https://doi.org/10.3311/PPtr.23464

Periodica Polytechnica Transportation Engineering, 52(2), pp. 151–158, 2024

Development of High-Speed Railway Network in Europe: A Case Study of Ukraine

Mykola Kurhan[1], Szabolcs Fischer[2*], Oleksii Tiutkin[1], Dmytro Kurhan[1] and Nelya Hmelevska[1]

[1] Department of Transport Infrastructure, Ukrainian State University of Science and Technologies, Lazaryan st. 2, 49010 Dnipro, Ukraine
[2] Department of Transport Infrastructure and Water Resources Engineering, Faculty of Architecture Civil Engineering and Transport Sciences, Széchenyi István University, Egyetem tér 1, H-9026 Győr, Hungary
[*] Corresponding author, e-mail: fischersz@sze.hu

Received: 16 September 2023, Accepted: 05 November 2023, Published online: 20 February 2024

Abstract
The current task today is the development of theoretical and methodological approaches, as well as practical recommendations for determining the technical feasibility of creating high-speed railway (HSR) lines in the European context. The development of railways in individual countries, followed by the creation of a pan-European high-speed railway network, has raised questions about the compatibility of the technical systems of individual national HSRs. This paper addresses these issues using the example of Ukraine. The research is based on an analysis of scientific developments related to the design of HSR lines and the synthesis of European experience in identifying priority route directions in Ukraine. For comparing various scenarios for the development of railway connections, the authors have developed a forecasting and efficiency assessment model based on the Net Present Value (NPV) indicator. It has been demonstrated that considering the population attracted to HSR and the volume of transit passenger transportation alone is insufficient to achieve the normative investment payback. This situation can only be rectified by implementing mixed traffic involving high-speed passenger trains and accelerated freight trains. However, mixed traffic of passenger and freight trains on high-speed rail lines may face numerous issues and constraints that require careful planning and coordination.

Keywords
railway, Net Present Value, transport corridor, high-speed railway, railway route

1 Introduction

In today's world, high-speed railways (HSR) have been introduced, where trains reach up to 350 km/h. Among European countries, the high-speed railway network exhibits varying levels of development. Some countries possess rail networks with speeds exceeding 300 km/h (France, Italy, the United Kingdom), while others approach similar levels of development (Germany, Spain). Additionally, there are networks that are actively undergoing HSR development. A comprehensive overview of the current state of HSR networks and the challenges they face is presented in the paper by Russo et al. (2023). In technologically advanced countries, there is no longer a question of the necessity of constructing HSRs; instead, the focus is on finding optimal financing schemes for realizing such projects. The development of high-speed railways in individual European countries and the subsequent creation of a pan-European high-speed railway network have raised questions about the compatibility of technical components between national HSRs, including rolling stock and stationary infrastructure. The study by Buier (2020) investigates the challenges of integrating high-speed railways into the pan-European network using Spain as a case study. In October 2018, Poland, the Czech Republic, Slovakia, and Hungary agreed to develop proposals for establishing high-speed rail connections between the capitals of Central Europe. Trains traveling at speeds of up to 250 km/h are planned to be launched between Warsaw, Vilnius, Riga, Tallinn, Prague, Bratislava, and Budapest. By 2030, the entire cross-border Rail Baltica corridor is planned to be constructed in Estonia, Latvia, and Lithuania, connecting Tallinn through Riga and Kaunas (with a branch to Vilnius) to the Polish state border. Additionally, during this time, a section of the high-speed rail line V4 (V4 means

Cite this article as: Kurhan, M., Fischer, S., Tiutkin, O., Kurhan, D., Hmelevska, N. (2024) "Development of High-Speed Railway Network in Europe: A Case Study of Ukraine", Periodica Polytechnica Transportation Engineering, 52(2), pp. 151–158. https://doi.org/10.3311/PPtr.23464

the "Visegrád Four", or in other words, the so-called "European Quartet"; a cultural and political alliance of four Central European countries: the Czech Republic, Hungary, Poland, and Slovakia) is set to be built between Prague, Brno, Bratislava, and Budapest. Investors envision creating a unified high-speed train network with shared schedules and ensuring consistent travel standards. As a central European state, Hungary serves as a crucial transit hub for various routes (Kurhan et al., 2023). However, the current highest passenger train speed is limited to 160 km/h, despite the opportunity to modernize the network, particularly the Trans-European Transport Network rail infrastructure, with an EU (European Union) funding. There is consideration for constructing a high-speed railway within the next decade, enabling trains to reach a design speed of up to 320 km/h. It is expected that the high-speed railway will significantly reduce travel times, with Budapest to Vienna, Budapest to Bratislava taking approximately 2 hours, Budapest to Prague around 3.5 hours, and the complete Budapest to Warsaw route covered in 5.5 hours by train. The National Infrastructure Development Agency (NIF) has announced the completion of a feasibility study and optimal location assessment for the planned high-speed line Budapest-Bratislava-Brno-Warsaw in Hungary. The technical and economic justification was carried out by NSV Varsó, a consortium comprising the consulting firm Trenecon and design companies Főmterv and Utiber, under a contract signed in 2019 (Railway Pro, 2023). (It has to be mentioned that NIF no longer exists since January 2023; the responsible authority and ministry is the so-called ÉKM, i.e., the Ministry of Construction and Transport). In Ukraine, these issues are currently under research. Their resolution requires consideration of the experience in implementing a range of interconnected issues: methodologies for calculating prospective population mobility, taking into account transit, organizational and technical prerequisites for introducing high-speed rail (Kurhan et al., 2022a; Hubar et al., 2020; Potapov et al., 2023), selection of critical conceptual approaches to infrastructure, power supply systems (Havryliuk, 2020; Havryliuk, 2021; Fischer and Szalai, 2023; Németh and Fischer, 2021; Szalai et al., 2022), rolling stock dimensions, and alignment of structures, control devices, and traffic safety organizations (Shvets, 2023; Sysyn et al., 2021) and so on.

Today's urgent task is the development of theoretical-methodological approaches and practical recommendations for determining the technical possibilities of creating high-speed railways in Ukraine according to European standards. Implementing high-speed rail would reduce the environmental impact of transportation (Ma et al., 2023; Pittman et al., 2020), enhance population mobility (Guan et al., 2023; Ma et al., 2023), improve transportation connections between countries, and create a competitive environment in the transportation services market. On January 19, 2023, the Centralny Port Komunikacyjny (CPK) and the Ukrainian Railways (Ukrzaliznytsia) signed a cooperation agreement aimed at closer collaboration in the construction of new railway infrastructure, including high-speed railways (Center for Transport Strategies, 2023; Lviv Public Portal, 2023). One of the key objectives of this agreement is the development of new cross-border connections with the European standard gauge of 1.435 mm, including the construction of a high-speed rail line. The document outlines joint preparations for the technical and economic justification of the planned new railway line between Poland and Ukraine, see Fig. 1. The agreement emphasizes the necessity of building a high-speed line along the Warsaw-Lviv-Kyiv route, with a projected maximum operational speed of 250 km/h. As part of this cooperation, the adoption of EU standards in railway infrastructure design, construction, and maintenance, including automation and telecommunications, is planned (Pomykała and Engelhardt, 2023).

The rationale for selecting the future HSR route is, in itself, a complex multifactorial scientific issue (Di Gangi and Vitetta, 2021; Venezia, 2023). In perspective, it makes sense to explore the potential HSR network beyond the Warsaw-Kyiv route, but the current state of affairs undeniably indicates that, for Ukraine, the primary need is to establish a connection between the capital and the European Union. The purpose of this study is to analyze

Fig. 1 Prospective HSR routes of the European railway between Poland and Ukraine (the figure was created based on Google Maps)

various scenarios for organizing high-speed rail systems in the most developed countries and, based on this analysis, assess Ukraine's potential in preparing for the design and construction of high-speed railways. The research is based on an analysis of scientific developments related to high-speed rail design, a synthesis of initial experience from design institutes and educational institutions regarding route prioritization, and the development of so-called "pilot" high-speed rail projects in Ukraine.

2 Materials and methods

When researching the future HSR network's layout, it is advisable to consider directions with existing railway lines. Transportation flows in these directions tend to be the most intensive. Therefore, the presence of a railway is one of the crucial criteria for identifying directions suitable for organizing high-speed train operations.

In order to select criteria for assessing the feasibility of constructing HSR in a specific region, in-depth research and the development of a decision-making methodology are necessary. The main criteria for determining prospective directions for HSR construction can be categorized into two groups. The first group of criteria characterizes the urbanization that leans towards the proposed HSR project. The second group of criteria evaluates the technical and economic potential of the prospective HSR network directions (length of lines, construction complexity, cost of HSR construction, passenger travel time).

Implementing large-scale investment projects involving significant financial outlays, and the need to account for numerous factors requires the application of appropriate methods for assessing efficiency. Preliminary assessment of investment projects can be based on various methods (European Commission, 2014; OECD, 2020; UNESCO, 2022): the Investment Project Profitability Analysis Guide, the Organization for Economic Co-operation and Development Guidelines, Criteria for Development Assistance, the United Nations Development Program, and others. Analysis of such methods reveals that in American companies, the primary indicators of efficiency are the Internal Rate of Return (IRR) (76%) and the Net Present Value (NPV) over the entire calculation period (75%). In the United Kingdom, the NPV criterion is the most widely used method for evaluating the investment attractiveness of projects, employed in 80% of cases. According to research results in the Netherlands and Canada, the NPV criterion is the most popular method for evaluating the efficiency of investment projects. In Australia, the NPV criterion is the most prevalent when determining project effectiveness (accounting for 94%). Alternative criteria to NPV can include methods such as the Internal Rate of (IRR), Accounting Rate of Return (ARR), and Benefit-Cost Ratio (BCR). As contemporary research suggests (Arga et al., 2021; Priyanto et al., 2023; Venezia, 2023), NPV-based methods are preferred for evaluating railway projects. NPV serves as a powerful tool for assessing investment projects, enabling well-informed financial decision-making by accounting for the time value of money and maximizing investment profitability. For comparing various scenarios for the development of railway connections in Ukraine, the authors of this study have developed a forecasting and efficiency assessment model that takes into account all costs using the NPV indicator (Kurhan and Kurhan, 2019; Kurhan et al., 2022a, Venezia, 2023). This indicator can be calculated using Eq. (1):

$$\mathrm{NPV} = \sum_{t=0}^{T} \frac{D_t - C_t - P_t - K_t}{(1+E)^t}, \qquad (1)$$

where NPV stands for Net Present Value; D_t represents the forecasted annual revenues that the railway will generate from the implementation of high-speed train operations; C_t denotes the forecasted annual operating expenses (excluding depreciation) from the implementation of high-speed train operations; it is calculated as the total operating expenses (materials, wages, payroll taxes, fuel, electricity, etc.); P_t represents the forecasted amount of corporate income tax for tax accounting in the calculation year resulting from the implementation of high-speed train operations; K_t signifies the forecasted investments required for the implementation of high-speed railways in the calculation year; it is determined as the annual total cost (excluding VAT) of railway infrastructure construction, reconstruction, and technical re-equipment, investments in the acquisition of rolling stock, and the reconstruction of existing depots for technical maintenance and repair of high-speed trains; E represents the modified discount rate; t is the calculation year number; T is the calculation period in years.

In the developed model, it is possible to investigate and forecast the revenues that the railway will generate in the future from the implementation of high-speed train operations for various levels of forecasts and transport volumes (Kurhan et al., 2022b). Based on the given methodology, the authors of this research will address the problem of calculating the necessary passenger transportation volume at which the new route will become profitable within a specified timeframe. In this case, the volume of freight transportation should be as minimal as possible, while the construction cost of the new route is indeterminately defined within a certain range. Thus, the problem statement can be expressed through Eq. (2):

$$\left(n,G\right)=\begin{cases}\text{NPV}\geq\text{NPV}_{\min};\ K\in\left[K_{\min};K_{\max}\right];\\ n\in\mathbb{N}_{>0},\ n\rightarrow\min;\ G\in\mathbb{R}^{0},\ G\rightarrow\min'\end{cases}\qquad(2)$$

where n and G are values of passenger and freight transport volumes.

3 Results

In the construction of a European standard railway track, various scenarios are possible, including the following:

1. Existing double-track sections with a broad gauge of 1.520 mm are converted into two single-track sections with 1.435 mm and 1.520 mm gauges.
2. A dual gauge track (1.435/1.520 mm) is laid on the main line.
3. A new railway track with a gauge of 1.435 mm is designed.

The authors of this study will analyze the scenario for designing a European standard railway track on a new route, using the examples of the Warsaw-Yagodin-Kyiv (northbound) and Warsaw-Lviv-Kyiv (southbound) directions.

3.1 Northbound route

At the proposal of the governments of Poland and Ukraine, the Gdansk-Warsaw-Lyubotyn-Yagodyn-Kovel-Zdolbuniv-Shepetivka-Koziatyn-Odesa corridor received the status of a pan-European corridor in 1997. A branch from this corridor to Kyiv would connect the capital of Ukraine through Warsaw to Berlin and other European capitals. It was envisaged that the direction of the new route would closely follow the contours of the existing railway line Kyiv-Korosten-Sarny-Kovel-Yagodyn.

In this study, authors consider the option of a new high-speed railway route proposed by the Research and Design Institute of Transport Construction "Kyivdiprotrans", in the direction of borderline-Yagodyn-Kovel-Kyiv (493 km), which is considered the most suitable for further planning, see Fig. 2. The total length of this section, Kyiv-Yagodyn-Warsaw, is 730 km. The high-speed rail route is located in a developed agricultural area, so the right-of-way is minimized, taking into account the placement of structural elements of the earthworks, drainage structures, snow protection, overhead high-voltage power lines, a continuous fence on both sides of the mainline, and a parallel access road. The average width of the right-of-way is approximately 70 meters. The monetary assessment of agricultural land is carried out separately for arable land, land under perennial plantings, natural grasslands, and pastures. Considering the high agricultural value of the lands through which the HSR route passes, the opening of ground quarries is limited. In this regard, the primary transportation scheme for delivering soil will involve rail transport from the quarry to the nearest station, reloading onto road transport, and delivery to the embankment site.

According to estimates, the construction cost of the HSR embankment amounts to approximately 20%. When evaluating the effectiveness of various options, forecasted investments for constructing a new European standard HSR are considered. According to the "Kyivdiprotrans" project, the total estimated cost for the borderline-Yagodyn-Kovel-Kyiv route amounted to 41.9 billion UAH in 2008, which equals 83.8 million UAH or 12.0 million euros per 1 km of railway. For the Kyiv-Konotop-borderline route, the total cost in 2011 amounted to 68.6 billion UAH, or 218.5 million UAH, or 19.3 million euros per 1 km. For comparison, Wuhan-Guangzhou line in China, which is 1,069 km long, cost 116.6 billion yuan, equivalent to 14.2 million euros. Therefore, it can be assumed that the forecasted construction cost of 1 km of HSR is 15–20 million euros per 1 km, corresponding to global prices.

According to the forecasted passenger transport volumes for the Kyiv-Warsaw connection, it has been determined that there are insufficient volumes to make project economically viable for pure passenger transportation. Further research was conducted to determine the conditions under which the European gauge HSR of 1 435 mm can be effectively used for international passenger transport and accelerated container or platform freight transport. For this purpose, calculations were performed for different values of passenger transport volumes (n, pairs of trains per day) and different values of accelerated freight transport volumes (G, million tons per year).

The results of variant calculations are shown in Table 1 and Fig. 3, the analysis of which allows us to establish approximate transport volumes that would ensure the profitability of the northern HSR.

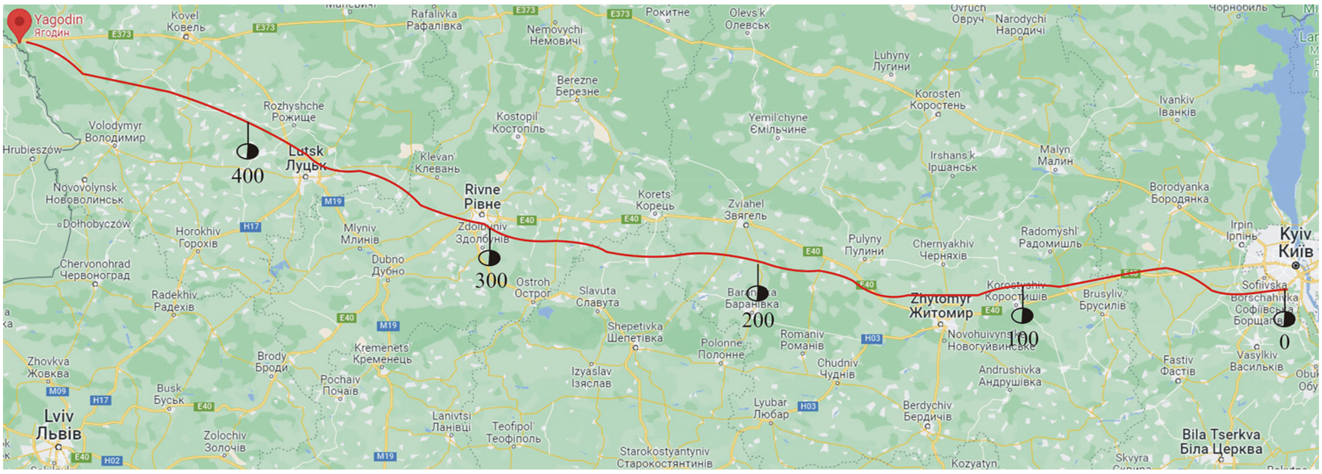

Fig. 2 Plan of the borderline-Yagodyn-Kovel-Kyiv route (the figure was created based on Google Maps)

Table 1 The cumulative Net Present Value (Warsaw-Yagodin-Kyiv direction) is increasing

The number of pairs of passenger trains/day					
Cost, million euros/km					
	5	10	15	20	25
20	–1427	191	1799	3417	5033
15	–666	952	2560	4178	5794
Volume of freight transport, million tons/year					
	20	25	30	35	40
20	–743	565	1883	3191	4499
15	779	2087	3405	4713	6021

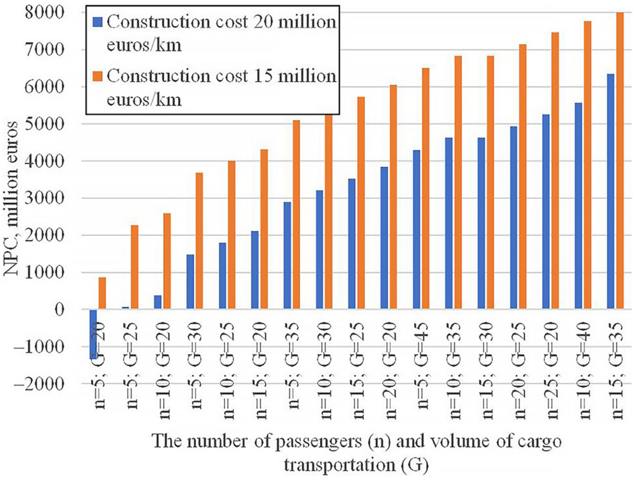

Fig. 3 The dependency of NPV on transport volumes for the Warsaw-Yagodin-Kyiv route

3.2 Southbound route

The HSR route, Kyiv-Lviv, crosses four regions: Kyiv, Zhytomyr, Khmelnytskyi, and Lviv. Its construction length is 477 km, which represents a reduction of 114 km compared to the existing railway, as shown in Fig. 4. The total land allocation required for the HSR in the Kyiv-Lviv section is estimated at 2.610 hectares. The total length of the Kyiv-Lviv-Warsaw route is 806 km. In addition to regular passengers, transit passengers also need to be considered, but providing an accurate forecast for transit passengers for specific routes is very challenging. The outcome depends on numerous factors that can change over time. The Kyiv-Lviv route passes through central and western regions of Ukraine, making it attractive to transit passengers traveling between cities in these regions. The Kyiv-Warsaw route connects two capitals, which could increase the number of passengers traveling for business or tourism purposes. Depending on the economic activity in each city, transit passengers may constitute a significant portion of the passenger traffic. The presence of well-developed transportation infrastructure and convenient connections on each route can attract more transit passengers. The political and social situation in the countries and cities through which the routes pass can also influence transit traffic. This issue requires further research, and the results could significantly impact the HSR project's effectiveness.

The authors in publications (Kurhan et al., 2023; Kurhan et al., 2022a; Zou and Tang, 2023) have demonstrated that taking into account the population size attracted to HSR and the volume of transit passenger transportation alone is insufficient to achieve the normative investment payback. As mentioned above, this situation can only be rectified by implementing mixed traffic involving high-speed passenger trains and accelerated freight trains (Kurhan et al., 2022b).

The research results for the southern direction of HSR are presented in Table 2 and Fig. 5. Therefore, the cost-effectiveness of constructing the HSR on a new route will be ensured at a construction cost of 15 million euros per kilometer for the following transport volumes: 5 pairs of passenger trains and 20 million tons of freight

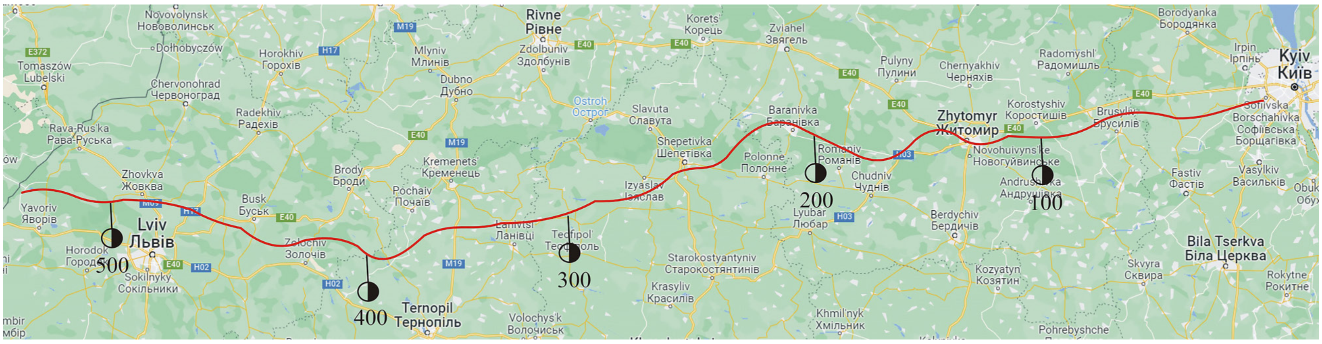

Fig. 4 Route Kyiv-Shepetivka-Lviv-Western border (the figure was created based on Google Maps)

Table 2 The cumulative Net Present Value (Warsaw-Lviv-Kyiv direction) is increasing

The number of pairs of passenger trains/day					
Cost, million euros/km					
	5	10	15	20	25
20	–1212	520	2243	3975	5698
15	–478	1254	2977	4709	6432
Volume of freight transport, million tons/year					
	20	25	30	35	40
20	–134	1280	2694	4108	5513
15	1338	2752	4166	5580	6985

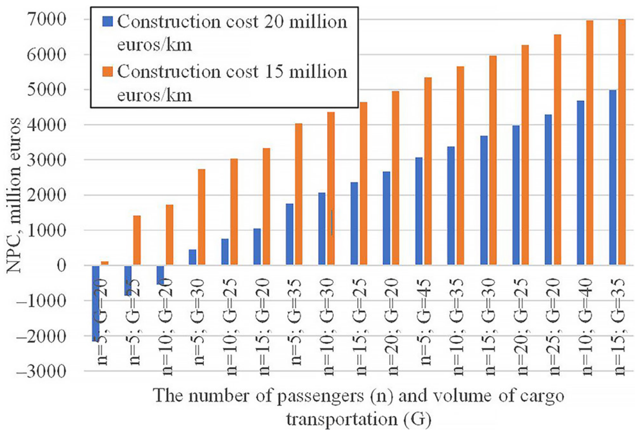

Fig. 5 Dependence of NPV on the transport volumes for the Warsaw-Lviv-Kyiv route

transport at a cost of 20 million euros per kilometer, respectively – 5 pairs of passenger trains and 25 million tons of freight per year. Other combinations are also possible; for example, at a construction cost of 20 million euros per kilometer, passenger transport volume can be ten pairs of trains per day and 20 million tons of freight transport per year. To achieve the same Net Present Value, for example, 5 billion euros, on the southern route, it is necessary to have transport volumes of 15 pairs of passenger trains and 35 million tons of freight transport, and on the northern route, respectively, 15 pairs of trains and 30 million tons for freight transport. The cost-effectiveness of constructing the HSR on a new route will be ensured at a construction cost of 15 million euros per kilometer for the following transport volumes: 5 pairs of passenger trains and 20 million tons of freight transport at a cost of 20 million euros per kilometer, respectively – 5 pairs of passenger trains and 30 million tons of freight per year. Other combinations are also possible; for example, at a construction cost of 20 million euros per kilometer, passenger transport volume can be ten pairs of trains per day and 25 million tons of freight transport per year.

4 Discussion

In this paper, it has been demonstrated that considering the population attracted to HSR and the volume of transit passenger transportation alone is insufficient to achieve the normative investment payback. As mentioned, rectifying this situation can only be achieved by implementing mixed traffic involving high-speed passenger trains and accelerated freight trains. The practice of constructing high-speed railways worldwide has shown that the main reasons for establishing sections of mixed traffic involve overcoming contour or elevation obstacles and justifying investments in HSR construction, where the demand for passenger transportation is insufficient, and profitability is ensured through additional revenue from freight transportation when organizing mixed traffic.

Mixed traffic of passenger and freight trains on high-speed rail lines may face numerous issues and constraints that require careful planning and coordination. Passenger and freight trains have different schedules and need to be synchronized to avoid conflicts and ensure safety and operational efficiency. The new HSR route must be adapted for the operation of high-speed passenger trains and freight container trains. This includes the construction of dedicated tracks for various types of trains, the establishment of passing sections, the construction of special crossings, and the implementation of signaling and safety systems. Passenger stations and stations for freight container trains should be strategically located to ensure easy passenger access, transfers, and efficient cargo operations. Mixed traffic can pose additional challenges in terms of environmental sustainability and safety. Considering all these aspects and conducting proper planning and coordination can facilitate the successful mixed operation of high-speed and freight container trains on the new route. However, this requires further scientific research and the development of appropriate recommendations.

5 Conclusions

As global practice shows, all existing HSR systems are built on routes with high and very high passenger traffic, which is the main prerequisite for the economic efficiency of such a transport system. The presence of a continuous minimum necessary demand for trips by the population is the most critical criterion for determining route's location. International experience shows that the construction of HSR is reasonable when the population in the catchment area is 20–25 million people and passenger traffic is not less than 5–6 million people per year. Implementing the HSR network in Ukraine will require significant investments in the construction of transportation infrastructure and the purchase of rolling stock. Many questions arise regarding land allocation for construction, land plot costs, the possibility of private sector involvement, and construction organization. The specific purpose of HSR determines special requirements for its design and construction. Research conducted on the construction of the Kyiv – borderline HSR in the direction of Warsaw allowed us to determine the approximate construction cost of the railway at the level of 15–22 million euros per 1 kilometer, corresponding to international construction experience. Economic integration of European Union countries allows for an increase in passenger flows in international connections. This circumstance leads to solving the problem of connecting national high-speed rail lines into a single European network. Implementing the European program for expanding the high-speed network to Eastern European countries will enable the integration of Ukraine's railways into the European high-speed network.

Acknowledgement

This research was funded by The National Research Foundation of Ukraine under the project "Scientific Justification of the Introduction of the European Track on the Territory of Ukraine in the Post-War Period" (project registration number 2022.01/0021), which was obtained through the "Science for the Recovery of Ukraine in the War and Post-War Periods" competition. Authors express gratitude to the employees of the Ukrainian State University of Science and Technologies, and the members of the "SZE-RAIL" research team at Széchenyi István University.

References

Arga, K., Susetyo, B., Syafwandi, S. (2021) "Feasibility study of a railway construction project as intermodal transportation in Tanjung Perak port", SINERGI, 25(1), pp. 59–68. https://doi.org/10.22441/sinergi.2021.1.008

Buier, N. (2020) "The second coming of rail: the spanish high-speed rail-finance complex", Antipode, 52(6), pp. 1603–1623. https://doi.org/10.1111/anti.12672

Center for Transport Strategies (2023) "Польський СРК та "Укрзалізниця" спільно працюватимуть над будівництвом високошвидкісної залізниці", (Polish CPK and Ukrzaliznytsia will jointly work on the construction of a high-speed railway), [online] Available at: https://cfts.org.ua/news/2023/01/19/polskiy_cpk_ta_ukrzaliznitsya_spilno_pratsyuvatimut_nad_budivnitstvo_visokoshvidkisno_zaliznitsi_73421 [Accessed: 03 September 2023] (in Ukrainian)

Di Gangi, M., Vitetta, A. (2021) "Quantum utility and random utility model for path choice modelling: Specification and aggregate calibration from traffic counts", Journal of Choice Modelling, 40, 100290. https://doi.org/10.1016/j.jocm.2021.100290

European Commission (2014) "Guide to cost-benefit analysis of investment projects", [pdf] European Commission, Brussels. Belgium. Available at: https://ec.europa.eu/regional_policy/sources/studies/cba_guide.pdf [Accessed: 03 September 2023]

Fischer, S., Szalai, S. (2023) "Detection process of energy loss in electric railway vehicles", Facta Universitatis, Series: Mechanical Engineering, 21(1), pp. 81–99. https://doi.org/10.22190/FUME221104046F

Google Maps "Ukraine", [online] Available at: https://www.google.com/maps/@48.6985584,30.1960359,6z?hl=en&entry=ttu [Accessed: 10 October 2023]

Guan, C., Chen, L., Li, D. (2023) "Does the opening of high-speed railway improve high-quality economic development in the Yangtze river delta, China?", Land, 12(8), 1629. https://doi.org/10.3390/land12081629

Havryliuk, V. (2020) "Detecting of signal distortions in cab signalling system using ANFIS and WPESE", In: 2020 IEEE 4th International Conference on Intelligent Energy and Power Systems (IEPS), Istanbul, Turkey, pp. 231–236. ISBN 978-1-6654-0515-7 https://doi.org/10.1109/IEPS51250.2020.9263165

Havryliuk, V. (2021) "Model of propagation of traction current harmonics from trains to a track circuit receiver", In: 2021 Asia-Pacific International Symposium on Electromagnetic Compatibility (APEMC), Nusa Dua - Bali, Indonesia, pp. 1–4. ISBN 978-1-7281-7622-2 https://doi.org/10.1109/APEMC49932.2021.9597152

Hubar, O., Markul, R., Tiutkin, O., Andrieiev, V., Arbuzov, M., Kovalchuk, O. (2020) "Study of the interaction of the railway track and the rolling stock under conditions of accelerated movement". IOP Conference Series: Materials Science and Engineering, 985, 012007. https://doi.org/10.1088/1757-899X/985/1/012007

Kurhan, M., Kurhan, D. (2019) "Providing the railway transit traffic Ukraine–European Union", Pollack Periodica, 14(2), pp. 27–38 https://doi.org/10.1556/606.2019.14.2.3

Kurhan, M., Kurhan, D., Hmelevska, N. (2022a) "Development of the high-speed running of trains in Ukraine for integration with the international railway network", Acta Polytechnica Hungarica, 19(3), pp. 207–218. https://doi.org/10.12700/APH.19.3.2022.3.16

Kurhan. M., Kurhan, D., Husak M., Hmelevska, N. (2022b) "Increasing the efficiency of the railway operation in the specialization of directions for freight and passenger transportation", Acta Polytechnica Hungarica, 19(3), pp. 231–244. https://doi.org/10.12700/APH.19.3.2022.3.18

Kurhan, M., Fischer, S., Kurhan, D. (2023) "The prospect of using the dual gauge line for the Ukraine–Hungary railway connection", Periodica Polytechnica Transportation Engineering, 51(1), pp. 70–78 https://doi.org/10.3311/PPtr.20572

Lviv Public Portal (2023) "A European-standard railway will be built in the Lviv region", [online] Available at: https://forpost.lviv.ua/novyny/43414-na-lvivshchyni-zbuduiut-zaliznychnu-koliiu-za-ievropeiskym-standartom [Accessed: 03 September 2023] (in Ukrainian)

Ma, C., Tan, K., He, J. (2023) "The impact of opening a high-speed railway on urban innovation: A comparative perspective of traditional innovation and green innovation", Land, 12(9), 1671 https://doi.org/10.3390/land12091671

Ma, G., Hu, J., Zhang, R. (2023) "Spatial-temporal distribution and coupling relationship of high-speed railway and economic networks in Metropolitan Areas of China", Land, 12(6), 1193 https://doi.org/10.3390/land12061193

Németh, A., Fischer, S. (2021) "Investigation of the glued insulated rail joints applied to CWR tracks", Facta Universitatis, Series: Mechanical Engineering, 19(4), pp. 681–704. https://doi.org/10.22190/FUME210331040N

OECD (2020) "Dac criteria for evaluating development", [pdf] OECD, Paris, France. Available at: https://www.oecd.org/dac/evaluation/49756382.pdf [Accessed: 03 September 2023]

Pittman, R., Jandová, M., Król, M., Nekrasenko, L., Paleta, T. (2020) "The effectiveness of EC policies to move freight from road to rail: Evidence from CEE grain markets", Research in Transportation Business & Management, 37, 100482. https://doi.org/10.1016/j.rtbm.2020.100482

Pomykała, A., Engelhardt, J. (2023) "Concepts of construction of high-speed rail in Poland in context to the european high-speed rail networks", Socio-Economic Planning Sciences, 85, 101421. https://doi.org/10.1016/j.seps.2022.101421

Potapov, D., Vitolberg, V., Shumyk, D., Boyko, V., Kulik, S. (2023) "Study into stresses in rail track elements from high-speed rolling stock in Ukrainian main lines", AIP Conference Proceedings, 2684, 020010. https://doi.org/10.1063/5.0120022

Priyanto, S., Churniawan, E., Darmawan, E. S. (2023) "Financial feasibility study and economic impact of Krl electrification project development yogyakarta - solo", Jurnal Syntax Transformation, 4(7), pp. 58–67. https://doi.org/10.46799/jst.v4i7.760

Railway Pro (2023) "Visegrad countries push forward the HSR project", [online] Available at: https://www.railwaypro.com/wp/visegrad-countries-push-forward-the-hsr-project/ [Accessed: 03 September 2023]

Russo, F., Sgro, D., Musolino, G. (2023) "Sustainable Development of Railway Corridors: Methods and Models for High Speed Rail (HSR) Demand Analysis", In: International Conference on Computational Science and Its Applications, Athens, Greece, pp. 527–538. ISBN 978-3-031-37122-6 https://doi.org/10.1007/978-3-031-37123-3_36

Shvets, A. (2023) "Influence of the instability form on the traffic safety indicator of freight rolling stock", Engineering Applications, 2(3), pp. 206–217.

Sysyn, M., Nabochenko, O., Kovalchuk, V., Przybyłowicz, M., Fischer, S. (2021) "Investigation of interlocking effect of crushed stone ballast during dynamic loading", Reports in Mechanical Engineering, 2(1), pp. 65–76. https://doi.org/10.31181/rme200102065s

Szalai, S., Kocsis Szürke, S., Harangozó, D., Fischer, S. (2022) "Investigation of deformations of a lithium polymer cell using the digital image correlation method (DICM)", Reports in Mechanical Engineering, 3(1), pp. 116–134. https://doi.org/10.31181/rme20008022022s

UNESCO (2022) "Results-based management approach as applied at UNESCO", [online] Available at: https://unesdoc.unesco.org/ark:/48223/pf0000177568 [Accessed: 03 September 2023]

Venezia, E. (2023) "Cost–benefit analysis in high-speed railway projects: appraisal of methodological approaches and an initial social equity evaluation, a case study", Sustainability, 15(14), 11344. https://doi.org/10.3390/su151411344

Zou, Z., Tang, Y. (2023) "Evaluation of sustainable development potential of high-speed railway station areas based on "Node-Place-Industry" Model", ISPRS International Journal of Geo-Information, 12(9), 349. https://doi.org/10.3390/ijgi12090349