Vol. 4, No. 1, 2023

Bohdan Gera[1], Yuliia Hermaniuk[1], Vasyl Matviiv[2]
1. Lviv Polytechnic National University
12, S. Bandery Str., Lviv, 79013, Ukraine

2. JSC "Ukrzaliznytsia"
1, Hoholia Str, Lviv, 79007, Ukraine

https://doi.org/10.23939/tt2023.01.029

ORGANIZATION OF PASSENGER RAIL TRANSPORTATION ON THE SECTION WITH THE COMBINED TRACK NYZHANKOVYCHI-STARZHAVA

Summary: *Passenger transportation by rail is an important component of ensuring cross-border cooperation between our country and neighboring EU countries. Transport transformations are being carried out on both sides of the border, and directives are being developed and implemented to establish uniform rules and standards for the successful operation of transport and passenger movement. At the same time, the organization of traffic is being improved, taking into account the features of the infrastructure, as well as changes in traffic flows, in particular passenger flows at border areas. An important difference between the railway system of our country and neighboring EU countries is different tracks. The width of the track on our side of the border is mainly 1520 mm and 1435 mm in EU countries. This leads to a number of related features of rail transport. In addition, there are different approaches to traffic regulation. Therefore, it is essential to develop approaches for managing through transportation, in particular, on test sections of the railway track.*

This work is aimed at solving the current problem of organizing passenger transportation in areas adjacent to the Khyriv station. Both the 1,520 mm track and the combined 1,520/1,435 mm track are used on the site, which allows organising traffic with cars designed for the appropriate track width. A mathematical model of the movement of passengers using trains on different tracks is built – a combined track between two stations on the border with Poland (Nyzhankovychi-Starzhava) and a track with a width of 1520 mm (Sambir-Khyriv), taking into account the topology of the station with conditional distances and stations as the vertices of the corresponding graph. In view of the peculiarities of the stations, possible routes are considered for choosing a train formation scheme, namely, routes between stations of train formation and rotation.

As a result, schedules for following passenger trains on border sections were constructed and studied, which allows for determining a rational scheme of train movement and their maintenance at stations. As an example, calculations were made for the Nizhankovychi-Starzhava section. It was found that in order to ensure the given passenger flow and organization of traffic on this section and adjacent tracks, it is necessary to introduce at least three passenger trains. The developed methodology can be used also for other border areas between the stations of Poland and Ukraine. The implementation of the proposed international route State Border – Nyzhankovychi – Khyriv – Starzhava – State Border along the 1435 mm track will allow our Polish neighbors to unite their two provinces with the help of their rolling stock passing through our territory, as well as to reduce the mileage of rolling stock and the distance between the two large cities of Poland. We, in turn, benefit *from providing transport services and opening new international passenger routes, with further implementation of freight transport routes on the same sections of tracks.*

Key words: *international passenger transportation, organization of passenger trains, cross-border cooperation, mathematical model.*

1. INTRODUCTION

Railway transport is an essential component for ensuring cross-border cooperation between our country and neighboring EU countries. In these countries, transport transformations are being carried out, and directives are being developed and implemented to establish uniform rules and standards of operation, in particular for railway transport. For our part, more and more attention has recently been paid to the convergence of the transport system with the structure and transport management of neighboring countries to the west of the border. It is important to improve the movement of passengers and cargo across the border in both directions. Gradually, there is a need to improve the organization of traffic, taking into account the characteristics of the infrastructure, as well as changes in traffic flows, in particular passenger flows at border areas. At the same time, there is a difference in track: first of all, different track widths, mostly 1520 mm on our side and 1435 mm with EU countries; secondly, different approaches to traffic regulation. We get the problem of the contact of two transport systems with slightly different characteristics. Therefore, in the mathematical modeling of transport flows, it is necessary to take into account the appearance of a transitional area from one transport system to another due to the peculiarities of each, as well as the state of the contact area itself.

2. RESEARCH STATEMENT

Separate tasks related to cross-border cooperation are found in a number of works. For example, in a study [1] solutions to the problems related to the creation of a cross-border transport and logistics cluster related to the introduction of changes in the legal framework for the organization of traffic between the border regions of Ukraine (Volyn, Zakarpattia, and Lviv regions) and the countries of the Visegrad Four (Poland, Slovakia, Hungary) were investigated. Issues of cross-border cooperation are also raised in work [2] on the example of Poland and two neighboring countries – the Czech Republic and Germany, where the issues of border crossing and maneuvering are considered. Passenger transportation has its own characteristics.

In this direction, a comprehensive analysis of passenger transportation in Ukraine was carried out in the context of the range of night train transportation. Regions for suburban train transportation were analyzed [3, 4]. An analysis of possible options for the logistics of passenger transportation from Eastern Ukraine (in particular, from Kharkiv) to Kraków was carried out with the help of the implementation of new railway transport routes [11], improving the technology of passenger intermodal transport with the involvement of railway transport in the conditions of tourism development [10], developing a mathematical model for calculating the plan for the formation of high-speed passenger trains, which allows realizing the maximum passenger flow while minimizing operational costs [15].

In recent years, scientific works have been increasingly devoted to issues of interdependence and competition of participants in transport processes. In particular, the competition between railway passenger operators of the EU countries is studied in [5], and the competition for transit cargo transportation is highlighted in [6]. The paper [7] analyzes the reasons for the competitive failure of the operator of regional passenger transportation in Poland. Sufficient attention is paid to studying the price strategy of operators, as well as cooperation with markets [8].

Considerable attention in scientific works on the organization of passenger transportation has been paid to issues related to projects for the construction of new high-speed railway lines [12], to the establishment of such operational and technical parameters of domestic high-speed railway lines that would have operational compatibility with the Trans-European HSN [13], to the increase of throughput capacity in the mixed organization of freight and passenger transportation [9], improving the quality of the traffic schedule for suburban trains, taking into account the stops of time-dependent passenger demand [14].

Considering the wide range of problems that arise in the study of cross-border cooperation, it is necessary to foresee the possibility of using new technologies, if organizing the movement of trains to the western border. Therefore, it is important to develop approaches for managing through transportation, in particular, on test sections of the railway track.

3. MATHEMATICAL MODEL OF TRACKING PASSENGER TRAINS IN BORDER AREAS

This study examines the organization of passenger rail transportation in areas adjacent to the Khyriv station (Lviv Railway). It is one of the many problems that arise when establishing border and cross-border railway transportation. Both the 1.520 mm track and the combined 1.520/1.435 mm track are used on the site, which allows organizing traffic with cars designed for the corresponding track width.

Passenger flows can occur and disappear on the railway route. There are passengers moving from the initial station to the final station, while others rotate within the station. There are various variants of passenger train rotation schemes. Rotation schemes are established depending on the power of the passenger flow, taking into account the provision of comfortable conditions for passengers. The choice of the number, assignments and routes of following passenger trains depends on many factors that are taken into account when choosing a variant of the formation plan. For example, let's take a railway section, on which we have part of the 1520 mm track, part of the European 1435 mm track and part of their combined track. GoogleMap fragment Fig.1 [16] shows the following tracks: Przemysl-Nyzhankovychi – 1435 mm, Khyriv-Nyzhankovychi – combined, Khyriv-Starzhava – combined, Starzhava-Ustryki Dolishni – 1435 mm, Khyriv-Sambir 1520 mm. So, here we have a railway network consisting of different types of tracks. Nyzhankovichi is a border station with Poland. The Starzhava station is located in Ukraine, the European track goes further to the border. All the tracks shown in Figure 1 pass through Khyriv station. We can estimate the distances from Khyriv station to other nearby stations and boarding points: Sambir – 31 km, Nizhankovichi – 23 km, Starzhava – 8 km. It should be noted that Khýriv is a hub, a border railway station of the 4th class of the Lviv Directorate of the Lviv Railway, 41 km from the Przemyśl station on the territory of Poland. The Khyriv – Korostenko checkpoint on the border with Poland also operates at the station. Khyriv station was an important railway junction from the beginning of its construction until the First World War. Nowadays, it has lost its strategic importance. Until the quarantine in 2022, modern Khyriv received two pairs of suburban trains per day. Future tourist routes or an active railway connection in this region between Poland and Ukraine can restore the former significance of the station.

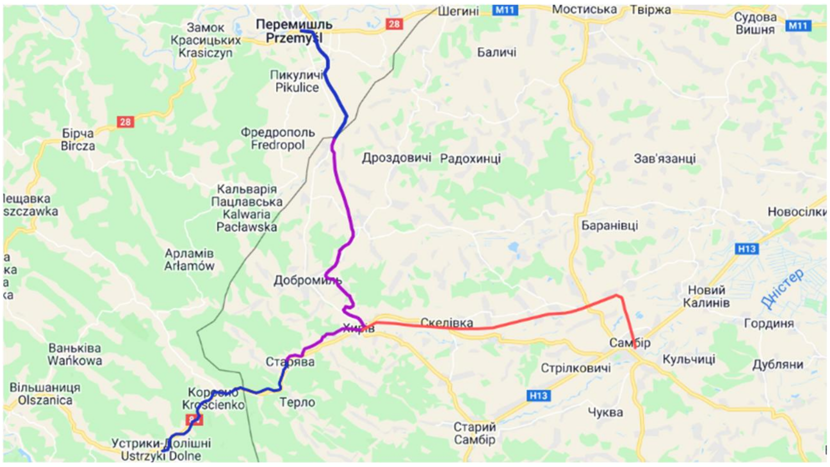

Fig. 1. Railway tracks of the Khyriv station section. Blue lines – 1435 mm tracks, red line – 1520 mm tracks, lilac line – combined track.

In order to formalize the research, the graph of the railway station is constructed in the form as shown in Fig. 2, where the topology of the station is displayed with conditional distances and stations at the vertices of the graph, indicated with capital letters. There is a combined Nyzhankovychi-Starzhava track (H-T) and a 1.520-mm-wide track Sambir-Khyriv (S-X). Stations C (Sambir), X (Khyriv), H (Nyzhankovychi), and P (Przemysl) are considered train formation and rotation stations, T (Starzhava), U (Ustryki) stations are train rotation stations, B (Voyutichy), D (Dobromil) – for boarding and disembarking passengers.

On the combined track, the existing platforms are not provided for 1435 mm cars.

Only trains on the 1520 mm track can board and disembark at the stop platforms. All trains can stop at the stations. Trains crossing the border are inspected by customs at stations H and U.

Possible routes on the network are considered, taking into account the properties of the stations. Suppose that the rotation schemes of passenger trains are set independently for the 1520 mm track and the 1435 mm track to ensure the flow of passengers. The interaction of train movements on the combined part of the track will be taken into account in this version only in the train movement schedules. In this way, seven routes are considered, for the selection of the train formation scheme – routes between train formation and rotation stations. For this example, the routes C-X, C-T, C-H, X-T, X-H, H-T, and P-U were analyzed (see Fig. 3).

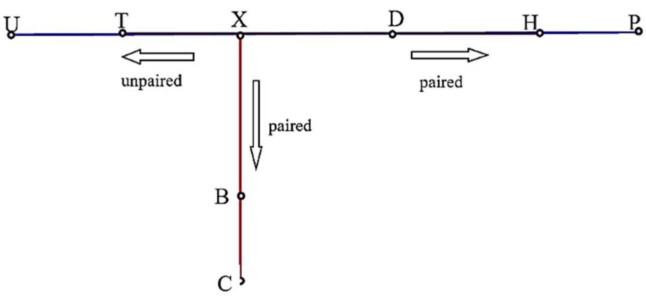

Fig.2. Graph of the railway section

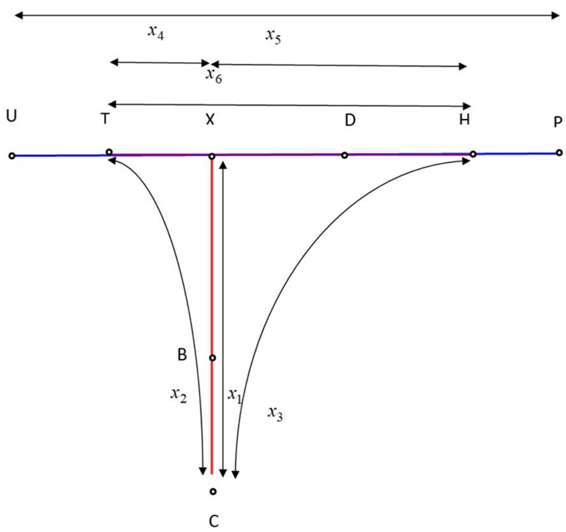

Fig. 3. Route options on the site network

The statement of the problem is recorded, from the solution of which a rational scheme of the movement of passenger trains on the site is obtained. We denote the number of trains on each of the routes as x_1 for C-X, x_2 for C-T, x_3 for C-H, x_4 for X-T, x_5 for X-H, x_6 for H-T, and y for P-U. The number of trains on the P-U section of 1435 mm track, including part of the combined track, should provide possible passenger flows on all its parts P-H, H-X, X-T, T-U. If the number of passengers m in the train follows P-U – this corresponds to the condition for the number of trains y:

$$my \geq A_{PU} = \max(A_{PH}, A_{HX}, A_{XT}, A_{TU}) \qquad (1)$$

If it is necessary to reduce railway costs by reducing the number of trains, we will determine the smallest integer y satisfying this condition (1). Thus we get

$$y = \begin{cases} \dfrac{A_{PU}}{m}, & \text{if } \left\{\dfrac{A_{PU}}{m}\right\} = 0 \\ \left[\dfrac{A_{PU}}{m}\right] + 1, & \text{if } \left\{\dfrac{A_{PU}}{m}\right\} > 0 \end{cases} \qquad (2)$$

If it turns out that $m \geq A_{PU}$, then $\left[\dfrac{A_{PU}}{m}\right] = 0$ and $y = 1$. That is, one train is enough to provide the necessary flows between all stations. With $m < A_{PU}$ will have to organize more trips, but if the difference $A_{PU} - m$ is small, within the capacity of the car, if possible, you can increase the number of cars in the train and not increase the number of trips. When reducing the number of trains, the intervals between trains in the direction are increased. If you set the conditions on the intervals between the trains, we get a different scheme of formation and rotation of trains. The work also describes the formalization of the problem along the 1520 mm track.

Let be the number of passenger seats in trains belonging to groups x_i constitutes respectively m_i. In order to ensure the transportation of passengers in quantities $A_{CB}, A_{BX}, A_{XT}, A_{XD}, A_{HD}$ between individual stations, let's write down the conditions that must be satisfied x_i, $i = \overline{1;6}$

$$\begin{cases} m_1x_1 + m_2x_2 + m_3x_3 \geq \max(A_{CB}, A_{BX}) \\ m_2x_2 + m_4x_4 + m_6x_6 \geq A_{XT} \\ m_3x_3 + m_5x_5 + m_6x_6 \geq \max(A_{XD}, A_{XH}) \end{cases} \tag{3}$$

$$x_i \geq 0,\ x_i - \text{whole numbers},\ i = \overline{1;6} \tag{4}$$

We indicate the costs of one local train x_i by c_i. Then the total cost of organizing traffic on the section of the 1520 mm track will be

$$L = \sum_{j=1}^{n} c_j x_j \tag{5}$$

This function must be minimized under conditions (3), (4).

The solution of the problem largely depends on the number of passengers departing from the stations and arriving at each of them. If we get zero values among x_i, then the scheme will be simplified, since the corresponding trains do not need to be formed.

As an example, calculations were made where one pair of trains on a track of 1435 mm passes daily at sections P-H and T-U. In other sections, two pairs of trains pass daily. On the C-B and B-X, these are trains of 1520 mm track, and on the combined tracks X-T and X-H one by 1520 mm and 1435 mm.

To illustrate, we will carry out calculations and determine x_i, $i = \overline{1;6}$ and y with conditional numerical data values. Accept $m = 600$, $m_1 = m_2 = m_3 = 320$, $m_3 = m_4 = m_5 = 290$, $A_{CB} = 500$, $A_{BX} = 550$, $A_{XT} = 300$, $A_{XD} = 320$, $A_{HD} = 300$, $A_{PH} = 450$, $A_{TU} = 350$, $c_1 = 42$, $c_2 = 53$, $c_3 = 72$, $c_4 = 20$, $c_5 = 48$, $c_6 = 82$.

In formula (1), $A_{PU} = \max(A_{PH}, A_{HX}, A_{XT}, A_{TU}) = \max(450, 320, 300, 350) = 450$. Therefore, from formulae (1), (2) we obtain that $y = 1$.

To receive x_i, $i = \overline{1;6}$ have a linear programming problem

$$L = 42x_1 + 53x_2 + 72x_3 + 20x_4 + 48x_5 + 82x_6 \to \min$$

$$\begin{cases} 320x_1 + 320x_2 + 320x_3 \geq 550 \\ 320x_2 + 290x_4 + 290x_6 \geq 300 \\ 320x_3 + 290x_5 + 290x_6 \geq 320 \end{cases}$$

$$x_i \geq 0,\ x_i - \text{integers.}$$

The solution to this linear programming problem is $x_1 = 0$, $x_2 = 1$, $x_3 = 1$, $x_4 = 0$, $x_5 = 0$, $x_6 = 0$, which leads to the use of trains only between stations P-U, C-T, C-H. If the input data changes slightly, we can get a different scheme from this.

For certainty and involvement, we will take the received number of trains and show their routes in Fig. 4. So we have three pairs of passenger trains passing through station X.

At the P-H and T-U stations, one pair of trains runs on the 1435 mm track every day. At other stations there are two pairs of trains every day. On C-B and B-X, these are trains of 1520 mm track, and on the combined X-T and X-H track, each on 1520 mm and 1435 mm.

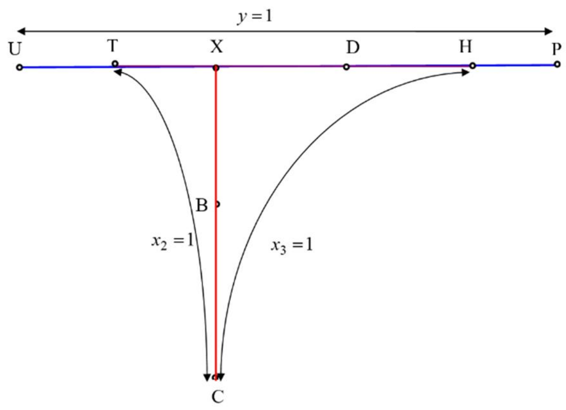

Fig. 4. Commuter train routes

The presented section is characterized as single-track and equipped with automatic blocking. In addition to stations, there may be stopping platforms. The running speed of trains on track 1435 mm is 60 km/h and on track 1520 mm – 50 km/h.

The passenger train departure schedule is drawn up for the received traffic pattern. Movement on a combined track is carried out either on a 1520 mm (Table 1–4) or 1435 mm (Table 5–6) track. Boarding and disembarking of passengers on 1520 mm tracks can be carried out both at stations and at stops where there are equipped platforms. Boarding and disembarking of passengers on the 1435 mm track will be carried out only at stations where platforms will be equipped according to the rolling stock. This section of the track is a single-track race, and passing the trains takes place on one track with a crossing at stations with the appropriate track development. For example, on the schedule of train movements, a suburban train is crossed with an international rail bus (train) at Khyriv station, which makes it possible to simultaneously pick up passengers on a 1520 mm track from Sambir station to Khyriv, where they can transfer to an international flight to Poland and travel along the track 1435 mm.

Table 1

Schedule of suburban trains on the track 1520 mm – 6144 Starzhava-Sambir

Separate item	Time of following	Separate item	Time of following	Separate item	Time of following
Starzhava	06.00	Horodovychi	06.29–06.30	Voiutychi	06.50–06.51
Zarichne	06.07–06.08	Skelivka	06.34–06.35	Biskovychi	06.57–06.58
Khyriv Pas.	06.18–06.20	Susidovychi	06.39–06.40	Sambir	07.10
Slokhynia	06.23—06.24	Nadyby	06.45–06.46		

Table 2

Schedule of suburban trains on the track 1520 mm – 6141-6142 Nyzhankovychi-Sambir

Separate item	Time of following	Separate item	Time of following	Separate item	Time of following
Nyzhankovychi	14.50	Khyriv Pas.	15.33–15.43	Nadyby	16.08–16.09
Borshevychi	14.57–14.58	Slokhynia	15.46–15.47	Voiutychi	16.13–16.14
Bonevychi	15.08–15.09	Horodovychi	15.52–15.52	Biskovychi	16.19–16.20
Dobromyl	15.14–15.15	Skelivka	15.57–15.58	Sambir	16.32
Rozheve	15.20–15.21	Susidovychi	16.02–16.03		

Table 3

Schedule of suburban trains on the track 1520 mm – 6141/6142 Sambir-Nyzhankovychi

Separate item	Time of following	Separate item	Time of following	Notes
1	2	3	4	5
Sambir	08.10	Slokhynia	08.55–08-56	

Table continuation 3

1	2	3	4	5
Biskovychi	08.20–08.21	Khyriv Pas.	09.00–09.10	Skhr z p. No. 939
Voiutychi	08.25–08.26	Rozheve	09.21–09.22	
Nadyby	08.30–08.31	Dobromil	09.27–09.28	
Susidovychi	08.36–08.37	Bonevychi	09.33–09.34	
Skelivka	08.42–08.43	Borshevychi	09.44–09.45	
Horodovychi	08.48–08.49	Nyzhankovychi	09.52	

Table 4

Schedule of suburban trains on the track 1520 mm – 6143 Sambir-Starzhava

Separate item	Time of following	Separate item	Time of following	Notes
Sambir	20.40	Horodovychi	21.18–21.19	
Biskovychi	20.50–20.51	Slokhynia	21.25–21.26	
Voiutychi	20.55–20.56	Khyriv Pas.	21.30–21.32	Skhr z p. No. 940
Nadyby	21.00–21.01	Zarichne	21.41–21.42	
Susidovychi	21.06–21.07	Starzhava	21.50	
Skelivka	21.12–21.13			

Table 5

Schedule of international trains on the track 1435 mm

Separate item	Time of following	Notes	Separate item	Time of following	Notes
939 Derzh. Kordon (Nyzhankovychi)-Derzh. Kordon (Starzhava)			**940 Derzh. Kordon (Starzhava)-Derzh. Kordon (Nyzhankovychi)**		
Derzh. Kordon	07.35		Derzh. Kordon	20.17	
Nyzhankovychi	07.40–08.30		Starzhava	20.26–21.16	
Khyriv Pas	09.00–09.20	Skhr z p. No. 6142	Khyriv Pas	21.25–21.45	Skhr z p. No. 6141
Starzhava	09.32–10.22		Nyzhankovychi	22.14–23.04	
Derzh. Kordon	10.31		Derzh. Kordon	23.09	

Table 6

Schedule of international trains on the track 1435 mm
(in the absence of border and customs clearance at border stations)

Separate item	Time of following	Notes	Separate item	Time of following	Notes
939 Derzh. Kordon (Nyzhankovychi)-Derzh. Kordon (Starzhava)			**940 Derzh. Kordon (Starzhava)-Derzh. Kordon (Nyzhankovychi)**		
Derzh. Kordon	08.05		Derzh. Kordon	20.47	
Nyzhankovychi	08.10–08.30		Starzhava	20.56–21.16	
Khyriv Pas	09.00–09.20	Skhr z p. No. 6142	Khyriv Pas	21.25–21.45	Skhr z p. No. 6141
Starzhava	09.32–09.52		Nyzhankovychi	22.14–22.34	
Derzh. Kordon	10.01		Derzh. Kordon	22.39	

4. CONCLUSIONS AND RESEARCH PERSPECTIVES

As a result of the work, a mathematical model for tracking passenger trains on border sections was built. As an example, calculations were made for the Nyzhankovychi-Starzhava section. It was calculated that three trains should be implemented to organize traffic on the section and ensure the transportation of the given passenger flow. This mathematical model can be used for other border areas between the stations of Poland and Ukraine. The implementation of the proposed international route State Border – Nyzhankovychi – Khyriv – Starzhava – State Border along the 1435 mm track will allow our Polish neighbors to unite their two provinces with the help of their rolling stock passing through our territory, as well as to reduce the mileage of rolling stock and the distance between the two large cities of Poland. We, in turn, will open new international passenger routes, with further implementation of freight transportation on these routes.

References

1. Liashenko, V., Trushkina, N. (2021) Institutional Principles of Formation of Cross-border Transport and Logistics Cluster in the Conditions of Digital and Sustainable Development. *Green, Blue and Digital Economy Journal, 2*(3), 90–100. doi: 10.30525/2661-5169/2021-3-14 (in English).

2. Gamon, Wojciech & Gómez, José Manuel. (2019). Main Problems of Railway Cross-Border Transport Between Poland, Germany and Czech Republic. *Sustainability. 11*. 4900. doi: 10.3390/su11184900 (in English).

3. Shablii, O., Borsuk, Yu. (2021). Heolohistychni aspekty zaliznychnykh pasazhyrskykh perevezen v Ukraini [Geologistic aspects of railway passengertransportation in Ukraine]. *Chasopys sotsialno-ekonomichnoi heohrafii [Human geography journal], 31,* 37–46. doi: 10.26565/2076-1333-2021-31-03 (in Ukrainian).

4. Bolzhelarskyi Ya.V, Hermaniuk Yu. M., Palii I.M. (2019). Doslidzhennia perspektyvy orhanizatsii pasazhyrskykh perevezen na diliantsi Derzhkordon-Nyzhankovychi-Truskavets-Morshyn [Study of the perspective of the organization of passenger transportation on the Derzhkordon-Nyzhankovichi-Truskavets-Morshyn section]. In *VIII Mizhnarodna naukovo-praktychna konferentsiia "Perspektyvy vzaiemodii zaliznyts ta promyslovykh pidpryiemstv" [8-th of the International Conference "Prospects of cooperation between railways and industrial enterprises"].* (pp. 22–23) (in Ukrainian).

5. Gutiérrez-Hita, C., & Ruiz-Rua, A. (2019). Competition in the railway passenger market: The challenge of liberalization. *Competition and Regulation in Network Industries*, 20(2), 164–183. doi: 10.1177/1783591719858737 (in English).

6. Kozachenko, D., Skalozub, V., Gera, B., Hermaniuk, Y., Korobiova, R. & Gorbova, A. (2019). A Model of Transit Freight Distribution on a Railway Network. *Transport Problems. 14*(3), 17–26. doi: 10.20858/tp.2019.14.3.2 (in English).

7. Król, M., Taczanowski, J., & Kołoś, A. (2018). The rise and fall of Interregio . Extensive open-access passenger rail competition in Poland. *Research in Transportation Economics*, *72*, 37–48. doi: 10.1016/j.retrec.2018.06.008 (in English).

8. Ma, Yi., Johnson, D., Wang, J. & Shi, Xianliang. (2020). Competition for rail transport services in duopoly market: Case study of China Railway(CR) Express in Chengdu and Chongqing. *Research in Transportation Business & Management*, *38*. 100529. doi: 10.1016/j.rtbm.2020.100529 (in English).

9. Xu, Guangming, Zhong, L. & Wu, R. & Hu, Xinlei & Guo, Jing. (2022). Optimize train capacity allocation for the high-speed railway mixed transportation of passenger and freight. *Computers & Industrial Engineering*, *174*, 108788. doi: 147. 10.1016/j.cie.2022.108788 (in English).

10. Butko, T., Prokhorov, V., Parkhomenko, L. & Prokopov, A. (2021). Improvement of Technology of Passenger Intermodal Transportation with Involvement of Railway Transport in the Conditions of Tourism Development. *Nauka ta prohres transportu* [*Science and Transport Progress*], *1*(91). 37–50. 10.15802/stp2021/228106 (in English).

11 Aloshynskiy, E. S., Prymachenko, G. O. (2018). Vprovadzhennia lohistychnykh pidkhodiv do analizu perspektyv rozvytku mizhnarodnykh pasazhyrskykh zaliznychnykh perevezen [Implementation of logistic approaches to the analysis of prospects for the development of international passenger rail transportation]. *European Journal of Intelligent Transportation Systems, 1*(1)*,* 30-35. doi: 10.31435/rsglobal_ejits/30112018/6221 (in Ukrainian).

12. Pomykala, A. & Engelhardt, J. (2022). Concepts of construction of high-speed rail in Poland in context to the European high-speed rail networks. *Socio-Economic Planning Sciences*, *85*. 101421. doi: 10.1016/j.seps.2022.101421 (in English).

13. Kurhan, D., Kurhan, M., & Hmelevska, N. (2022). Development of the High-Speed Running of Trains in Ukraine for Integration with the International Railway Network. *Acta Polytechnica Hungarica*, *19*. 207–218. doi: 10.12700/APH.19.3.2022.3.16 (in English).

14. Dong, X., Li, D., Yin, Y., Ding, S., & Cao, Z. (2020). Integrated optimization of train stop planning and timetabling for commuter railways with an extended adaptive large neighborhood search metaheuristic approach. *Transportation Research Part C: Emerging Technologies*, 117, 102681. doi: 10.1016/j.trc.2020.102681 (in English).

15. Prokhorov, V., Kalashnikova, T., Murakhovskyi, T., Lotysh, Yu., & Shabatura, V. (2019). Rozrobka matematychnoi modeli dlia optymizatsii planu formuvannia shvydkisnykh pasazhyrskykh poizdiv [Development of a mathematical model to optimize the train formation plan of high-speed passenger trains]. *Informatsiino-keruiuchi*

systemy na zaliznychnomu transporti [Information and control systems at railway transport], *24*(5). 19–23. doi: 10.18664/ikszt.v24i5.181287 (in Ukrainian).

16. Map of Peremyshl – Ustryky. Retrieved from: https://www.google.com/maps /d/u/0/viewer?mid=15WmRXhQ_4WLkhhM3Q-t-W-Ph-po&ll=49.607137683829094%2C22.904429200000028&z=10 (in English)

Received 20.01.2023; Accepted in revised form 22.03.2023.

ОРГАНІЗАЦІЯ ПАСАЖИРСЬКИХ ЗАЛІЗНИЧНИХ ПЕРЕВЕЗЕНЬ НА ДІЛЯНЦІ ЗІ СУМІЩЕНОЮ КОЛІЄЮ НИЖАНКОВИЧІ–СТАРЖАВА

Анотація. *Зазначено, що пасажирські перевезення залізничним транспортом є важливою складовою забезпечення транскордонного співробітництва України з сусідніми країнами ЄС. З обох сторін кордону проводяться перетворення на транспорті, розробляються і впроваджуються директиви для встановлення єдиних правил і стандартів успішного функціонування транспорту і переміщення пасажирів. Водночас вдосконалюється організація руху з врахуванням особливостей інфраструктури, а також зміни потоків перевезень, зокрема потоків пасажирів на прикордонних ділянках. Важливою відмінністю залізничної системи України від сусідніх країн ЄС є інша колія. Ширина колії з нашого боку кордону переважно становить 1520 мм і 1435 мм у країн ЄС. Це призводить до цілого ряду пов'язаних із цим особливостей залізничного транспорту. Крім того, відрізняються підходи до регулювання руху. Тому важливою на сьогодні є розробка підходів для управління наскрізними перевезеннями, зокрема, на тестових ділянках залізничної колії.*

Ця робота спрямована на вирішення однієї актуальної проблеми організації пасажирських перевезень на ділянках, що примикають до станції Хирів. На ділянці експлуатується як колія 1520 мм, так і суміщена колія 1520/1435 мм, що дає змогу організовувати рух із вагонами, розрахованими на відповідну ширину колії. З цією метою у роботі, враховуючи топологію дільниці з умовними відстанями і станціями як вершинами відповідного графа, побудовано математичну модель переміщення пасажирів із використанням поїздів на різних коліях – суміщеній колії між двома станціями на кордоні з Польщею (Нижанковичі–Старжава) та колії шириною 1520 мм (Самбір–Хирів). Зважаючи на особливості станцій, розглядаються можливі маршрути для вибору схеми формування поїздів, тобто маршрути між станціями формування і обертання поїздів.

У результаті дослідження побудовано графіки слідування пасажирських поїздів на прикордонних ділянках, що дає змогу визначити раціональну схему руху поїздів та їх обслуговування на станціях. Як приклад, проведено розрахунки для ділянки Нижанковичі–Старжава. Отримано, що для забезпечення заданого пасажиропотоку і організації руху на цій ділянці і прилеглих коліях потрібно ввести щонайменше три пасажирські поїзди. Побудована методика може бути використана також для інших прикордонних ділянок між станціями Польщі і України. Впровадження запропонованого міжнародного маршруту Держ Кордон–Нижанковичі–Хирів–Старжава–Держ Кордон колією 1435 мм допоможе нашим польським сусідам об'єднати два своїх воєводства за допомогою проходження їхнього рухомого складу через територію України. Це дає змогу скоротити пробіг рухомого складу і відстані між двома великими містами Польщі. Україні, своєю чергою, вигідно забезпечувати обслуговування перевезень та відкрити нові міжнародні пасажирські маршрути з подальшим впровадженням на тих самих ділянках колій маршрутів вантажних перевезень.

Ключові слова: *міжнародні пасажирські перевезення, організація руху пасажирських поїздів, транскордонне співробітництво, математична модель.*