

PAPER • OPEN ACCESS

Assessment of combined high-speed passenger and freight train movement to mitigate environmental impact

To cite this article: Mykola Kurhan *et al* 2025 *IOP Conf. Ser.: Earth Environ. Sci.* **1491** 012023

View the [article online](#) for updates and enhancements.

You may also like

- [Special issue on applied neurodynamics: from neural dynamics to neural engineering](#)
Hillel J Chiel and Peter J Thomas
- [Study of Bypasses for High-speed Passenger Trains, as an Alternative to the Reconstruction of Railway Stations](#)
N V Kukleva and D N Kuklev
- [SRP Annual General Meeting: Health Physics Instrumentation and Analytical Techniques Edinburgh, 24-26 April 2001](#)
Barbara Gallani, Dave Drury and Steve Gower



UNITED THROUGH SCIENCE & TECHNOLOGY

 **The Electrochemical Society**
Advancing solid state & electrochemical science & technology

**248th
ECS Meeting**
Chicago, IL
October 12-16, 2025
Hilton Chicago

**Science +
Technology +
YOU!**

**Register by
September 22
to save \$\$**

REGISTER NOW

Assessment of combined high-speed passenger and freight train movement to mitigate environmental impact

Mykola Kurhan^{1,3}, Szabolcs Fischer², Dmytro Kurhan¹ and Nelya Hmelevska¹

¹Ukrainian State University of Science and Technologies, Lazaryan St., 2, Dnipro, 49010, Ukraine

²Széchenyi István University, Egyetem tér 1, Győr, 9026, Hungary

³Corresponding author: d.m.kurhan@ust.edu.ua

Abstract. The purpose of the study is to investigate the primary reasons for the feasibility of the combined movement of high-speed passenger and freight trains. The research includes the analysis and theoretical synthesis of materials related to the combined movement of high-speed passenger and freight trains in European Union countries. The combination of different train categories on high-speed rail lines is not only possible but also, under certain conditions, advisable. The main reasons for arranging sections of combined passenger and freight movement include overcoming contour or height obstacles and justifying investments in the construction of high-speed railways where the demand for passenger transportation is insufficient and profitability is ensured through additional income from cargo transportation. The combined movement of high-speed passenger and freight trains can reduce environmental impact by ensuring the efficient use of railway infrastructure and decreasing transport emissions. The authors have proposed a comprehensive approach to assessing the effectiveness of implementing the movement of high-speed passenger and accelerated freight trains, considering the net present value and ensuring the capacity of the double-track railway line during concurrent train movements. The research results enable enhancing the stability of railway transportation on high-speed railways.

1. Introduction

High-speed railways (HSRs) have been widely utilized in various countries over the past few decades with the superstructural setups of ballastless tracks [1], as well as traditional ballasted tracks [2], as well as. Today, a plethora of scientific research is dedicated to exploring avenues for further development of the Trans-European high-speed rail network. One such project, the Next Generation Train (NGT), was developed by eight institutes of the German Aerospace Center (DLR). The primary idea behind NGT was to define a network grid for high-speed railways in Europe, designed to accommodate the movement of next-generation trains (NGT) at speeds of 400 km/h, reducing travel time and energy consumption, noise and wear while simultaneously enhancing passenger safety and comfort and reducing life cycle costs and environmental impact. The model network includes most European countries [3].

Given current trends, passenger and freight transportation will continue growing in Europe and globally. This growth, alongside progress, entails increased energy demand and higher emissions of CO₂ and other atmospheric pollutants. Further development of railways could mitigate this growth. High-speed rail can be an alternative to air transportation [4].

The current transport policy of the European Union aims to create a unified Pan-European transport network (TEN-T) encompassing roadways, railways, inland waterways, and air routes [5]. Giving



preference to rail transport for passenger and freight services could reduce energy consumption and harmful emissions [6]. By 2050, half of automotive freight and passenger transportation is projected to shift to rail and water transport. The construction of a unified European high-speed rail network that provides accessible, fast, and comfortable inter-state passenger connections aligns with the primary goals of TEN-T.

It is considered that achieving high speeds and reducing operational costs of high-speed railways necessitates the construction of dedicated passenger lines. However, in some cases, freight transportation on HSR may be possible or even necessary. In [7] examines the experience and prospects of high-speed rail for freight transport and concludes that accelerating logistic and freight transport flows can be compatible with the capabilities of high-speed rail. Nevertheless, the potential of high-speed rail freight services is not fully utilized due to logistical constraints and network capabilities.

The creation of international networks based on the potential of individual countries leads to the need to establish such operational and technical parameters for national high-speed rail lines that would have operational compatibility with the Trans-European HSR. The relationship between passenger traffic volume and these factors allows forecasting prospective passenger flows and assessing the effectiveness of organizing high-speed travel on specific routes. The economic integration of European Union countries enables increased passenger traffic in international travel. This circumstance necessitates addressing the issue of integrating national high-speed corridors into a single European network [8].

Considerable attention has been devoted to scientific works ranging from the organization of passenger transport to matters related to the construction projects of new high-speed rail lines. These include creating national high-speed rail lines that would be operationally and technically compatible with Trans-European HSR and increasing capacity with mixed freight and passenger transport organization. In [9] examined issues related to the construction projects of new high-speed rail lines (HSR) in Poland. Significant changes regarding HSR construction projects took place in Poland in 2017 with the new concept of building the Solidarity Transport Hub (STH) near Warsaw. By the end of 2021, the concept had not entered the implementation stage, and its main principles and critical remarks are outlined in this article.

In [10] discuss the issue of train capacity allocation for a mixed passenger and freight transportation scheme in HSR systems, where railway operators implement revenue management to determine the optimal plan for distributing train capacity for each service. However, HSR assets such as trains, stations, and railway lines are often underutilized, especially during off-peak hours. With the increasing demand for intercity freight transport in high-volume, high-speed, cost-effective, and timely deliveries, there is significant potential value in utilizing these HSR resources for freight delivery. During off-peak hours in the HSR system, passenger demand is insufficient, and passenger trains still have excess transport capacity to transport high-value goods such as electronics, fresh produce, clothing, express shipments, and more. Mixed transportation, where passengers and freight can be transported on the same HSR train, has been tested and demonstrated as feasible in many countries, such as Germany, Denmark, and France.

The most commonly cited arguments for deciding on the construction of high-speed rail lines include increasing the capacity of existing lines and the desire to address transport "bottlenecks" by diverting passenger high-speed trains to new lines; the desire to restore the competitiveness of rail transport through significant travel time reductions, mitigating transport's negative impact on the environment; stimulating the national economy through increased innovation, investment levels, and market access; and mobility shifts related to time savings and increased spatial accessibility. In [11] provide an analysis of various aspects of the effectiveness of freight transport policy shifting from road to rail.

Railway operators operate in market conditions and have strong incentives to focus on providing transportation between major urban centers, while smaller and intermediate cities typically have poorer rail services. In [12] explain strategic planning in four municipalities with HSR railway stops in Sweden. Information comparing municipalities and urban settlements where planned train stops are located is presented.

Analysis of scientific literature has shown that combined passenger and freight transportation can be carried out using different schemes. Scheme 1 involves the transportation of perishable goods, parcels,

and valuable items by high-speed trains, the same ones used for passenger transportation. Scheme 2 entails the transportation of goods by express freight trains with a relatively small speed differential between trains of different types to reduce the train passage coefficient and ensure the required capacity. Considering the necessity of applying European standards on new HSR lines, questions arise regarding the need to justify the critical technical parameters of such a corridor and its capacity for the combined operation of high-speed passenger and express freight trains.

This study aims to identify the main reasons for the feasibility of combined operation of high-speed passenger and freight trains in European Union countries using analysis and theoretical generalization of materials related to this topic.

2. Methods

One of the challenges of combined passenger and freight transportation is determining track construction parameters that simultaneously meet the standards of both types of transport [13]. Freight trains exert greater force on railway tracks, especially in curved sections, which imposes more significant requirements on their movement parameters [14]. Therefore, when determining the minimum radius, the type of high-speed railway must be considered. With some approximation, three main conceptual approaches to infrastructure and high-speed rail organization can be identified: type (i) - exclusively high-speed operation. Type (i) includes HSR in France, Belgium, Germany, and others; type (ii) - high-speed passenger transportation combined with regular passenger trains at lower speeds. This group includes Spain and some lines in Belgium and the Netherlands; type (iii) - mixed passenger transportation (high-speed and regular) and freight traffic. Italy, Germany, and new lines in Spain, France, and England fall into this group. For example, in Germany, there are lines where passenger trains reach speeds of up to 280 km/h, while freight trains operate at 120 km/h. Therefore, two principal variants are considered: purely passenger traffic and predominantly passenger traffic, where HSR infrastructure can be used for passing special container and long-distance passenger trains with speeds up to 160 km/h.

When designing an HSR track, the minimum curve radius can be determined through the allowable value of unbalanced acceleration

$$R_{\min} = \frac{V_{\max}^2}{3.6^2 \left([\alpha_p] + \frac{gh}{S} \right)}, \quad (1)$$

where R_{\min} – minimum curve radius, m; V_{\max} – maximum speed of passenger train, km/h; h – elevation of outer rail in a curve, mm; S – distance between rail axes, mm; g – acceleration due to gravity, 9.81 m/s²; α_p – unbalanced acceleration of passenger train, m/s².

In the presence of trains of other categories, such as express freight trains, the minimum curve radius is established, taking into account the condition

$$R_{\min} = \frac{V_{\max}^2 - V_{\min}^2}{3.6^2 (\alpha_p - \alpha_c)}, \quad (2)$$

where V_{\min} – minimum speed of freight train, km/h; α_c – unbalanced acceleration of freight train, m/s².

In most European countries, for high-speed passenger trains, the unbalanced acceleration α_p is 0.4 m/s², for freight trains, $-0.3 \leq \alpha_c \leq 0.3$ m/s², and the distance between rail axes $S=1,500$ mm (for a track gauge of 1,435 mm).

Based on the calculations using (1) and (2), graphs depicting the dependency of the minimum radius on the maximum speeds of passenger trains for various combinations with freight trains have been constructed, as shown in figure 1.

In the example illustrated in figure 1, it is evident that the presence of freight trains, even with a high minimum speed of 160 km/h, leads to a significant increase in the minimum radius required during the

design of an HSR track. This is due to the inability to establish the total amount of outer rail elevation. Considering scenarios with freight trains traveling at even lower speeds would further increase the minimum curve radius.

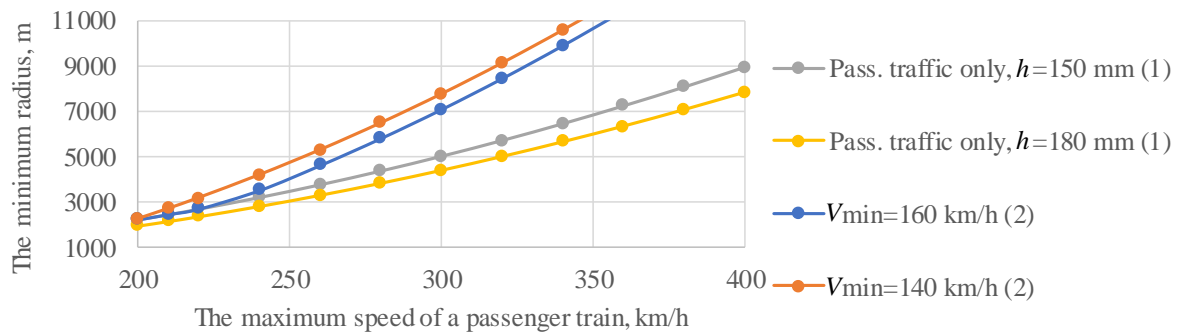


Figure 1. Dependency graphs of the minimum radius on the speeds of passenger and freight trains.

The presence of trains of different categories (high-speed and accelerated container) results in significant differences in speed on steep inclines. The speed level depends on the weight of the freight train. Accelerated freight trains with masses of 1,000 t, 1,500 t, and 2,000 t were considered to investigate this issue.

The passage of special trains on HSR on a new track with a gauge of 1,435 mm can be carried out by locomotives such as the EU44, which is used on Polish railways. The EU44 and EU43 series locomotives, also known as "Husarz," are among the powerful and modern electric locomotives designed for long-distance freight and passenger transportation.

The train speed along a sufficient length of longitudinal profile elements depends on the type of locomotive, train mass, and total resistance. To determine the constant speed on different gradient elements of the longitudinal profile, combined $F_k(V)$ – locomotive traction characteristic and $W(V)$ – total resistance curves will be used. The abscissa of the intersection point of the $F_k(V)$ and $W(V)$ curves corresponds to the constant train speed on the gradient (i), as shown in figure 2.

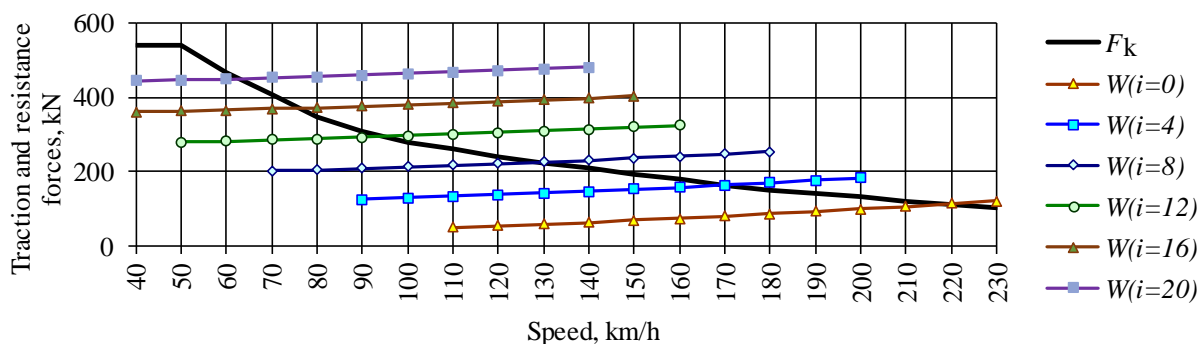


Figure 2. Traction characteristics and total resistance curves, EU44 Husarz electric locomotive, train mass 2000 tons (F_k – locomotive traction force; W – locomotive resistance force).

Figure 2 illustrates that on steep inclines up to 20 %, the freight train's speed may decrease to 60 km/h. It becomes necessary to consider the impact of the ratio of speeds of passenger and freight trains on the train passage coefficient and, ultimately, on the reduction of throughput capacity [15].

The train passage coefficient of the passenger train graph on sections equipped with automatic blocking depends on the section distance, block section length, travel time through block sections for passenger and freight trains, and station intervals upon arrival and departure [16].

During high-speed movement of passenger trains (170 to 200 km/h) and freight train speeds of 60 km/h, with block section lengths ranging from 1.0 to 2.6 km, using three-section automatic blocking and an interstation section length of 10 km, the train passage coefficient can vary from 6.2 to 7.8, as

shown in figure 3a.

The maximum number of freight trains that can pass through a section per day with non-parallel schedules is determined by (3).

$$G = N - \varepsilon n, \quad (3)$$

where N – total number of trains, pairs/day; n – number of passenger trains, pairs/day; ε – train passage coefficient.

The results of calculations according to (3) for the following initial data: $N=100$ train pairs per day; $\varepsilon=6.0-8.0$; $n=5-30$ train pairs per day are presented in figure 3b.

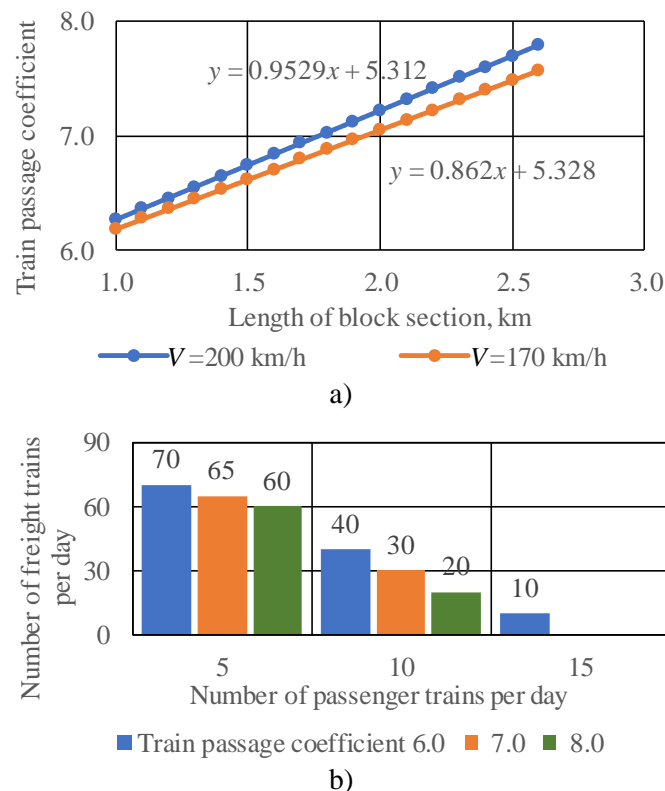


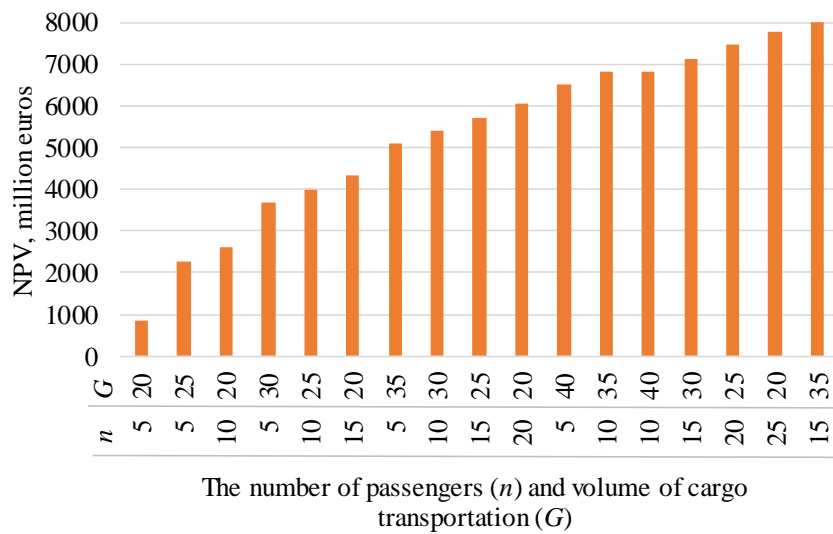
Figure 3. The influence of the train passage coefficient: a) dependency of the train passage coefficient on the block section length (with options for approximation equations); b) maximum possible number of freight trains depending on passenger traffic volumes and train passage coefficient.

Figure 4 shows that the freight movement of accelerated trains on a high-speed section can be organized with no more than ten pairs of passenger trains per day (at $\varepsilon=6.0 - 15$ train pairs).

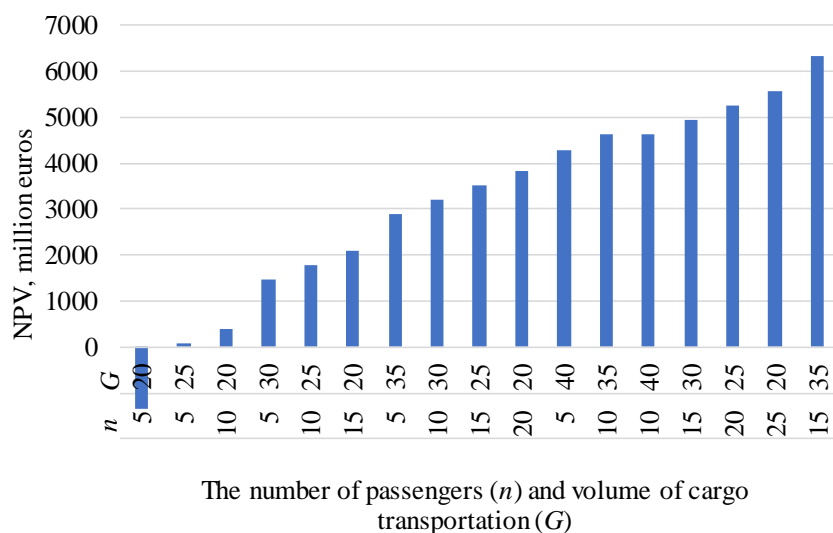
3. Results and discussion

Comparison of investment projects with different ratios of passenger and freight trains can be conducted using the Net Present Value (NPV). In [17] utilized this metric to evaluate the HSR link Bari – Naples. In [18] applied NPV to assess the intermodal transportation project at Tanjung Perak Port.

In [19] described such methodology and made forecast calculations for several variants of high-speed rail construction according to European standards in Ukraine. Fig. 4 displays the NPV calculation results for different combinations of passenger and freight trains when constructing the new Warsaw – Lviv – Kyiv HSR based on the mentioned study.



a)



b)

Figure 4. Dependency of NPV on transport volumes: a) construction cost 15 million euros/km; b) construction cost 20 million euros/km (n – number of passenger trains, pairs/day; G – number of freight trains, pairs/day).

Comparison of the results presented in figures 4 and 5 shows that on the high-speed section, combined train traffic can be organized, resulting in a net present value of 4,006 million euros with ten pairs of passenger trains per day and 25 pairs of freight trains per day, assuming a construction cost of 15 million euros/km and the train passage coefficient of 6.0-7.0.

On the high-speed section, combined train traffic can also be organized, resulting in a net present value of 1,800 million euros with ten pairs of passenger trains per day and 25 pairs of freight trains per day, assuming a construction cost of 20 million euros/km and a coefficient of freight train displacement by passenger trains of 6.0-7.0. With the same passenger transport volumes and the train passage coefficient 8.0, the freight traffic cannot exceed 20 pairs of trains per day, resulting in decreased revenue.

4. Conclusions

The sustainable development of high-speed rail networks depends on the substantiation of project decisions, including the issue of combined passenger and freight train operations. Results can only be achieved by applying a comprehensive approach, which includes compliance with appropriate technical parameters, justification of economic benefits, and ensuring reduced environmental impact.

The minimum allowable radius should be set differentially depending on the maximum train speed, considering the specialization of routes. The choice of curve parameters is primarily influenced by the type of high-speed rail: exclusively high-speed operations (France, Belgium, Germany), or high-speed trains sharing tracks with conventional passenger trains (Spain and certain routes in Belgium and the Netherlands), or mixed passenger transport (high-speed and conventional) and freight operations (Italy and Germany, among others). When designing new high-speed rail lines, the question of choosing the type of high-speed rail – purely passenger or combined train operations – remains essential, as it determines the route alignment, axle load, infrastructure condition, and profile and alignment parameters.

Combining high-speed and accelerated freight train operations is possible if passenger and freight transportation revenues ensure the investment profitability in building a new high-speed rail line. For example, with a train passage coefficient of 6.0-7.0 and a construction cost of a new double-track high-speed rail line of 15-20 million euros/km, combined train operations (high-speed passenger and accelerated freight) can be implemented with up to 10 pairs of passenger trains per day and up to 25 pairs of freight trains per day.

Acknowledgments

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. The authors express gratitude to the employees of the Ukrainian State University of Science and Technologies, and the members of the "SZE-RAIL" research team and the Vehicle Industry Research Center at Széchenyi István University.

References

- [1] Bian X, Jiang H, Cheng C, Chen Y, Chen R and Jiang J 2014 Full-scale model testing on a ballastless high-speed railway under simulated train moving loads *Soil Dynamics and Earthquake Engineering* **66** 368–384
- [2] Ezsias L, Tompa R and Fischer S 2024 Investigation of the Possible Correlations Between Specific Characteristics of Crushed Stone Aggregates *Spectrum of Mechanical Engineering and Operational Research* **1**(1) 10–26
- [3] Schumann T, Moensters M, Meirich C and Jaeger B 2019 NGT CRGO - Concept for A High-Speed Freight Train in Europe *WIT Transactions on The Built Environment* **181** 555–565
- [4] IEA 2019 The Future of Rail Opportunities for energy and the environment https://iea.blob.core.windows.net/assets/fb7dc9e4-d5ff-4a22-ac07-ef3ca73ac680/The_Future_of_Rail.pdf accessed 05.04.2024
- [5] European Commission 2024 Trans-European Transport Network (TEN-T) https://transport.ec.europa.eu/transport-themes/infrastructure-and-investment/trans-european-transport-network-ten-t_en accessed 05.04.2024
- [6] Ezsias L, Brautigam A, Kocsis Szurke S, Szalai S and Fischer S 2023 Sustainability in railways – a review *Chemical, Engineering Transactions* **107** 7–12
- [7] Nazarov O A 2018 Problems and Prospects of the High-Speed Passenger Railway Transport Development *Transport Systems and Transportation Technologies* **16** 77–82
- [8] European Commission 2015 Guide to Cost-Benefit Analysis of Investment Projects https://ec.europa.eu/regional_policy/sources/studies/cba_guide.pdf accessed 05.04.2024

- [9] Pomykała A and 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
- [10] Xu G, Zhong L, Wu R, Hu X and Guo J 2022 Optimize train capacity allocation for the high-speed railway mixed transportation of passenger and freight *Computers & Industrial Engineering* **174** 108788
- [11] Pittman R, Jandová M, Król M, Nekrasenko L and 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
- [12] Hermelin B and Gustafsson S 2022 Strategic Planning for High-speed Rail Investments – A Comparative Study of Four Intermediate Stations in Sweden *Planning Practice & Research* **37**(5) 547–563
- [13] Kurhan M, Kurhan D, Husak M and Hmelevska N 2022 Increasing the Efficiency of the Railway Operation in the Specialization of Directions for Freight and Passenger Transportation *Acta Polytechnica Hungarica* **19**(3) 231–244
- [14] Shvets A O, Bolotov O M, Percevoj A K, Ghlukhov V V, Bolotov O O and Saparova L S 2020 Research of dynamic indicators and influence of different types of rolling stock on railway track *IOP Conf. Ser.: Mater. Sci. Eng.* **985** 012010
- [15] Strelko O, Toropov B, Horban A, Hrushevska T and Bernatskyi A 2023 Some Issues of the Project Analysis of Options for the Implementation of European Standard Railways in Ukraine *Transactions on Transport Sciences* **1**/2024 64–70
- [16] Vernyhora R V, Papakhov O Yu and Logvinova N O 2013 Analytical calculation of the coefficients of freight of passenger trains in conditions of high-speed traffic *East European Journal of Advanced Technologies* **62** 51–55
- [17] 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** 11344
- [18] Arga K, Susetyo B and Syafwandi S 2021 Feasibility study of a railway construction project as intermodal transportation in Tanjung Perak Port *Sinergi* **25**(1) 59–68
- [19] Kurhan M, Fischer S, Tiutkin O, Kurhan D and Hmelevska N 2024 Development of High-Speed Railway Network in Europe: A Case Study of Ukraine *Periodica Polytechnica Transportation Engineering* **52**(2) 151–158