Scientific Journal of Silesian University of Technology. Series Transport
Zeszyty Naukowe Politechniki Śląskiej. Seria Transport

Volume 120 **2023**

p-ISSN: 0209-3324

e-ISSN: 2450-1549

DOI: https://doi.org/10.20858/sjsutst.2023.120.7

Journal homepage: http://sjsutst.polsl.pl

Article citation information:
Kagramanian, A., Aulin, D., Trubchaninova, K., Caban, J., Voronin, A., Basov, A. Perspectives of multifunctional integrated suburban-urban rail transport development. *Scientific Journal of Silesian University of Technology. Series Transport*. 2023, **120**, 105-115. ISSN: 0209-3324. DOI: https://doi.org/10.20858/sjsutst.2023.120.7.

Artur KAGRAMANIAN[1], Dmitriy AULIN[2], Karyna TRUBCHANINOVA[3], Jacek CABAN[4], Anatoly VORONIN[5], Alexsandr BASOV[6]

PERSPECTIVES OF MULTIFUNCTIONAL INTEGRATED SUBURBAN-URBAN RAIL TRANSPORT DEVELOPMENT

Summary. Main requirements for rolling stock design and organization of the operating system are determined by membership in a certain transportation category for which such a transportation facility is designated. Thus, a specific feature of rolling stock operation is considered to the maximum extent, and functional correspondence with stated tasks is ensured. The significant disadvantage of the existing structure of rolling stock traffic is the necessity of time-space agreements of passenger traffic due to the necessity of shifting different transport types with the minimum time consumption. The solution to such an issue can be found in the development and use of a universal (multifunctional) integrated transport system. The list of issues arising during the creation of a multifunctional

[1] Ukrainian State University of Railway Transport, Feuerbach Square 7, 61000 Kharkov, Ukraine. Email: kartal2@ukr.net. ORCID: https://orcid.org/0000-0003-3520-4911
[2] Ukrainian State University of Railway Transport, Feuerbach Square 7, 61000 Kharkov, Ukraine. Email: dimmo@ex.ua. ORCID: https://orcid.org/0000-0002-7990-4808
[3] Ukrainian State University of Railway Transport, Feuerbach Square 7, 61000 Kharkov, Ukraine. Email: karyna.trubchaninova@kart.edu.ua. ORCID: https://orcid.org/0000-0003-2078-2647
[4] Faculty of Mechanical Engineering, Lublin University of Technology, Nadbystrzycka 36 Street, 20-618 Lublin, Poland. Email: j.caban@pollub.pl. ORCID: https://orcid.org/0000-0002-7546-8703
[5] Simon Kuznets Kharkov National University of Economics, Nauky Avenye 9A, 61166 Kharkov, Ukraine. Email: voronin61@ukr.net. ORCID: https://orcid.org 0000-0003-2570-0508
[6] Scientific Production Enterprise «TOR» Victory Avenue 71B, Kharkov, Ukraine. Email: tor.bs1960@gmail.com. ORCID: https://orcid.org/ 0000-0003-0848-628X.

transport system can be funnelled into two groups: social and economic and organizational and technical. The first group is social and economic and shall conceptually solve issues of the multifunctional system feasibility for certain urban settlement conditions (conglomerate of urban settlements). The second group consists of organizational and technical issues. This study proposes to eliminate certain material issues in the sphere of suburban and urban traffic by the infrastructure improvement with the significant traffic increase and fluctuations.

Keywords: infrastructure, passenger transportation, suburban transport, urban transport, multifunctional transport

1. INTRODUCTION

The transport sector is influenced by a wide range of external social and economic factors such as demographics, living standards of the population, urban planning, organization of production, structural changes in the society and accessibility to transport infrastructure [29]. In terrestrial transport, a significant traffic volume (over 40%) is carried out by rail transport. Historically, transportations depending on the route length and points between which they are carried out are divided into the following categories: urban, suburban, and intercity.

System failures in suburban and urban transport operations of industrial, scientific and educational centers result in a rapid increase in transportation time expenditures, material resource consumption, the number of road traffic incidents, and environmental degradation. In the literature, many scientific and research works have been devoted to these issues, for example: [9,10,16,20]. In particular, the issues of transport safety are presented in [17,30] and concerning the impact on the natural environment in [7,33] and operation costs and transportation quality [14,15]. Eventually, such circumstances will result in an increase in passenger transportation cost, decrease in their quality and reliability, a considerable degradation of living standards, and consequently, in a social strain escalation. A widely discussed problem is the quality of passenger transport [13,18] passenger's satisfaction [1], and public transport costs [27]. Passengers particularly welcome effective, fast and cheap transportation [5]. Transfer passengers, on the other hand, have practical problems when switching to long-distance transport [1].

The vehicle-to-urban population ratio continues to grow, provided that such a process proceeds at the same pace notwithstanding the size of a city. At the moment, many cities have exceeded the critical level of vehicle quantity per 1000 inhabitants. At the same time, the dynamics of vehicle-to-urban population ratio growth outruns the dynamic of roadway network development. These problems lead to the formation of the phenomenon of transport congestion, which is also widely discussed in the available literature, such as: [25]. The situation in Europe, in terms of the number of passenger cars per 1,000 inhabitants in 2020, is shown in Fig. 1. As shown in Fig. 1 the average number of passenger cars in the European Union per 1,000 inhabitants is 560.

Under such conditions, it is required to direct the joint efforts of industry specialists and central and regional governing bodies on the improvement of transport complex functioning. In other words, a systematic approach to the creation of new transport infrastructure and the organization of existing infrastructure operations is required [3]. The good economic situation and living standards are also reflected positively in the increasing demand for services in passenger and freight rail transport [11]. The aim of this study is to identify and eliminate some significant problems in the area of suburban and urban traffic by improving infrastructure with significant growth and fluctuations in traffic.

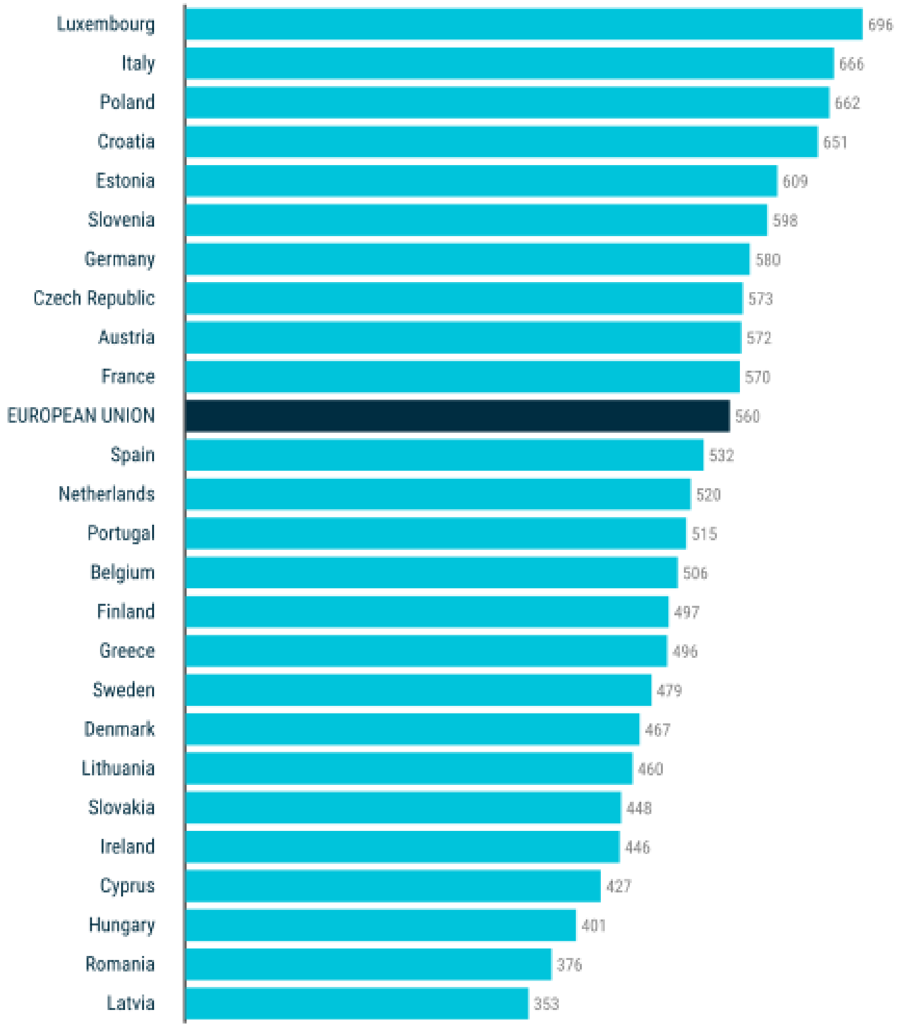

Fig. 1. The number of passenger cars per 1,000 inhabitants in 2020 in UE [21]

2. ANALYSIS

The purpose of the transport system functioning is to provide a downtown transport accessibility for suburban residents [31]. In addition, it is required to reduce the number of vehicles on the roads, which has been signalled by many researchers [24,28,32]. An essential fault of existing traffic structure (including rail transport) is the necessity of passenger traffic space-time adjustment driven by the availability of different transport changings during the movement from an initial point to a point of destination wit in no time [23].

The traditional passenger traffic flow diagram considering the required changings of suburban and urban transport is shown in Fig. 2.

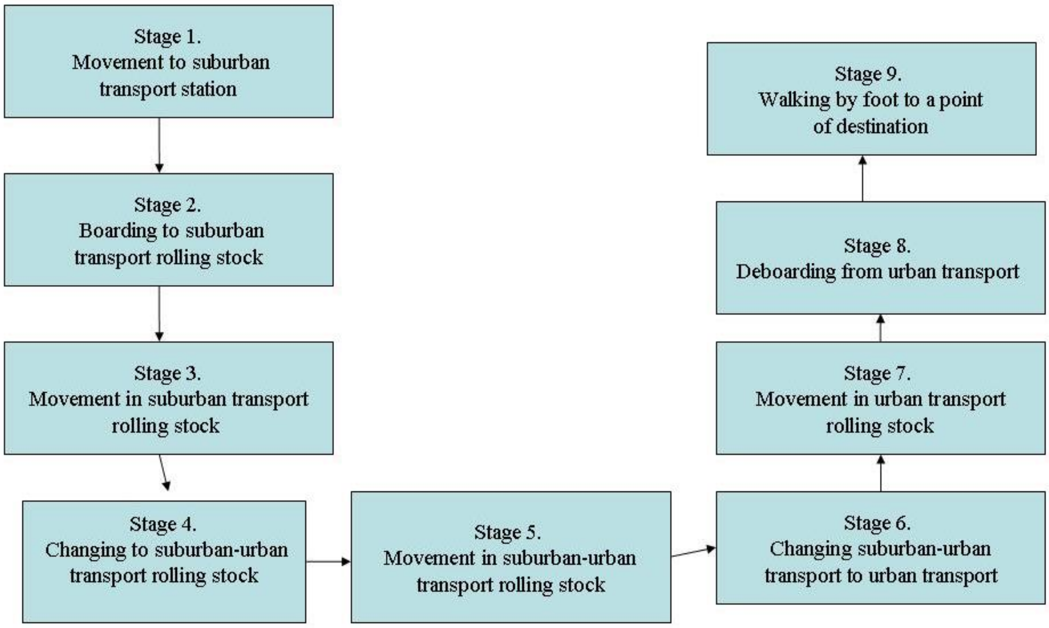

Fig. 2. Suburban and urban transport passenger traffic flow

3. PURPOSE AND THE TASKS OF THE RESEARCH

In the cargo transportation organization, the door-to-door delivery was developed, and allows minimizing labour and time expenditures on transhipments during delivery to a final receiver [2,32]. In the last years, new technological solution has also found use in the passenger transportation system; light rail transits were developed and put into operation [6,8,19] which partly erased the issue of interim changings. The principle of passenger traffic organization eliminating interim changings during transportation from an initial point to a point of destination is offered to be included into the innovative passenger transport system. Application of new technologies for transport is one of the ways to improve transportation [4,22]. Table 1 shows examples of data for passenger transport in 2018-2020 from Poland. As you can see, the share of transport in this period has been increasing; unfortunately, the last year has slightly disturbed the general trend due to the COVID-19 pandemic.

Tab. 1

Sample data from Poland regarding rail passenger transport [26]

	2020	2019	2018	change 2020/2019 [%]	change 2019/2018 [%]
Number of passengers [mln]	209.15	335.90	310,28	-37.73	8.26
Transport performance [mln pass-km]	12 654.31	22065.20	21047.33	-42.65	4.84
Operating performance [mln train-km]	160.21	170.97	165.60	-6.29	3.24

The passenger transportation system in a city-suburban zone is the most wide-spread, regular and socially desirable; its optimal organization is the most complicated. Decisive factors in the passenger traffic development within the questioned transportation mode are motor transport (a bus) and suburban railway transport. As the volume and share of urban public passenger transport, including a bus, in the result of vehicle-to-urban population ratio growth decreases in the general passenger traffic, the quality of urban population transport services degrades. Traffic jams on street-roadway networks have become regular and persistent. In order to improve the public transport role, it is required to increase the quality of services rendered, and ensure a high level of passenger servicing.

In the scope of surface transportation, the significant share (over 40%) is accounted for by the rail transport. It is caused by the following factors:

- Minimum weather performance influence (nearly all-weather capability);
- High average speed of transportation;
- Comfortableness;
- Reliability and corresponding low crush rate;
- High passenger capacity of rolling stock.

All surface transportation (including rail transport) historically was divided depending on the route distance into the following categories:

- Urban;
- Suburban;
- Interurban.

The advantage of rail transport in comparison with other public transport is its remarkable traffic-carrying capacity. Among other rail transport modes, the electric street railway remains unchallenged in terms of the ones required for infrastructure deployment. The urban space is a limited resource, and the railway uses it to its maximum effect. An electrical train, along with passenger transportation, releases the roadway network load providing comfortable movement for people who use personal transport.

The main requirements for rolling stock design and organization of the operating system are determined by the membership in a certain transportation category that is carried out by such a transportation facility. Thus, a specific feature of rolling stock operation is considered to the maximum extent, and the functional correspondence with stated tasks is ensured.

The main, fundamental issue is the development of objective, make-or-break considerations. Traditionally, travel time, value and safety are used as such factors in transport logistics.

The solution, in the authors' opinion, can be the development and implementation of universal (multi-functional) rail transport combining features of suburban and urban rolling stock, providing the possibility of transportation by railways and public rail electric transport lines.

Thus, it is prospective to consider transport system concepts eliminating interim changing as: "Tram-Suburban Train", "Light Rail Transit-Suburban Train", "Underground-Suburban Train".

4. THE RESEARCH RESULTS

The passenger traffic flow diagram using multi-functional integrated suburban and urban transport is shown on Fig. 3.

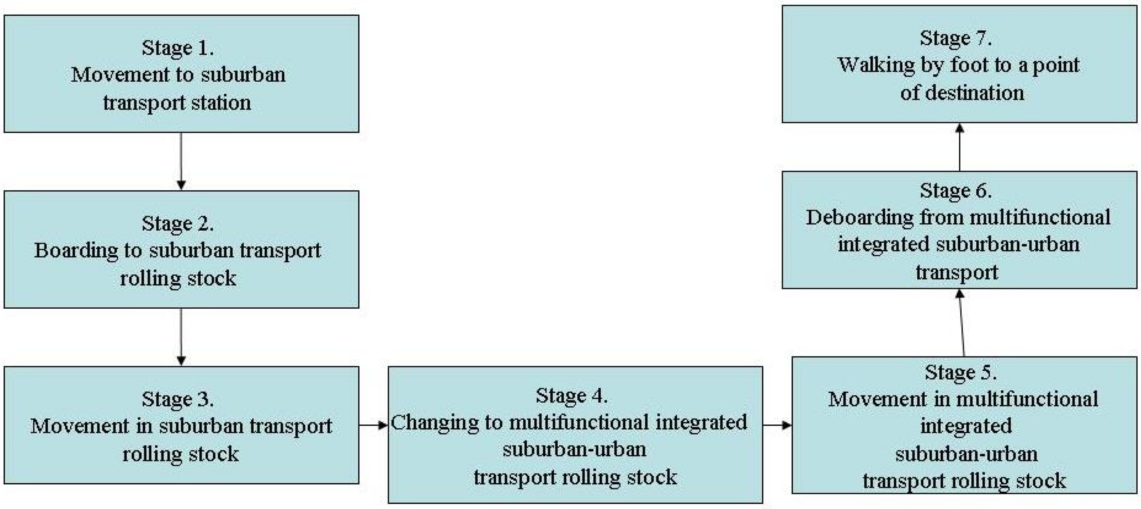

Fig. 3. Passenger traffic flow diagram using multi-functional integrated suburban and urban transport

The range of issues arising in solving the multifunctional transport system creation task can be combined into two groups.

The first group is social and economic; it conceptually solves issues of multi-functional system applicability under the conditions of a certain urban settlement (conglomerate):

- Availability of persistent and intensive passenger traffic;
- Project implementation cost-effectiveness analysis.

The second group of organizational and technical issues foresees:

- Development of criteria for justified selection of multi-functional transport structures (suburban transport-tram; suburban transport-light rail transit; suburban transport-underground) in accordance with the certain structure;
- Solution of technical issues with respect to the creation of a multi-functional transport facility with its present structure and its adaptation to operating conditions.

The topical issue of the passenger traffic development task is the optimal selection of transport modes. The task foresees the availability of certain preferences based on which the optimum shall be determined. Factors affecting the preference can be, for example, travel time, value, safety, etc.

For qualitative forecasting of two transport mode interactions, it is reasonable to simulate the process.

The paper authors take as an example the known dynamic model of transportation offered by Deneubourg et al. [12]. The model action mechanism foresees the equality of the pair "point of departure-point of destination" between the transportation scope D is implemented upon two different available transport modes. It is supposed that x_i is a number of transportations of i (i = 1,2). The dynamics of transport preference are described by a system of two differential equations:

$$\frac{dx_i}{dt_{\mathrm{i}}} = D_i - x_i, i=1,2 \tag{1}$$

Subject to this balanced proviso: $x_1 + x_2 = D$.

If the so-called preference function is entered for each i as $A_i(x_i)$, then in the case of $D_i(x_1, x_2)$ it will have the following representation:

$$D_i(x_1, x_2) = \frac{D \cdot A_i(x_i)}{A_1(x_1) + A_2(x_2)} \quad i=1,2 \tag{2}$$

It is quite evident that the clear dynamic behaviour of system (1) is determined by the certain type of analytical functions $A_i(x_i)$. The mentioned authors assume a simplified situation under which the preference $A_i(x_i)$ equals V_i - an average transportation of i. It is also assumed that there is no interaction between transport modes. It should be noted that Deneubourg et al. [12] to be specific, indicated that x_1 and x_2 are the numbers of motor and railway transportations accordingly. Such assumptions played a pivotal role initially for qualitative description, and further for quantitative description of radically different preference functions $A_1(x_1)$ and $A_2(x_2)$. Provided that the explicit form of such functions has analogues in mathematical biophysics, as Deneubourg is a famous scientist in this sphere.

Further, it will not clarify the explicit form of $A_1(x_1)$ and $A_2(x_2)$ in order to preserve some generality of system behavioural properties (1) taking into account (2) represented in the form of:

$$\begin{cases} \dot{x}_1 = \dfrac{D \cdot A_1(x_1)}{A_1(x_1) + A_2(x_2)} - x_1; \\ \dot{x}_2 = \dfrac{D \cdot A_2(x_2)}{A_1(x_1) + A_2(x_2)} - x_2. \end{cases} \tag{3}$$

The system (3) is able to have several states of equilibrium determined by the following conditions:

$$x_1 + x_2 = D, \; x_2 A_1(x_1) = x_1 A_2(x_2) \tag{4}$$

It is assumed that the system of two algebraic equations (4) has solutions x_1^*, x_2^*.

In order to analyse the dynamic system (3) stability in the small neighbourhood of the state of equilibrium x_1^*, x_2^* a matrix B of linear part shall be composed (3):

$$B = \begin{pmatrix} q_1 - 1 & q_1 \\ q_2 & q_2 - 1 \end{pmatrix} \tag{5}$$

where, $q_1 = \dfrac{DA_1'(x_1^*) \cdot A_2(x_2^*)}{\left(A_1(x_1^*) + A_2(x_2^*)\right)^2}$, $q_2 = \dfrac{DA_1(x_1^*) \cdot A_2'(x_2^*)}{\left(A_1(x_1^*) + A_2(x_2^*)\right)^2}$

where, q_1, q_2 is a corresponding elasticity of preference functions.

Values $A'_1(x_1^*)$ and $A'_2(x_2^*)$ are derivatives of the preference function in the state of equilibrium. The matrix B has a characteristic equation for eigenvalues:

$$\lambda^2 + (2-q)\cdot\lambda + 1 - q = 0 \qquad (6)$$
$$q = q_1 + q_2$$

It is evident that the solution (6) is $\lambda_1 = q - 1$, $\lambda_2 = -1$. It means that in the case of $q < 1$ the equilibrium is a stable node, and if $q > 1$ there is a saddle, i.e. unstable equilibrium. The parameter $q = 1$ is a bifurcation as the stability type change carries out catastrophically. The catastrophe type is "fold".

The parameter $q = q_1 + q_2$ can be meaningfully interpreted as an overall elasticity of preference functions by number of transportations by corresponding transport mode. For the general preference function, the corresponding aperiodic type of dynamic behaviour is determined. Considering this, it is reasonable to carry out qualitative forecasting (in paths) for transport mode preference system dynamics.

The offered mathematical model is designated for passenger traffic equilibrium stability problem analysis. The above material is a formalization of possible alternatives to conventional concepts of transport infrastructure development paths in suburban-urban traffic.

5. CONCLUSIONS

This paper includes the summary of historically developed systems of passenger traffic services in suburban-urban traffic, and a list of transport issues caused by the corresponding evolutionary trends in this sphere. The alternative approach solving issues arising in the transport infrastructure – the multi-functional integrated rail transport was offered. The perspective development options of the offered transport system were reviewed. A comparative analysis of the existing classic transport system and passenger transportation by the multi-functional integrated rail transport was carried out.

The transport model describing the dynamics of transport mode selection for certain number of transportations was studied. States of equilibrium for the equation system representing the model were found, and their stability for forecasting purposes and transportation management was studied. The offered mathematical model is designed to analyse the problem of passenger traffic balance stability. The model stability ranges were determined, which means that in the case of $q < 1$ the equilibrium is a stable node, and if $q > 1$ we obtain a saddle, i.e., unstable equilibrium. On the other hand, when the parameter $q = 1$ is a bifurcation, because changing the type of stability is catastrophic.

The solution of the studied improvements for urban transport issues will allow ensuring the necessary conditions for passenger transportation security gains, effective use of all transport resources, an increase in urban territories utilization degree and improvement in living standards.

References

1. Abramović Borna. 2017. „Passenger's Satisfaction on Long Distance Terminals: Case Study City of Zagreb". *Periodica Polytechnica Transportation Engineering* 45(1): 42-47. ISSN: 1587-3811. DOI: 10.3311/PPtr.9197.

2. Behnam Tahmasbi, Hossein Haghshenas. 2019. „Public transport accessibility measure based on weighted door to door travel time”. *Computers, Environment and Urban Systems* 76: 163-177. ISSN: 0198-9715. DOI: 10.1016/j.compenvurbsys.2019.05.002.
3. Bobylev Nikolai. 2010. „Underground space in the Alexanderplatz area, Berlin: Research into the quantification of urban underground space use”. *Tunneling and Underground Space Technology* 25(5): 495-507. ISSN: 0886-7798, DOI: 10.1016/j.tust.2010.02.013.
4. Brumercik Frantisek, Roman Danko. 2014. „Transport application of hybrid simulation”. *Communications - Scientific Letters of the University of Žilina* 16(2): 20-24. ISSN: 1335-4205.
5. Brumercik Frantisek, Michal Lukac, Zbigniew Krzysiak, Leszek Krzywonos. 2017. „Model of integrated transportation system”. *Communications - Scientific Letters of the University of Žilina* 19: 23-26. ISSN: 1335-4205, DOI: 10.26552/com.C.2017.2.23-26.
6. Chen Yao, Kun An. 2021. „Integrated optimization of bus bridging routes and timetables for rail disruptions”. *European Journal of Operational Research* 295(2): 484-498. ISSN: 0377-2217, DOI: 10.1016/j.ejor.2021.03.014.
7. Ciziuniene Kristina, Bureika Gintautas, Jonas Matijosius. 2022. „Challenges for intermodal transport in the Twenty-First Century: reduction of environmental impact due the integration of green transport modes”. *Studies in Systems, Decision and Control* 400: 307-354. ISSN: 2198-4182, DOI: 10.1007/978-3-030-87120-8_6.
8. Claire Schuch, Isabelle Nilsson. 2022. „Rail Transit, for Who? Perceptions and factors influencing light rail ridership in Charlotte, NC”. *Travel Behaviour and Society* 27: 38-46. ISSN: 2214-367X, DOI: 10.1016/j.tbs.2021.06.001.
9. Czech Piotr. 2017. „Physically disabled pedestrians - road users in terms of road accidents”. Advances in Intelligent Systems and Computing 505: 33-44. DOI: 10.1007/978-3-319-43991-4_4. Springer, Cham. ISBN: 978-3-319-43990-7; 978-3-319-43991-4. ISSN: 2194-5357. In: Sierpinski Grzegorz (eds), Intelligent transport systems and travel behaviour, 13th Scientific and Technical Conference „Transport Systems Theory and Practice”, Katowice, Poland, September 19-21, 2016.
10. Czech Piotr. 2017. „Underage pedestrian road users in terms of road accidents”. Advances in Intelligent Systems and Computing 505: 33-44. DOI: 10.1007/978-3-319-43991-4_4. Springer, Cham. ISBN: 978-3-319-43990-7; 978-3-319-43991-4. ISSN: 2194-5357. In: Sierpinski Grzegorz (eds), Intelligent transport systems and travel behaviour, 13th Scientific and Technical Conference „Transport Systems Theory and Practice”, Katowice, Poland, September 19-21, 2016.
11. Danis Jozef, Anna Dolinayova, Lenka Cerna, Vladislav Zitricky. 2019. „Impact of the Economic Situation in the Slovak Republic on Performances of Railway Transport”. *Periodica Polytechnica Transportation Engineering* 47(2): 118-23. ISSN: 1587-3811. DOI: 10.3311/PPtr.11185.
12. Denebnorg Jean-Louis, Andre de Palma, David Ali Kahn. 1979. „Dynamic Models of Competition Between Transportation Modes”. *Environment and Planning A: Economy and Space* 11(6): 656-673. DOI: 10.1068/a110665.
13. Dižo Ján, Miroslav Blatnický, Juraj Gerlici, Bohuš Leitner, Rafał Melnik, Stanislav Semenov, Evgeny Mikhailov, Mariusz Kostrzewski. 2021. „Evaluation of Ride Comfort in a Railway Passenger Car Depending on a Change of Suspension Parameters”. *Sensors* 21(23): 8138. ISSN: 1424-8220, DOI: 10.3390/s21238138.
14. Droździel Paweł, Henryk Komsta, Leszek Krzywonos. 2012. „An analysis of costs of vehicle repairs in a transportation company. Part II”. *Transport Problems* 7: 5-11. ISSN: 1896-0596.

15. Figlus Tomasz, Tomasz Czachor. 2018. „Preliminary studies of the effect of travelling speed and propulsion type on the sound level in the passenger compartment of a vehicle with a hybrid propulsion system”. In: *11th International Science and Technical Conference Automotive Safety*: 1-5. 18-20 April 2018, Casta, Slovakia. ISBN: 978-1-5386-4579-6. DOI: 10.1109/AUTOSAFE.2018.8373346.
16. Gerhátová Zuzana, Vladislav Zitrický, Vladimir Klapita. 2021. „Analysis of customs processing of wagon consignment at Slovakia-Ukraine border”. *LOGI - Scientific Journal on Transport and Logistics* 12(1): 58-66. ISSN: 2336-3037, DOI: https://doi.org/10.2478/logi-2021-0006.
17. Hlavatý Jozef, Jan Ližbetin. 2021. „Innovation in rail passenger transport as a basis for the safety of public passenger transport”. *Transportation Research Procedia* 53: 98-105. ISSN: 2352-1465, DOI: 10.1016/j.trpro.2021.02.013.
18. Hurtova Ivana, Marie Sejkorova, Jan Verner, Michal Kucera. 2018. „Preference and area coordination of public transport in modern city”. *Engineering for Rural Development* 17: 2085-2091. DOI: 10.22616/ERDev2018.17.N345.
19. Malichová Eva, Yannick Cornet, Martin Hudák. 2022. „Travellers’ use and perception of travel time in long-distance trips in Europe”. *Travel Behaviour and Society* 27: 95-106. ISSN: 2214-367X, DOI: 10.1016/j.tbs.2021.12.003.
20. Mikhailov Evgeny, Stanislav Semenov, Hanna Shvornikova, Juraj Gerlici, Maxim Kovtanets, Ján Dižo, Miroslav Blatnický, Jozef Harušinec. 2021. „A Study of Improving Running Safety of a Railway Wagon with an Independently Rotating Wheel’s Flange”. *Symmetry* 13(10): 1955. ISSN: 2073-8994, DOI: 10.3390/sym13101955.
21. „Motorisation rates in the EU, by country and vehicle type”. 2 Apr. 2020. Available at: https://www.acea.auto/figure/motorisation-rates-in-the-eu-by-country-and-vehicle-type/.
22. Polak Rafał, Dariusz Laskowski, Robert Matyszkiel, Piotr Łubkowski, Łukasz Konieczny, Rafał Burdzik. 2020. „Optimizing the Data Flow in a Network Communication Between Railway Nodes”. *Advances in Intelligent Systems and Computing* 1032: 351-362. ISBN: 978-3-030-27686-7. DOI: 10.1007/978-3-030-27687-4_35.
23. „Project Grand Paris Express”. Available at: https://undergroundexpert.info/opyt-podzemnogo-stroitelstva/stroyashhiesya-obekty/proekt-grand-pari-ekspress/.
24. Rusca Florin, Aura Rusca, Eugen Rosca, Mircea Rosca, Oana Dinu, Florian Ghionea. 2019. „Algoritm for traffic allocation when are developed park and ride facilities”. *Procedia Manufacturing* 32: 936-943. ISSN: 2351-9789. DOI: 10.1016/j.promfg.2019.02.306.
25. Sommerauerova Dana, Jan Chocholac, Klara Urbanova. 2020. „Sustainable green city logistic solution for the Prague agglomeration and retail chain”. *Perner’s Contacts* 15(2). ISSN: 1801-674X, DOI: 10.46585/pernerscontacts.2020.15.1644.
26. „Statystyka przewozów pasażerskich”. Available at: https://utk.gov.pl/pl/raporty-i-analizy/analizy-i-monitoring/statystyka-przewozow-pa.
27. Stopka Ondrej, Vladimir Ľupták, Iwona Rybicka. 2021. „Proposal of specific measures in the context of streamlining operating costs in a selected company”. *Transport Problems* 16(4): 121-134. ISSN: 1896-0596. DOI: 10.21307/tp-2021-065.
28. Turoń Katarzyna, Piotr Czech, Michał Juzek, Grzegorz Wojnar, Paweł Słowiński, Rafał Burdzik. 2017. „Supplier audit as a tool for sustainable supply chains”. In: *Transport Means 2017 - Proceedings of the 21st International Scientific Conference,* 2017, 20-22 September 2017, Juodkrante, Lithuania.

29. Veternik Milan, Marian Gogola. 2017. „Examining of correlation between demographic development of population and their travel behaviour". *Procedia Engineering* 192: 929-934. ISSN: 1877-7058. DOI: 10.1016/j.proeng.2017.06.160.
30. Vlkovský Martin, Petr Veselík. 2020. „Cargo securing - Comparison of the selected trucks". *Transport Problems* 15: 265-274. ISSN: 1896-0596. DOI: 10.21307/TP-2020-065.
31. Zhi Zhang, Wenwu Tang, Jian Gong, Ji'e Huan. 2017. „Property rights of urban underground space in China: A public good perspective. *Land Use Policy* 65: 224-237. ISSN: 0264-8377. DOI: 10.1016/j.landusepol.2017.03.035.
32. Zhihong Huang, Weilai Huang, Fang Guo. 2019. „Integrated sustainable planning of self-pickup and door-to-door delivery service with multi-type stations". *Computers & Industrial Engineering* 135: 412-425. ISSN: 0360-8352. DOI: https://doi.org/10.1016/j.cie.2019.06.022.
33. Zvolenský Peter, Dalibor Barta, Juraj Grenčík, Paweł Droździel, Ľubomir Kašiar. 2021. „Improved method of processing the output parameters of the diesel locomotive engine for more efficient maintenance". *Eksploatacja i Niezawodnosc – Maintenance and Reliability* 23(2): 315-323. ISSN: 1507-2711. DOI: 10.17531/ein.2021.2.11.

Received 10.01.2023; accepted in revised form 28.03.2023