyses the extent to which an open access rail freight market has enabled new Pan-European rail freight services, using a case study within the context of policy. A novel transport concept called "synchromodality" has been proposed recently to green freight transport by fostering a modal shift towards environmentally friendly modes (Tavasszy *et al.* 2010; Buiel *et al.* 2015) of transport such as water (barge or short sea), rail and/or road can be used (Topsector Logistiek 2011) for container transportation (Buiel *et al.* 2015; Norman *et al.* 2015). Miletić *et al.* (2017) emphasised the issue of the environmental impact of mode choice since the transport sector is the second largest source of greenhouse gas emissions (after energy production). Synchromodality is a new logistic concept, which aims to increase the efficiency of transport and achieve lower transport costs (Fawcett *et al.* 2007; Van der Burgh 2012, Lucassen, Dogger 2012) while increasing customer service (Fawcett *et al.* 2007; Behdani *et al.* 2016). As outcome of this improved decision-making (Pleszko 2012), real-time chain (or service) composition can both reduce bottlenecks in the physical infrastructure, optimize utilization of existing infrastructure capacity in main hubs of transport corridors (Kapetanis *et al.* 2016) through synchromodality (Hofman, Bastiaansen 2014; Solvay *et al.* 2016).

The synchromodality is a flexible (Behdani *et al.* 2016; Dong *et al.* 2018) and sustainable transport system services (Overbeek *et al.* 2011; Defares 2011; Lucassen, Dogger 2012; Roth *et al.* 2013; Buiel *et al.* 2015) with dynamic information exchange (Overbeek *et al.* 2011; ALICE 2014; Hofman, Bastiaansen 2014; Agbo, Zhang 2017) that facilitates the synchronisation of the different modes – parallel availability of at least two modalities, cooperation instead of competition between modalities (Tavasszy *et al.* 2010; Van der Burgh 2012, Topsector Logistiek 2011; Ayed *et al.* 2011; Van Gool 2012; Behdani *et al.* 2016; Hofman, Bastiaansen 2014). Tavasszy *et al.* (2010), Hofman *et al.* (2012) and Agbo, Zhang (2017) characterized as the ability to real-time switching between integrated transport modes (ALICE 2015) at particular times (Defares 2011; Van Stijn *et al.* 2011; Roth *et al.* 2013; Pfoser *et al.* 2016). When this information contains real-time data about transport logistics, multimodal becomes synchromodal (Hofman *et al.* 2012). It enables efficient supply chains in which shippers book their transport service "mode-free" (Overbeek *et al.* 2011; Van der Burgh 2012; Pfoser *et al.* 2016) available capacity is used at all times (Tavasszy *et al.* 2010; Fan 2013) the adaption of all infrastructure, services and stakeholders to one another (Van der Burgh 2012) and considering real-time information on the current conditions of the transport system (e.g., delays, congestion, reliability, transit times, pricing, availability, etc.) (Reis 2015) caused by the environment of that modality during its execution (e.g. predicted traffic density and weather forecasts) (Hofman 2016). It offers a better utilization of transportation modes and resources, a better consolidation of loads, flexibility and freedom to switch modes, and synchronization of the services.

Synchronization of operations (ALICE 2015) between complete transportation network (Buiel *et al.* 2015; Hintjens *et al.* 2015) and the customers' demands occurs when the supply of services between different modalities is tailored to a coherent transport product, which meets the transport demand of shippers at any moment in terms of price, timeliness, reliability and/or sustainability (Defares 2011; Zuidwijk 2015). It provides the possibility to integrate and modify these services in a dynamic manner (ALICE 2015) and it will be then dynamically adjusted (Tavasszy *et al.* 2010).

The continual synchronization of chains of goods, chains of transport and infrastructure in such a way that the best modal choice can be made at any moment for the aggregated demand for transport (Van der Burgh 2012). Collaboration between actors is essential, to create synchronized services and to cope with future pressures on efficiency, flexibility and sustainability: this collaboration requires a fit between operational processes of horizontal and vertical business partners (ALICE 2015; Steadieseifi *et al.* 2014). The synchronisation is the most difficult task for transit planners and schedulers (Ceder *et al.* 2001). This task is sometimes accomplished intuitively in practice by simplifying the problem in the favour of coordination in a few key points in the network. However, a network-wide synchronisation is a complex task by nature.

The shipper only agrees on cost, quality and sustainability targets (Vinke 2016; Rossi 2012; Bol Raap 2016) but leaves the mode choice free for the logistics service provider to decide, making it possible to offer the shipper an integrated, one-stop shop solution where cargo is not left waiting for transport to become available (Topsector Logistiek 2018). One or more coordinators of complete transport chains or transport chain sections are monitoring the synchromodal transport chain (Tavasszy *et al.* 2010). This coordination involves the planning of services (Buiel *et al.* 2015), the performance of services and information about services (Defares 2011) and control (Lucassen, Dogger 2012). The cornerstone of Synchromodal Freight Transport concept is an integrated view in the planning and management of different modalities to provide flexibility in handling transport demand. Because multiple modalities are involved in a door-to-door journey chain, the integration of service has always been an important issue for intermodal freight transport (Tavasszy *et al.* 2015). In addition, the planning flexibility can be used to deal with uncertainties and disturbances, and thus increasing the on-time performance and reliability of the transportation.

Accordingly, the transport units deployed in the synchromodal network have to meet specific requirements that include interconnectivity and interoperability, standardisation and modularisation as well as hyperconnected intelligence. Practical examples underline the feasibility and implementation status of the described requirements (Pfoser *et al.* 2017).

Synchromodal transport furthermore implies making optimum use of the factor time: push instead of pull. Containers no longer remain at the deep-sea terminals in anticipation of action on the part of the recipient (pull), but are directly moved by barge or train to the inland terminals in the hinterland in a pro-active fashion (push). The realization of a synchromodal transport system is not that easy. The consolidation of volumes is essential in this respect. Intihar *et al.* (2017) have examined the impact of integration of macroeconomic indicators on the accuracy of the container throughput forecasting model. Only then frequent connections are possible between all the hubs using all three modalities: rail, inland shipping and road. The result is an optimal sustainable and reliable transport system (Pleszko 2012). Putz *et al.* (2015) based on the literature review indicated seven main categories of potential key enablers were determined: (1) awareness and mental shift; (2) cost, service and quality; (3) information, data, Information and Communications Technologies (ICT) and Intelligent Transport Systems (ITS); (4) legal and political issues; (5) network and cooperation/trust; (6) physical infrastructure; (7) sophisticated planning and simulation.

For synchromodal planning, the service network design is assessed, considering additional corridors between inland terminals and container transportation over paths with multiple consecutive legs and intermediate transfers (Van Riessen *et al.* 2013). The objective of Aditjandra *et al.* (2012) study is to gain a better understanding of whether a freight corridor concept, as promoted by the EU TEN-T initiative, is feasible and sound and can be promoted to reduce the environmental (greenhouse gas) impact of long distance freight operation. The inland transportation in North-West Europe is still organised per corridor and not for the network as a whole. Firstly, no suitable methods for creating an integrated network plan exist yet. Secondly, adapting the plan in real-time responding to delays and other changes occurs manually, by planning operators that focus on specific corridors and inland connections. Thirdly, because of the customer's restrictions with transportation orders, the network orchestrator misses the flexibility to switch between modes and routes and thus cannot achieve the benefits of synchromodal planning (Buiel *et al.* 2015).

Vinke (2016) provided the key aspects for synchromodal transport based on Behdani *et al.* (2016) methodology – are mode-free (or A-modal) booking, joint planning and coordination, bundling, flexibility, and visibility) and Fan (2013) (mode free booking, dynamic planning of transportation, real-time switching between modes, decision-making based on network utilization, combining transport flows, cooperation between actors in the transportation chain, information availability and visibility among actors).

According to Defares (2011) the core of the concept of synchromodality is that the gearing within and between the goods flows, the transport chains and the infrastructure chains is made such that goods volumes can largely be consolidated and the unused capacities of transport modes and the infrastructures can be better be utilized.

By Behdani *et al.* (2016) – the integration of transport chains in a synchromodal transport system includes synchronizing both "stationary resources" – like transport infrastructure (e.g., roads, rails, and navigable waters) or transhipment nodes (e.g., inland terminals) – and "moving resources" (e.g., trucks, trains, and barges), which provide the transport services between specific origins and destinations.

Synchromodal transport emerged as a new concept in freight transport (Behdani *et al.* 2016; Lucassen, Dogger 2012; Steadieseifi *et al.* 2014). It integrates different transport modes and gives the logistics service providers the freedom to deploy different modes of transportation in a flexible way, which enables better utilization of the existing infrastructure capacities in main hubs of transport corridors (Kapetanis *et al.* 2016).

Defares (2011) and Behdani *et al.* (2016) presented synchromodality definitions and concept are closest to the opinion of authors of the paper. The above authors have a more wide approach toward the concept of synchromodality. In general, it could be stated that, according to these authors, the synchromodal transport system includes both, transport operations and transport infrastructure (e.g., inland terminals) resources.

2. Identification the indicators influencing on synchromodality

The authors of this paper based on scientific literature review proposed the following definition of synchromodality "it is a process of freight transportation, in which information simultaneously is exchanged to maximize the advantages of different transport modes and transport nodes in terms of efficiency and environmental impact".

A comprehensive literature analysis allowed to preliminary identify the main indicators (criterions) impacting synchromodality. These indicators are presented in Table 1.

The next necessary step was to assess the significance (rank and weight) of each main indictor for the development of synchromodal transport.

During the past year, articles have been published to deal with transport problems using MCDM methods. MCDM methodology for selecting beneficial sites of Park-and-Ride (P&R) lots and for outlining desirable directions of development of the city of Vilnius with incorporated P&R facilities was employed in the paper (Palevičius *et al.* 2017). Analysis of the trend of electric

Table 1. Indicators influencing synchromodality of transport activity

Indicator			Reference
Abbreviation	Name	Content	
A	Efficiency	Absolute limit cost and alternative cost	Cruijssen *et al.* (2007); Defares (2011); Rossi (2012); Vinke (2016); Behdani *et al.* (2016); Kos *et al.* (2017)
B	Service quality	Transport time, service and waiting time, handling time, working hours, reliability, frequency of service, cargo safety and security	Behdani *et al.* (2016); Bontekoning *et al.* (2004); Brümmerstedt *et al.* (2017); Geerlings *et al.* (2017); Mason *et al.* (2007); Pedersen *et al.* (2009); Pomponi *et al.* (2015); Tavasszy *et al.* (2015); Van der Burgh (2012); Veenstra *et al.* (2012)
C	Infrastructural sufficiency	Congestion, bottlenecks, obstructions	Dolinsek *et al.* (2013); Veenstra *et al.* (2012)
D	Technical properties of terminals	Availability of technical means to service intermodal transport at main intermodal transport nodes	Alessandri *et al.* (2007); Nabais *et al.* (2013)
E	Interaction of technologies	Accessibility of seaports, airports, railway stations, inland waterways, logistics centres; loading according to requests received in advance	Bontekoning *et al.* (2004); Jarašūnienė *et al.* (2012); Brümmerstedt *et al.* (2017)

vehicles makes evident that the target does not have a real chance to be achieved without targeted efforts. In order to improve the infrastructure of electric vehicles in major cities and resorts of Lithuania, Palevičius *et al.* (2018) have carried out a comparative analysis of public infrastructure for electric vehicles. For the quantitative analysis, authors proposed eight criteria describing such an infrastructure. As perception of the infrastructure by owners of electric cars depends on complex factors, Palevičius *et al.* (2018) used MCDM methods for evaluation of the current state of its development by four such methods: (1) Evaluation based on Distance from Average Solution (EDAS), (2) Simple Additive Weighting (SAW), (3) Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and (4) Preference Ranking Organization Method for Enrichment of Evaluations II (PROMETHEE II). The Multilevel Grey Evaluation (MGE) and TOPSIS methods are employed in the paper Chen *et al.* (2014) to evaluate the overall performance of passenger transfer at large transport terminals in different alternatives. The integrated weighting method is adopted to overcome the biased weight set from individual subjective or objective perspectives in the evaluation.

3. Methodology determining significance of indicators

3.1. Rank correlation method

The research was processed by applying Kendall's rank correlation method and experts options compatibility was analysed using concordance coefficient. When given a prepared questionnaire, the experts $E_1, E_2, ..., E_n$ were asked to give quantitative rank values $X_1, X_2, ..., X_m$ (ranks $R_1, R_2, ..., R_m$) to synchromodality indicators based on their knowledge, experience and intuition. The lowest rank (an integer number) is given to the most important synchromodality indicator (criterion); one rank less is given to the next criterion; and the highest rank is given to the least important indicator (criterion).

According to Kendall and Gibbons (1990) the value of calculation of the concordance coefficient is that the calculated square sum S of the deviation of all indicator (criteria) ranks from average shows that experts' evaluations are completely different from the total mean evaluation. Therefore, reliability of the expertise can be expressed by the expert evaluation concordance coefficient W, indicating a degree of similarity of individual opinions. A set of values of the concordance coefficient W is $[0,1]$, i.e. $0 \le W \le 1$. The higher W, the stronger correlation of variables. When all the ranks coincide, then $W = 1$.

After an expert questionnaire evaluations were ranked. The experts n qualitatively evaluates m indices of objects. Evaluations R_{ij}, when $i = 1, 2, ..., n$ compose a matrix, where: n – the number of rows; m – the number of columns $j = 1, 2, ..., m$ (Table 2).

Table 2. Importance evaluated indicators by ranks

Indicator $j = 1, 2, ..., m$ / Expert $i = 1, 2, ..., n$	X_1	X_2	...	X_m
E_1	R_{11}	R_{12}	...	R_{1m}
E_2	R_{21}	R_{22}	...	R_{2m}
E_3	R_{31}	R_{32}	...	R_{3m}
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
E_n	R_{n1}	R_{n2}	...	R_{nm}

The idea of Kendall's coefficient of concordance is related to indicators of synchromodality to each index taking into account the sum of ranks R_j of all experts (Kendall, Gibbons 1990):

$$R_j = \sum_{i=1}^{n} R_{ij}. \tag{1}$$

R_j deviation from the square sum S of the total mean:

$$S = \sum_{j=1}^{m} \left(R_j - \bar{R} \right)^2. \tag{2}$$

Then total mean could be calculated according to the equation:

$$\bar{R} = \frac{\sum_{j=1}^{m} R_j}{m} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m} R_{ij}}{m} = \frac{n \cdot (m+1)}{2}. \tag{3}$$

The average rank $\bar{R}_j$ of each indicator (criteria) is calculated by dividing the sum of ranks by the number of experts:

$$\bar{R}_j = \frac{\sum_{i=1}^{n} R_{ij}}{n}, \tag{4}$$

where: R_{ij} – the rank of indicator (criteria) given by the expert; n – number of experts.

If S is a real sum of squares (Equation (2)), the coefficient of concordance when there are no related ranks, is defined by the ratio of the calculated S and S_{max}:

$$W = \frac{12 \cdot S}{n^2 \cdot \left(m^3 - m \right)}. \tag{5}$$

The deviation of ranks of each indicator (criteria) R_{ij} from the average rank square sum S is calculated according to the equation:

$$S = \sum_{j=1}^{m} \left(\sum_{i=1}^{n} R_{ij} - \frac{1}{2} \cdot n \cdot (m+1) \right)^2, \tag{6}$$

where: m – number of indicator (criteria) ($j = 1, 2, ..., m$); n – number of experts ($i = 1, 2, ..., n$).

For the compatibility of expert views, it was necessary to calculate the coefficient of concordance W.

If the number of objects (criteria) is $m > 7$, the importance of the concordance coefficient can be defined by applying χ^2 (chi-square) of Pearson's criteria. Random value:

$$\chi^2 = n \cdot (m-1) \cdot W - \frac{12 \cdot S}{n \cdot m \cdot (m+1)}. \quad (7)$$

Concordance coefficient can be applied in practice, if its limit value is defined and shows when expert evaluations can be considered as consistent.

The lowest value of the concordance coefficient W_{min}, when it is impossible to state that opinions of all n experts about the quality of an object under investigation composed of m compared indicator (criteria) under the defined (needed) significant level α and level of freedom $v = m - 1$ are coordinated, can be calculated by applying the following equation (Sivilevičius 2011a):

$$W_{min} = \frac{\chi^2_{\upsilon,\alpha}}{n \cdot (m-1)}, \quad (8)$$

where: $\chi^2_{\upsilon,\alpha}$ – critical Pearson's statistics, the value of which is found in the research by Montgomery (2013), when the degree of freedom υ and significant level α are taken.

3.2. ARTIW method

The criteria subjective weights can be defined by ARTIW methodology (Sivilevičius 2011a; Sivilevičius, Maskeliūnaitė 2018) by which the importance (weight) of *A*, *B*, *C*, *D*, *E* criteria (Table 1) is defined. For that, the following equation presented by the author is applied:

$$\omega_j = \frac{(m+1) - \bar{R}_j}{\sum_{j=1}^{m} \bar{R}_j}, \quad (9)$$

where: m – number of criteria (indices) showing importance of synchromodality; $\bar{R}_j$ – average rank of j criterion, calculated according to Equation (4).

3.3. AHP method

Traditional MCDM methods evaluate all alternatives at a single level, which inadvertently restricts the simultaneous comparison of numerically heterogeneous alternatives (Saaty, Shang 2011). The decision-maker can specify preferences about the importance of each performance criteria in form of either natural language or numerical value (Taylan *et al.* 2014).

In the real world, it is very difficult to extract accurate data pertaining to measurement factors since all human preferences are susceptible to a degree of uncertainty. Decision-makers are also inclined to favour natural language expressions over exact numbers when assessing criteria and alternatives (Heo *et al.* 2010).

The advantage of the AHP method over other multipurpose decision-making methods is its flexibility, convenience for decision-makers, and the possibility to verify compatibilities (Ramanathan 2001). The AHP method can assess both qualitative (subjective) and quantitative (objective) attributes of alternatives. The twin comparison methodology reduces partiality and bias in decision-making. The AHP method uses relative values and is, hence, a suitable tool to deal with attributes of various dimensions.

The AHP method makes it possible to identify the weight (importance) of indicators at one level of hierarchy against a higher level, or the hierarchically non-structured weights of indicators. The essence of the method lies in the matrix of twin comparison (Sivilevičius 2011b).

This method is very convenient as it is much easier to compare indicators taken pair by pair than to compare them all at one time. The comparison of indictors, as such, is not a sophisticated process as it simply indicates the extent, to which one indicator carries more weight than the other. Moreover, the method concerned makes it possible for the expert to transform a qualitative evaluation of indicators into the quantitative one.

As the outcome of comparison is produced in the form of the square matrix $[A] = a_{ij}$ $(i, j, ..., n)$, the evaluation process, as proposed by Saaty (1980), shall be carried out using a five-score scale (1–3–5–7–9) widely applied in practice.

The elements of matrix $[A]$ shall be completed in compliance with the following requirements (Saaty 1980): first, when both indicators being compared carry equal weight with respect to the phenomenon (object) of the study, i.e. when both are equally important, the elements of matrix $[A]$ must be $a_{ij} = 1$. In such a case, all the elements of the main diagonal must be $a_{ij} = 1$ $(i = 1, 2, ..., n)$ as each indicator is compared with itself; second, when indicator R_i carries a higher weight than indicator R_j, the elements of matrix $[A]$ must be $a_{ij} = 3$; third, when indicator R_i carries a much higher weight than indicator R_j, the elements of matrix $[A]$ must be $a_{ij} = 5$; fourth, when indicator R_i carries a substantially higher weight than indicator R_j, the elements of matrix $[A]$ must be $a_{ij} = 7$; fifth, when indicator R_i carries a comparatively higher weight than indicator R_j, the elements of matrix $[A]$ must be $a_{ij} = 9$. The estimates of even order $(a_{ij} = 2, 4, 6, 8)$ are used as intermediary and compromise variants; generally, they are applied when the situation being investigated based on the opinion of the expert diverges from a typical one (Maskeliūnaitė *et al.* 2009).

Methods of determining the weights of the criteria to describe the synchromodality indicators priority are considered to be subjective if they are evaluated by experts. In that case, experts' qualification should be high because the agreement of their estimates depends on it. For this purpose, the method of pairwise comparison of criteria suggested by Saaty (1980) and widely known as AHP is well suited. This approach allows the researchers to determine the weights of the criteria of the same hierarchical level with respect to higher level criteria or to determine hierarchically unstructured criteria weights. Experts compare all the evaluated criteria R_i and R_j $(i, j = 1, ..., n)$, where: n is the number of the compared criteria.

The application of AHP requires highly developed logical thinking, in particular, the estimate of one highly qualified expert may be more important than the estimates made by a number of inexperienced (not logically thinking) specialists. Therefore, researchers usually interview a number of highly qualified experts, for e.g. 5 experts (Farhan, Fwa 2009).

The matrix of the comparison of evaluation criteria $\left(a_{ji}=\frac{1}{a_{ij}}\right)$ is as follows:

$$\left[A\right]=\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1j} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2j} & \cdots & a_{2n} \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ a_{i1} & a_{i2} & \cdots & a_{ij} & \cdots & a_{in} \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nj} & \cdots & a_{nn} \end{bmatrix}. \quad (10)$$

Let us find the eigenvector (weight of indicator), which may be calculated in four ways (Sivilevičius, Maskeliūnaitė 2010). We will use the 4-th method:

1) The elements of each row are multiplied together and the results obtained are written as follows:

$$\omega_i''=\prod_{j=1}^{n} a_{ij}; \quad (11)$$

2) n-th root is extracted from the element of each row. The results obtained are written as follows:

$$\omega_i'=\sqrt[n]{\prod_{j=1}^{n} a_{ij}}; \quad (12)$$

3) Let us add together the elements of this row:

$$\sum_{i=1}^{n}\omega_i'=\sum_{i=1}^{n}\sqrt[n]{\prod_{j=1}^{n} a_{ij}}; \quad (13)$$

4) Let us divide each element of this row by the sum obtained, i.e. the evaluations normalization:

$$\omega_i=\frac{\sqrt[n]{\prod_{j=1}^{n} a_{ij}}}{\sum_{i=1}^{n}\sqrt[n]{\prod_{j=1}^{n} a_{ij}}}. \quad (14)$$

Thus, the eigenvector ω is found (Step 4). The sum of its elements is equal:

$$\sum_{i=1}^{n}\omega_i=1. \quad (15)$$

It is known that the largest eigenvalue of the inverse symmetrical n-row matrix is $\lambda_{\max}\geq n$. The condition is satisfied.

Now, it is easy to calculate the consistency index CI, which is expressed as follows:

$$CI=\frac{\lambda_{\max}-n}{n-1}, \quad (16)$$

where: $\lambda_{\max}$ is the maximum eigenvalue of the pairwise comparison matrix and it can be calculated as fallows (Chen *et al.* 2016; Sivilevičius 2011b; Stanujkic 2016):

$$\lambda_{\max}=\frac{1}{n}\cdot\sum_{i=1}^{n}\frac{\sum_{j=1}^{n} a_{ij}\cdot\omega_j}{\omega_i}. \quad (17)$$

The relationship between the consistency index of the matrix and the average value of the random index RI, found from the table (Saaty 1980), is referred to as consistency ratio CR, showing the degree of matrix consistency:

$$CR=\frac{CI}{RI}, \quad (18)$$

where: CR denotes the consistency ratio of the pairwise comparison matrix $\left[A\right]$; CI is the consistency index and RI is the random index. The matrix will be consistent if the value of ratio CR is equal to 0.1 or lower. The smaller the CR value, the higher consistency of the matrix.

4. Results and discussion

In order to rank the main indicators (presented in Table 1) their importance on the development of synchromodal transport. The experts from Germany, Denmark, Sweden, Belarus, Ukraine and Lithuania conducted by using a questionnaire (during period of January–April 2017). The responses were received from 14 experts and this was done in the framework of TENTacle (2019) project of the BSR INTERREG (2019) programme. One of the aims of this project is to investigate prospects further development of transport networks, as well as, possibilities for a better convergence of transport planning, management and implementation of integrity of transport patterns linking the EU BSR and the EU Eastern Partnership Countries.

In the first step, while applying the rank correlation method, five criteria given by 14 experts to indicators (criteria) were processed. The average of each criteria ranks was calculated; it indicated the importance of indicators expressed in priorities. The sum of all criteria ranks is 15. Total sum of index difference squares S is 946. The data of the calculated index difference squares is indicated in the Table 3.

In order to be sure that expert views are not contradictive, coefficient of concordance W was calculated. When there are no related ranks coefficient of concordance is calculated according to Equation (5):

$$W=\frac{12\cdot S}{n^2\cdot\left(m^3-m\right)}=\frac{12\cdot 946}{14^2\cdot\left(5^3-5\right)}=0.4826.$$

It is necessary to define the indicator (criteria) χ^2, for which random value is calculated according to the Equation (7):

$$\chi^2=n\cdot\left(m-1\right)\cdot W=14\cdot\left(5-1\right)\cdot 0.4826=27.03.$$

When the number of experts n = 14 and the number of compared indicators (criteria) m = 5, the number of freedom degrees v = m = 1 = 4 is calculated and a significant level α = 0.05. Complying with the level $\chi^2_{\upsilon,\alpha}$ selected from the number of freedom degrees, which is equal to 9.49 and is lower than the estimated value χ^2.

Lowest value $W_{\min} = 0.1695 < W = 0.4826$. Therefore, it can be stated that opinions of experts in evaluating the main group indices are consistent, and estimated average ranks indicate a consensus view. Priority of indicators of synchomodalilty are $B \succ A \succ C \succ E \succ D$ (Figure 1).

Table 3. Importance of indicators influencing synchromodality by rank

Indicator $j = 1, 2, ..., m$ / Expert $i = 1, 2, ..., n$	A	B	C	D	E
E_1	3	1	5	4	2
E_2	1	2	5	4	3
E_3	1	3	2	4	5
E_4	2	3	5	1	4
E_5	3	1	2	5	4
E_6	3	1	4	5	2
E_7	1	2	5	4	3
E_8	1	2	3	5	4
E_9	2	1	4	3	5
E_{10}	3	1	2	5	4
E_{11}	2	1	3	5	4
E_{12}	4	2	1	3	5
E_{13}	2	1	3	5	4
E_{14}	2	1	3	5	4
$\sum_{i=1}^{n} R_{ij}$	30	22	47	58	53
$\overline{R}_j = \frac{\sum_{i=1}^{n} R_{ij}}{n}$	2.14	1.57	3.36	4.14	3.79
$\sum_{i=1}^{n} R_{ij} - \frac{1}{2} \cdot n \cdot (m+1)$	−12	−20	5	16	11
$\left(\sum_{i=1}^{n} R_{ij} - \frac{1}{2} \cdot n \cdot (m+1)\right)^2$	144	400	25	256	121
Priority	2	1	3	5	4

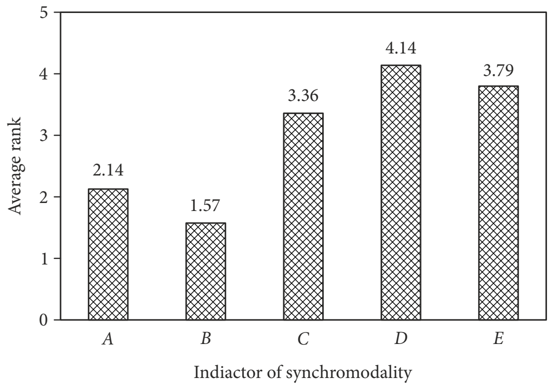

Figure 1. Average rank each indicator of synchromodality

Average $\overline{R}_i$ ranks set for the investigated indicator (criterion) allowed to establish the priority of indicator indicating that the most important criteria of the main indicators A, B, C, D, E influencing synchromodality of transport flows in the EWTC is B service quality $\left(\overline{R}_B = 1.57\right)$, which is characterized as freight transportation, handling, waiting and reloading time, frequency of services and freight safety in the main transport hubs (in the sea and land terminals). A less important indicator is $\left(\overline{R}_A = 2.14\right)$, which is described as an absolute and alternative service price. The third according priority is $\overline{R}_C = 3.36$ indicator that is described as infrastructure provision (expressed in transport congestion, bottlenecks and other obstacles). The forth-according priority is technical characteristics of terminals $\left(\overline{R}_E = 3.79\right)$ described as the ability of main hubs (terminals) of multimodal transport to serve different transport modes in the transport corridor. The least important (as having minor impact on synchromodality of transport flows) is $\overline{R}_D = 4.14$ indicator (criterion), which is described as an interface of technologies, i.e. connection with seaports, railway marshalling yards, airports, inland water transport, and logistics centres, and expressed in the distance between the main transport hubs.

Rank averages do not indicate superiority of one criterion over another. Besides, in practice, when evaluating criteria priorities, it is more convenient to apply their importance indicators – their best value (the most important indicator) is the highest value. For that ARTIW method was used, and its estimated results are presented in Table 4.

The weights of importance of the action group A, B, C, D, E criteria estimated according to Equation (9) are presented in Table 4, and ranking by the importance of coefficients of criteria weights – in Figure 2.

By applying the AHP method, during collective discussion a group of four experts defined the importance of synchromodality indicators. For that, at the beginning they gave ranks to five indicators. Afterwards they completed the pairwise comparison matrix by comparing all criteria in pairs. The results of pairwise comparison matrix are presented in Table 5.

Eigenvector of matrix (Table 5) indicates relative importance of indicators. It demonstrates that the most important criterion is B $\left(\omega_B = 0.5051\right)$; the second by importance is criterion A $\left(\omega_A = 0.2534\right)$; criterion C is of average importance $\left(\omega_C = 0.1227\right)$; the penultimate by importance is criterion D $\left(\omega_D = 0.0737\right)$ and the least important is criterion E $\left(\omega_E = 0.0451\right)$. The sum of normalised weight of indicators A, B, C, D, E is equal to 1. Consistency index $CI = 0.0426$, random index $RI = 1.12$, consistency ratio $CR = 0.0381$ and it is lower than 0.1. This demonstrates that pairwise comparison matrix is consistent.

By applying two methods (ARTIW and AHP), the indicated normalised weights of indicators are compared in the column diagram (Figure 2 and Table 6). It shows that the trend of indicator weights defined via two methods is equal. However, differences between the most important and least important indicator, defined via AHP method, is equal to 0.46. The difference of weights defined by ARTIW method and given to the most important and least important indicator, is equal to 0.098. Therefore it can be stated that AHP method is about 4.7 times more "sensitive" than ARTIW method.

The average value obtained by applying two methods (ARTIW and AHP) for evaluation of synchromodality indicators can be as results of investigated problem.

The following priority is received of indicators affecting transport sinchromodality with weights: $B \succ A \succ C \succ D \succ E$.

The authors' research revealed that criterion of the service quality becomes the main important factor impacting synchromodality. The outcomes of the research presented in the paper have shown that service quality (transport time, service and waiting time, handling time, working hours, reliability and flexibility) is the most important indicator (criterion) impacting synchromodality.

By evaluating this criterion as the most important, further research should aim to develop transport chain optimization models and synchromodal freight transport system. At the same time it is a big challenge for transport researches and transport process model developers, because this is a complex criterion, which includes minimum three sub-criteria: on-time times delivery, reliability and flexibility (Behdani *et al.* 2016). Moreover, it requires qualitatively new mathematical models for the creation of a synchromodal service design.

Table 4. The weight of indicators calculated by ARTIW method

Weight	Indicator				
	A	*B*	*C*	*D*	*E*
ω_j	0.2573	0.2953	0.1760	0.1240	0.1474
Priority	2	1	3	5	4

Table 5. The pairwise comparison matrix of synchromodality indicators (AHP method)

Indicator	Indicator					Eigenvector	Priority
	A	*B*	*C*	*D*	*E*		
A	1	1/3	3	4	5	0.2534	2
B	3	1	5	6	7	0.5051	1
C	1/3	1/5	1	2	4	0.1227	3
D	1/4	1/6	1/2	1	2	0.0737	4
E	1/5	1/7	1/4	1/2	1	0.0451	5

Table 6. Calculation of average weight of synchromodality indicator

Method	Indicator				
	A	*B*	*C*	*D*	*E*
ARTIW	0.2573	0.2953	0.1760	0.1240	0.1474
AHP	0.2534	0.5051	0.1227	0.0737	0.0451
Average	0.2553	0.4002	0.1493	0.0988	0.0962

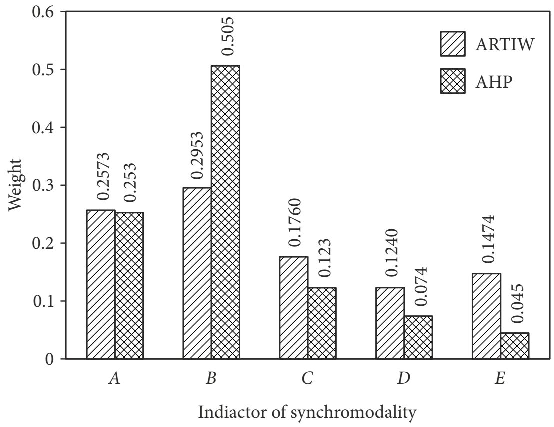

Figure 2. Comparison of results obtained by applying different methods

Conclusions

The paper will be useful for transport and logistics companies interested in moving towards synchromodal transport, as well as for future researchers. In the course of the research, it was determined that the normalized subjective weights of the five main criteria impacting synchromodality distributed in the following order: (1) service quality – 40%, (2) efficiency – 26%, (3) infrastructure sufficiency – 15%, (4) technical properties of terminals – 10% and (5) interaction of technologies – 9%.

The outcomes of the research in the paper have shown that service quality (transport time, service and waiting time, handling time, working hours, reliability and flexibility) is the most important indicator (criterion) impacting synchromodality.

In the following stages of the research, service quality indicator should be used to create models describing and facilitating synchronisation aiming to build an interconnected transport system spanning all modes of transport, where vehicles and transport infrastructure continuously interact, where the boundaries between different transport modes disappear completely and where businesses are provided with easy and safe door-to-door mobility services.

At the same time it is a big challenge for transport researchers because it requires to design and apply a qualitatively new mathematical models for optimisation of a synchromodal services along the chosen transport corridor in the BSR.

Finally, development of synchromodality creates good possibilities for better convergence of transport planning, management and implementation of integrity of transport patterns linking the EU BSR and the EU Eastern Partnership Countries.

Author contributions

Raimondas Šakalys and Algirdas Šakalys – development of the article concept.

Henrikas Sivilevičius – drawing up the methodology for ranking the main indicators impacting synchromodality.

Laima Miliauskaitė – analysis of literature references on synchromodality.

Raimondas Šakalys – execution of a survey (using specific questionnaire) in order to rank indicators of synchromodality, and preparation survey results.

Laima Miliauskaitė and Algirdas Šakalys – development of the text of the article.

References

Aditjandra, P. T. 2018. Europe's freight transport policy: analysis, synthesis and evaluation, *Advances in Transport Policy and Planning* 1: 197–243. https://doi.org/10.1016/bs.atpp.2018.07.006

Aditjandra, P. T.; Zunder, T. H.; Islam, D. M. Z.; Palacin, R. 2016. Green rail transportation: improving rail freight to support green corridors, in H. Psaraftis (Ed.). *Green Transportation Logistics*, 413–454. https://doi.org/10.1007/978-3-319-17175-3_12

Aditjandra, P. T.; Zunder, T. H.; Islam, D. M. Z.; Vanaale, E. 2012. Investigating freight corridors towards low carbon economy: evidence from the UK, *Procedia – Social and Behavioral Sciences* 48: 1865–1876. https://doi.org/10.1016/j.sbspro.2012.06.1161

Agbo, A. A.; Zhang, Y. 2017. Sustainable freight transport optimisation through synchromodal networks, *Cogent Engineering* 4(1): 1421005. https://doi.org/10.1080/23311916.2017.1421005

Alessandri, A.; Sacone, S.; Siri, S. 2007. Modelling and optimal receding-horizon control of maritime container terminals, *Journal of Mathematical Modelling and Algorithms* 6(1): 109–133. https://doi.org/10.1007/s10852-006-9052-3

ALICE. 2015. *Corridors, Hubs and Synchromodality: Research & Innovation Roadmap*. Alliance for Logistics Innovation through Collaboration in Europe (ALICE). 44 p. Available from Internet: http://www.etp-logistics.eu/?page_id=79

Ayed, H.; Habbas, Z.; Khadraoui, D.; Galvez-Fernandez, C. 2011. A parallel algorithm for solving time dependent multimodal transport problem, in *2011 14th International IEEE Conference on Intelligent Transportation Systems (ITSC)*, 5–7 October 2011, Washington, DC, US, 722–727. https://doi.org/10.1109/ITSC.2011.6082973

Behdani, B.; Fan, Y.; Wiegmans, B.; Zuidwijk, R. 2016. Multimodal schedule design for synchromodal freight transport systems, *European Journal of Transport and Infrastructure Research* 16(3): 424–444.

Bol Raap, W. 2016. *The Design of a Common Data Model for Generic Synchromodal Cargo-Tracking in Logistics Using Web Scraping and Big & Open Data.* Master Thesis. University of Twente, Netherlands. 160 p. Available from Internet: https://essay.utwente.nl/69690/1/BolRaap_MA_EEMCS.pdf

Bontekoning, Y. M.; Macharis, C.; Trip, J. J. 2004. Is a new applied transportation research field emerging? A review of intermodal rail–truck freight transport literature, *Transportation Research Part A: Policy and Practice* 38(1): 1–34. https://doi.org/10.1016/j.tra.2003.06.001

Brümmerstedt, K.; Van Beek, H. M.; Münsterberg, T. 2017. Comparative analysis of synchromodality in major European seaports, in C. Jahn, W. Kersten, C. M. Ringle (Eds.). *Digitalization in Maritime and Sustainable Logistics: City Logistics, Port Logistics and Sustainable Supply Chain Management in the Digital Age*, 59–76. https://doi.org/10.15480/882.1477

Buiel, E. F. T.; Visschedijk, G. C.; Lebesque, L. H. E. M.; Lucassen, I. M. P. J.; Van Riessen, B.; Van Rijn, A.; Te Brake, G. M. 2015. Synchro mania – design and evaluation of a serious game creating a mind shift in transport planning, in *46th International Simulation and Gaming Association Conference, ISAGA 2015*, 18–25 July 2015, Kyoto, Japan, 1–12.

Ceder, A.; Golany, B.; Tal, O. 2001. Creating bus timetables with maximal synchronization, *Transportation Research Part A: Policy and Practice* 35(10): 913–928. https://doi.org/10.1016/S0965-8564(00)00032-X

Chen, S.; Leng, Y.; Mao, B.; Liu, S. 2014. Integrated weight-based multi-criteria evaluation on transfer in large transport terminals: a case study of the Beijing south railway station, *Transportation Research Part A: Policy and Practice* 66: 13–26. https://doi.org/10.1016/j.tra.2014.04.015

Chen, S.; Pham, V. K.; Chen, J. K. 2016. Evaluating and selecting the best outsourcing service country in East and Southeast Asia: an AHP approach, *Journal of Testing and Evaluation* 44(1): 89–101. https://doi.org/10.1520/JTE20140065

Cruijssen, F.; Dullaert, W.; Fleuren, H. 2007. Horizontal cooperation in transport and logistics: a literature review, *Transportation Journal* 46(3): 22–39.

Defares, D. 2011. *Exploration of Future Container Transport to and from the Dutch Hinterland: Assessing the Need for Future Policies.* Master Thesis. Delft University of Technology, Netherlands. 226 p. Available from Internet: https://repository.tudelft.nl/islandora/object/uuid:a834577a-f4a3-4741-8185-267e51165566/datastream/OBJ

Dolinsek, M.; Hartl, S.; Hartl, T.; Hintergräber, B.; Hofbauer, V.; Hrusovsky, M.; Maierbrugger, G.; Matzner, B.; Putz, L.-M.; Sattler, M.; Schweighofer, J.; Seemann, L.; Simoner, M.; Slavicek, D. 2013. *Manual on Danube Navigation.* Österreichische Wasserstraßen-Gesellschaft mbH, Vienna. 218 p. Available from Internet: http://ines-danube.info/goto.php?target=file_1545_download&client_id=viailias4

Dong, C.; Boute, R.; McKinnon, A.; Verelst, M. 2018. Investigating synchromodality from a supply chain perspective, *Transportation Research Part D: Transport and Environment* 61: 42–57. https://doi.org/10.1016/j.trd.2017.05.011

EWTCA. 2018. *East-West Transport Corridor Association*. Vilnius, Lithuania. Available from Internet: http://www.ewtcassociation.net

Fan, Y. 2013. *The Design of a Synchromodal Freight Transport System: Applying Synchromodality to Improve the Performance of Current Intermodal Freight Transport System.* Master Thesis. Delft University of Technology, Netherlands. 97 p. Available from Internet: https://repository.tudelft.nl/islandora/object/uuid:ed9d790c-73bd-4afa-9401-04748a5c8ddf/datastream/OBJ/

Farhan, J.; Fwa, T. F. 2009. Pavement maintenance prioritization using analytic hierarchy process, *Transportation Research Record: Journal of the Transportation Research Board* 2093: 12–24. https://doi.org/10.3141/2093-02

Fawcett, S. E.; Osterhaus, P.; Magnan, G. M.; Brau, J. C., McCarter, M. W. 2007. Information sharing and supply chain performance: the role of connectivity and willingness, *Supply Chain Management: an International Journal* 12(5): 358–368. https://doi.org/10.1108/13598540710776935

Geerlings, H.; Kuipers, B.; Zuidwijk, R. 2017. *Ports and Networks: Strategies, Operations and Perspectives*. Routledge. 406 p. https://doi.org/10.4324/9781315601540

Hauge, J. B.; Boschian, V.; Pagenelli, P. 2011. Synchronization of material and information flows in intermodal freight transport: an industrial case study, in H. J. Kreowski, B. Scholz-Reiter, K. D. Thoben (Eds.). *Dynamics in Logistics*, 227–234. https://doi.org/10.1007/978-3-642-11996-5_20

Heo, E.; Kim, J.; Boo, K.-J. 2010. Analysis of the assessment factors for renewable energy dissemination program evaluation using fuzzy AHP, *Renewable and Sustainable Energy Reviews* 14(8): 2214–2220. https://doi.org/10.1016/j.rser.2010.01.020

Hintjens, J.; Vanelslander, T.; Van der Horst, M.; Kuipers, B. 2015. The evolution of the economic centre of gravity and the consequences for gateway ports and hinterland connections: the case of the Flemish-Dutch Delta, in *Proceedings of the IAME Annual Conference 2015, International Association of Maritime Economists*, 24–26 August 2015, Kuala Lumpur, Malaysia, 1–23.

Hofman, W. 2016. Data sharing requirements of supply – and logistics innovations – towards a maturity model, in *Information Systems, Logistics, and Supply Chain: 6th International Conference, ILS 2016*, 1–4 June 2016, Bordeaux, France, 1–8.

Hofman, W. J.; Bastiaansen, H. J. M. 2014. Roadmap towards a smart logistics ecosystem, in *7th European Conference on ICT for Transport Logistics – ECITL 2014*, 5–7 November 2014, Dortmund, Germany, 1–12.

Hofman, W.; Bastiaansen, H.; Van den Berg, J.; Pruksasri, P. 2012. A platform for secure, safe, and sustainable logistics, in *Proceedings of the e-Freight 2012 Conference*, 9–10 May 2012, Delft, Netherlands, 1–18.

INTERREG BSR. 2019. *INTERREG Baltic Sea Region Programme*. Available from Internet: https://www.interreg-baltic.eu

Intihar, M.; Kramberger, T.; Dragan, D. 2017. Container throughput forecasting using dynamic factor analysis and ARIMAX model, *Promet – Traffic & Transportation* 29(5): 529–542. https://doi.org/10.7307/ptt.v29i5.2334

Jarašūnienė, A.; Greičiūnė, L.; Šakalys, A. 2012. Research of competitive environment of Klaipėda Seaport comparing to other seaports in the eastern Baltic Sea region, *Transport* 27(1): 5–13. https://doi.org/10.3846/16484142.2012.662911

Kapetanis, G. N.; Psaraftis, H. N.; Spyrou, D. 2016. A Simple synchro – modal decision support tool for the Piraeus container terminal, *Transportation Research Procedia* 14: 2860–2869. https://doi.org/10.1016/j.trpro.2016.05.403

Kendall, M.; Gibbons, J. D. 1990. *Rank Correlation Methods*. Oxford University Press. 272 p.

Kos, S.; Vukić, L.; Brčić, D. 2017. Comparison of external costs in multimodal container transport chain, *Promet – Traffic & Transportation* 29(2): 243–252. https://doi.org/10.7307/ptt.v29i2.2183

Lucassen, I. M. P. J.; Dogger, T. 2012. *Synchromodality Pilot Study. Identification of Bottlenecks and Possibilities for a Network between Rotterdam, Moerdijk and Tilburg*. TNO Report 2012 P10128, Delft, Netherlands.

Maskeliūnaitė, L.; Sivilevičius, H.; Podvezko, V. 2009. Research on the quality of passenger transportation by railway, *Transport* 24(2): 100–112. https://doi.org/10.3846/1648-4142.2009.24.100-112

Mason, R.; Lalwani, C.; Boughton, R. 2007. Combining vertical and horizontal collaboration for transport optimisation, *Supply Chain Management: an International Journal* 12(3): 187–199. https://doi.org/10.1108/13598540710742509

Miletić, G.-M.; Gašparović, S.; Carić, T. 2017. Analysis of sociospatial differentiation in transport mode choice preferences, *Promet – Traffic & Transportation* 29(2): 233–242. https://doi.org/10.7307/ptt.v29i2.2198

Montgomery, D. C. 2013. *Design and Analysis of Experiments*. Willey. 752 p.

Muller, G. 1999. *Intermodal Freight Transportation*. Eno Transportation Foundation. 502 p.

Nabais, J. L.; Negenborn, R. R.; Botto, M. A. 2013. Hierarchical model predictive control for optimizing intermodal container terminal operations, in *16th International IEEE Conference on Intelligent Transportation Systems (ITSC 2013)*, 6–9 October 2013, The Hague, Netherlands, 708–713. https://doi.org/10.1109/ITSC.2013.6728314

Norman, B. A.; Rajgopal, J.; Lim, J.; Gorham, K.; Haidari, L.; Brown, S. T.; Lee, B. Y. 2015. Modular vaccine packaging increases packing efficiency, *Vaccine* 33(27): 3135–3141. https://doi.org/10.1016/j.vaccine.2015.04.091

Overbeek, S.; Klievink, B.; Hesketh, D.; Heijmann, F.; Tan, Y.-H. 2011. A web-based data pipeline for compliance in international trade, in *Proceedings of the 1st Workshop on IT Innovations Enabling Seamless and Secure Supply Chains (WITNESS-2011)*, 29 August 2011, Delft, Netherlands, 32–48.

Palevičius, V.; Podviezko, A.; Sivilevičius, H.; Prentkovskis, O. 2018. Decision-aiding evaluation of public infrastructure for electric vehicles in cities and resorts of Lithuania, *Sustainability* 10(4): 904. https://doi.org/10.3390/su10040904

Palevičius, V.; Sivilevičius, H.; Podviezko, A.; Griškevičiūtė-Gečienė, A.; Karpavičius, T. 2017. Evaluation of park and ride facilities at communication corridors in a middle-sized city, *Economic Computation and Economic Cybernetics Studies and Research* 51(2): 231–248.

Pedersen, M. B.; Crainic, T. G.; Madsen, O. B. G. 2009. Models and tabu search metaheuristics for service network design with asset-balance requirements, *Transportation Science* 43(2): 158–177. https://doi.org/10.1287/trsc.1080.0234

Pfoser, S.; Putz, L.-M.; Schauer, O.; Prandtstetter, M. 2017. Facilitating synchromodal transport through interconnected, modular and intelligent transport units, in *Proceedings of the 24th EurOMA Conference*, 1–5 July 2017, Edinburgh, Scotland, UK, 1–9.

Pfoser, S.; Treiblmaier, H.; Schauer, O. 2016. Critical success factors of synchromodality: results from a case study and literature review, *Transportation Research Procedia* 14: 1463–1471. https://doi.org/10.1016/j.trpro.2016.05.220

Pleszko, J. 2012. Multi-variant configurations of supply chains in the context of synchromodal transport, *LogForum* 8(4): 287–295.

Pomponi, F.; Fratocchi, L.; Tafuri, S. R. 2015. Trust development and horizontal collaboration in logistics: a theory based evolutionary framework, *Supply Chain Management: an International Journal* 20(1): 83–97. https://doi.org/10.1108/SCM-02-2014-0078

Putz, L.-M.; Haider, C.; Haller, A.; Schauer, O. 2015. Identifying key enablers for synchromodal transport chains in Central Europe, in *WCTRS SIG2 2015 Conference: the Port and Maritime Sector: Key Developments and Challenges*, 11–15 May 2015, Antwerp, Belgium, 1–19.

Ramanathan, R. 2001. A note on the use of the analytic hierarchy process for environmental impact assessment, *Journal of Environmental Management* 63(1): 27–35. https://doi.org/10.1006/jema.2001.0455

Reis, V. 2015. Should we keep on renaming a +35-year-old baby?, *Journal of Transport Geography* 46: 173–179. https://doi.org/10.1016/j.jtrangeo.2015.06.019

Rodrigue, J.-P. 1999. Globalization and the synchronization of transport terminals, *Journal of Transport Geography* 7(4): 255–261. https://doi.org/10.1016/S0966-6923(99)00018-6

Rossi, S. 2012. *Challenges of Co-Modality in a Collaborative Environment*. CO^3 Position Paper, Deliverable D2.3, Cranfield School of Management, UK. 41 p. Available from Internet: http://www.co3-project.eu/wo3/wp-content/up-loads/2011/12/CO3-D-2-3-Position-Paper-on-Co-modality_def.pdf

Roth, M.; Klarmann, A.; Franczyk, B. 2013. Future logistics – challenges, requirements and solutions for logistics networks, *International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering* 7(10): 898–903.

Saaty, T. L. 1980. *The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation*. McGraw-Hill. 287 p.

Saaty, T. L.; Shang, J. S. 2011. An innovative orders-of-magnitude approach to AHP-based mutli-criteria decision making: prioritizing divergent intangible humane acts, *European Journal of Operational Research* 214(3): 703–715. https://doi.org/10.1016/j.ejor.2011.05.019

Šakalys, R.; Batarlienė, N. 2017. Research on intermodal terminal interaction in international transport corridors, *Procedia Engineering* 187: 281–288. https://doi.org/10.1016/j.proeng.2017.04.376

Sivilevičius, H. 2011a. Application of expert evaluation method to determine the importance of operating asphalt mixing plant quality criteria and rank correlation, *The Baltic Journal of Road and Bridge Engineering* 6(1): 48–58. https://doi.org/10.3846/bjrbe.2011.07

Sivilevičius, H. 2011b. Modelling the interaction of transport system elements, *Transport* 26(1): 20–34. https://doi.org/10.3846/16484142.2011.560366

Sivilevičius, H.; Maskeliūnaitė, L. 2018. Multiple criteria evaluation and the inverse hierarchy model for justifying the choice of rail transport mode, *Promet – Traffic & Transportation* 30(1): 57–69. https://doi.org/10.7307/ptt.v30i1.2417

Sivilevičius, H.; Maskeliūnaitė, L. 2010. The criteria for identifying the quality of passengers' transportation by railway and their ranking using AHP method, *Transport* 25(4): 368–381. https://doi.org/10.3846/transport.2010.46

Solvay, A. F.; Haberstroh, M.; Thelen, S.; Schilberg, D.; Jeschke, S. 2016. New intermodal loading units in the European transport market, in S. Jeschke, I. Isenhardt, F. Hees, K. Henning (Eds.). *Automation, Communication and Cybernetics in Science and Engineering 2015/2016*, 687–697. https://doi.org/10.1007/978-3-319-42620-4_52

Stanujkic, D. 2016. An extension of the ratio system approach of MOORA method for group decision-making based on interval-valued triangular fuzzy numbers, *Technological and Economic Development of Economy* 22(1): 122–141. https://doi.org/10.3846/20294913.2015.1070771

Steadieseifi, M.; Dellaert, N. P.; Nuijten, W.; Van Woensel, T.; Raoufi, R. 2014. Multimodal freight transportation planning: a literature review, *European Journal of Operational Research* 233(1): 1–15. https://doi.org/10.1016/j.ejor.2013.06.055

Tavasszy, L. A.; Behdani, B.; Konings, R. 2015. *Intermodality and Synchromodality*. 15 p. https://doi.org/10.2139/ssrn.2592888

Tavasszy, L.; Janssen, R.; Van der Lugt, L.; Hagdorn, L. 2010. *Verkenning Synchromodaal Transportsysteem*. TNO Hoofdrapport TNO-034-DTM-2010-04431. Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek (TNO). 56 p. (in Dutch).

Taylan, O.; Bafail, A. O.; Abdulaal, R. M. S.; Kabli, M. R. 2014. Construction projects selection and risk assessment by fuzzy AHP and fuzzy TOPSIS methodologies, *Applied Soft Computing* 17: 105–116. https://doi.org/10.1016/j.asoc.2014.01.003

TENTacle. 2019. *New Transport Corridor Project in the Baltic Sea Region*. Available from Internet: http://www.tentacle.eu

Topsector Logistiek. 2011. *Partituur naar de top*. Adviesrapport Topteam Logistiek. 36 p. (in Dutch). Available from Internet: http://www.infrasite.nl/documents/bedrijven/1889/Adviesrapport%20TopTeam%20Logistiek%202011.pdf

Topsector Logistiek. 2018. *Platform Synchromodaliteit* (in Dutch). Available from Internet: http://www.synchromodaliteit.nl/definitie

Van der Burgh, M. 2012. *Synchromodal Transport for the Horticulture Industry: Requirements for Implementation in the Westland-Oostland Greenport*. Master Thesis. Erasmus University Rotterdam, Netherlands. 89 p. Available from Internet: https://thesis.eur.nl/pub/12943/MA-thesis%20M.%20van%20der%20Burgh%20(321516).pdf

Van Gool, M. J. 2012. *Travel Time Reduction through Real-Time Container Truck Assignment*. Master Thesis. Radboud University, Netherlands. 140 p. Available from Internet: https://theses.ubn.ru.nl/bitstream/handle/123456789/195/Gool%2c_M.J._van_1.pdf?sequence=1

Van Riessen, B.; Negenborn, R. R.; Dekker, R.; Lodewijks, G. 2013. *Service Network Design for an Intermodal Container Network with Flexible due Dates/Times and the Possibility of Using Subcontracted Transport*. Erasmus School of Economics, Erasmus University Rotterdam, Netherlands. 16 p. Available from Internet: https://repub.eur.nl/pub/40343

Van Stijn, E.; Hesketh, D.; Tan, Y.-H.; Klievink, B.; Overbeek, S.; Heijmann, F.; Pikart, M.; Buterly, T. 2011. The data pipeline, in *Global Trade Facilitation Conference 2011 – Connecting International Trade: Single Windows and Supply Chains in the Next Decade*, 12–13 December, Geneva, Switzerland.

Veenstra, A.; Zuidwijk, R.; Van Asperen, E. 2012. The extended gate concept for container terminals: Expanding the notion of dry ports, *Maritime Economics & Logistics* 14(1): 14–32. https://doi.org/10.1057/mel.2011.15

Vinke, P. J. 2016. *Dynamic Consolidation Decisions in a Synchromodal Environment: Improving the Synchromodal Control Tower*. Master Thesis. University of Twente, Netherlands, 102 p. Available from Internet: https://essay.utwente.nl/69109/1/Vinke_MA_BMS.pdf

Zhang, M.; Pei, A. J. 2016. Synchromodal versus intermodal freight transport: the case of Rotterdam hinterland container transport, in *TRB 95th Annual Meeting Compendium of Papers*, 10–14 January 2016, Washington, DC, US, 1–19.

Zuidwijk, R. 2015. *Are we connected? Ports in Global Networks*. Erasmus Research Institute of Management, Erasmus University Rotterdam, Netherlands. 44 p. Available from Internet: https://repub.eur.nl/pub/79091/EIA2015064L-IS9789058924353.pdf

Zunder, T. H.; Islam, D. M. Z.; Mortimer, P. N.; Aditjandra, P. T. 2013. How far has open access enabled the growth of cross border pan European rail freight? A case study, *Research in Transportation Business & Management* 6: 71–80. https://doi.org/10.1016/j.rtbm.2012.12.005