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## **ANALYSIS OF CHANGES IN TRANSPORT PROCESSES IN WARSAW PUBLIC TRANSPORT IN THE FACE OF DISRUPTIONS IN 2019-2022**

**Summary.** Public transport focuses on meeting the transport needs of people both within the city and in the suburban area. Passenger transport is a key element of sustainable development and improving the quality of life in agglomerations because it provides mobility for residents and tourists. In recent years, residents have become increasingly willing to use public transport. However, this trend was disrupted as a result of global changes taking place in the years 2019 - 2022. The aim of this publication was to analyse and assess the impact of crisis situations on the implementation of transport processes using the example of public transport in Warsaw. It has been shown that events such as the COVID-19 pandemic or the war in Ukraine also had a significant impact on the functioning of transport processes in Warsaw public transport. The study made it possible to identify recommendations aimed at securing the operation of public transport in the event of similar threats in the future.

**Keywords:** public transport, passenger transport, transport processes, urban transport system, transport needs, COVID-19 pandemic impact

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## 1. INTRODUCTION

Public urban transport ensures the mobility of people, bringing many benefits, both at the level of the individual and the entire society [1]. It is a key element of sustainable development and improvement of the quality of life in large urban agglomerations [2]. Events in recent years show that, apart from the development of urban transport, the resilience and stability of transport processes when exposed to disruptions, especially global ones, play an important role in assessing its quality [3, 4]. In December 2019, the first infection with the SARS-CoV-2 virus was reported in China, and it soon spread around the world, causing the COVID-19 pandemic [5]. This event dramatically changed the perception of public transport, which was then identified as the main vector of the spread of infection in densely populated areas, which in turn led to a decline in the interest in public transport [6]. Another event with serious consequences was Russia's invasion of Ukrainian territories in February 2022, which started the war. The consequence of this was the migration of the Ukrainian population to other countries in search of their safety, protection, and help [7]. This event had an impact on public transport in many Polish cities, including Warsaw. Taking into account the indicated events and the fluctuations related to them, the scientific goal of the research was to analyse and evaluate the impact of crisis situations on the implementation of transport processes using the example of public transport in Warsaw. For this purpose, the following hypothesis was formulated: "global threats from 2019 to 2022 had a significant impact on the implementation of transport processes in Warsaw public transport, causing changes in transport needs". As a result, areas requiring improvement were defined and recommendations were made to protect public transport in the event of similar threats in the future.

## 2. LITERATURE REVIEW

The impact of global threats on the functioning of public transport is widely discussed in the literature [8]. In the context of epidemic disruptions, there is a need to adjust restrictions to the actual level of risk, emphasizing that the implemented solutions will not always meet the expectations of users and the prevailing situation [9]. Research related to the impact of restrictions on the functioning of society showed a much lower level of mobility during the period of increased restrictions [10]. Other studies show that passengers were relatively relaxed about vehicle occupancy restrictions and often did not respect social distancing [11]. It has also been shown that there is a negative relationship between passenger traffic in public transport and the number of new COVID-19 cases [12]. Moreover, it was shown that as the number of new infections decreased, the use of public transport began to increase, which indicates that the demand for transport largely depends on the sense of security of passengers and the reliability and readiness of the transport means themselves [13, 14]. An analysis of changes in the daily mobility of Warsaw residents showed that passenger traffic weakened as the pandemic escalated and subsequent restrictions were introduced [15]. The outbreak of the pandemic also resulted in a change in preferences and travel patterns [16]. Moreover, it was shown that the lower use of public transport during the pandemic was related to changes in the structure of tickets purchased [17]. The publications also detail solutions and directions of the development of Warsaw public transport, emphasizing that global threats can be used as an opportunity to remodel selected areas of public transport in accordance, among the others with the concept of "smart mobility" [18, 19]. The literature review allowed us to assume that there is a research

gap in the area of analysis and assessment of processes taking place in urban public transport in Warsaw in the light of global disruptions in 2019 - 2022.

### 3. MATERIALS AND METHODS

The publication presents the results of the analysis and evaluation of the impact of global threats on the implementation of transport processes described using quantitative indicators, such as transport performance and the number of passengers transported, as well as changes in transport needs in terms of the number and structure of tickets sold. The case study for the research was the city of Warsaw (the capital of Poland) together with the neighbouring towns that together form the Warsaw agglomeration. The source materials for the research were obtained from the statistics of the Warsaw City Hall Office and the Public Transport Authority in Warsaw (ZTM) [20, 21]. The data collected was divided into periods: pre-pandemic, pandemic and since the outbreak of the war in Ukraine, which were subjected to exponential smoothing using the Brown or Holt method, depending on the characteristics of a given time series [22, 23]. According to Brown's method, the following equation was used for the first time moment  $t=1$ :

$$Y_1^* = \frac{Y_1 + Y_2 + Y_3}{3} \quad (1)$$

For the subsequent time moments, the following relationship was used:

$$Y_t^* = \alpha Y_{t-1} + (1 - \alpha) Y_{t-1}^* \quad (2)$$

where:  $Y_t^*$  - forecast value for the moment  $t$ ;  $Y_{t-1}$  - actual value for the moment  $t-1$ ;  
 $\alpha$  - exponential smoothing level coefficient,  $\alpha \in (0; 1)$ .

In turn, smoothing models using the Holt method were built in such a way that for the time moment  $t > n$ :

$$Y_t^* = F_n + (t - n) S_n \quad (3)$$

where:  $Y_t^*$  - forecast value for the moment  $t$ ;  $F_n$  - smoothed value of the forecast variable at the moment  $n$ ;  $S_n$  - assessment of trend growth at the moment  $n$ ;  $n$  - number of elements in the time series.

Taking into account that:

$$F_1 = Y_1 \quad (4)$$

$$F_{t-1} = \alpha Y_{t-1} + (1 - \alpha)(F_{t-2} + S_{t-2}) \quad (5)$$

$$S_1 = Y_2 - Y_1 \quad (6)$$

$$S_{t-1} = \beta(F_{t-1} - F_{t-2}) + (1 - \beta)S_{t-2} \quad (7)$$

where:  $F_{t-1}$  – smoothed value of the forecast variable at the moment  $t-1$ ;  $S_{t-1}$  – smoothed value of the trend increase at the moment  $t-1$ ;  $\alpha$  – exponential smoothing level coefficient,  $\alpha \in (0; 1)$ ;  $\beta$  – trend smoothing level coefficient,  $\beta \in (0; 1)$ .

In both methods, the parameters  $\alpha$ ,  $\beta$  were selected as to achieve a high fitting of the model with a real data by minimizing the mean absolute percentage error (MAPE) and the root mean squared error (RMSE) [24]:

$$MAPE = \frac{1}{n} \sum_{t=1}^n \left| \frac{Y_t - Y_t^*}{Y_t} \right| * 100 \quad [\%] \quad (8)$$

$$RMSE = \sqrt{\sum_{t=1}^n \frac{(Y_t^* - Y_t)^2}{n}} \quad (9)$$

Then, linear regression was determined for the exponential smoothed models:

$$Y_t = aX_t + b \quad (10)$$

where:  $Y_t$  – value of the dependent variable at the moment  $t$ ;  $X_t$  – value of the independent variable (predictor) at the moment  $t$ ;  $a$  – regression coefficient (slope);  $b$  – intercept.

Fitting of the regression model was evaluated using the  $R^2$  determination coefficient:

$$R^2 = \frac{\sum_{t=1}^n (Y_t - \bar{Y})(Y_t^* - \bar{Y})}{\sum_{t=1}^n (Y_t - \bar{Y})^2} \quad (11)$$

Consequently, by determining the parameters of the linear mathematical model, the changes taking place in the implementation of transport processes were analysed and evaluated.

#### 4. THEORETICAL BACKGROUND

Public transport in the Warsaw agglomeration is a transport system composed of bus and rail means of transport, which vary in terms of the number of passengers served and the transport performance (Table 1) [21].

Tab. 1  
Number of passengers transported and transport performance by individual means of transport in Warsaw public transport in 2022

Means of transport	Number of passengers		Transport performance	
	[mil]	[%]	[mil VKT]	[%]
Buses (MZA and other operators)	403,03	46,7	119,81	44,71
Warsaw Trams (TW)	247,22	28,6	51,26	19,1
The Warsaw Metro (MW)	160,82	18,6	44,47	16,6
Masovian Railways (KM)	30,96	3,6	34,18	12,8
Fast City Railway (SKM)	17,76	2,0	16,03	6,0
Warsaw Commuter Railway (WKD)	3,66	0,4	2,24	0,8

The metropolitan authorities are taking steps to develop sustainable transport, including the integration of public transport services in terms of tariffs, tickets, transfers, and timetables. Much attention is paid to reducing exhaust emissions and noise levels, regularly replacing old vehicles with new ones. Actions are also taken to reduce traffic congestion by providing more convenient conditions for travelling by public transport [20]. The outbreak of the COVID-19 pandemic led to a different functioning of public transport due to the imposition of limits on the number of passengers transported in the individual means of transport. The restrictions introduced significantly limited transport possibilities, leading to a discrepancy between demand and supply for transport. On the other hand, society's fears of contracting the virus reduced the number of travellers, which caused some vehicles to operate with minimal occupancy [12, 16]. Another global threat affecting Warsaw public transport was the Russian invasion of Ukraine on February 26, 2022. The huge influx of immigrants translated into greater passenger traffic in many Polish cities, which in support, provided among the others, free travel on public transport [7]. Taking into account the population growth in Warsaw caused by the influx of refugees and, therefore, the increased demand for passenger transport, it is noted that this may be an opportunity to reduce losses caused by the COVID-19 pandemic.

## 5. RESULTS AND DISCUSSION

### 5.1. Tickets sold

Demand for transport services can be expressed by the number of tickets sold for public transport in a given area. It is an indicator used to analyse the popularity and availability of public transport, and changes in travellers' preferences, as well as to assess the functioning of the urban transport system. Data on the number of tickets sold is crucial for transport organizers and operators because based on sales results, decisions are made regarding applicable ticket offers, routes served, and even planning the development of the transport network.

Analysing data on the structure of ticket sales in the years 2018 - 2022, it can be concluded that the greatest popularity concerned 20-minute time tickets, because on average 3.6 million of them were sold per month. In second place were time tickets (75 or 90 minutes) with average sales of PLN 2.69 million per month. Significantly fewer people bought long-term tickets, on average 352.9 thousand a month. Passengers were the least likely to decide to purchase short-term tickets because the average sale was 161.9 thousand a month. Changes in the structure of tickets sold were seasonal, depending on a specific month of the year. The highest results were usually recorded in October, due to the return to educational institutions and workplaces after the holiday period. The lowest sales occurred in the winter months, which may have resulted from the more frequent use of own means of transport due to weather conditions, as well as from reduced mobility due to the Christmas break or holidays. There were also differences in the structure of tickets sold over the years. An example of this is in 2020, when the outbreak of the COVID-19 pandemic led, among the others, to the reduction of the activity and mobility of society due to the applicable restrictions and the so-called lockdown. The consequence of this were changes in transport needs, which are reflected in the structure of tickets sold in March-June 2020, as the share of short- and long-term tickets decreased. The increase in ticket sales has been noticeable only since March 2022, which is not only related to the end of the epidemic crisis but is also the result of demographic changes in the Warsaw agglomeration due to the influx of Ukrainian immigrants (Fig. 1) [7].

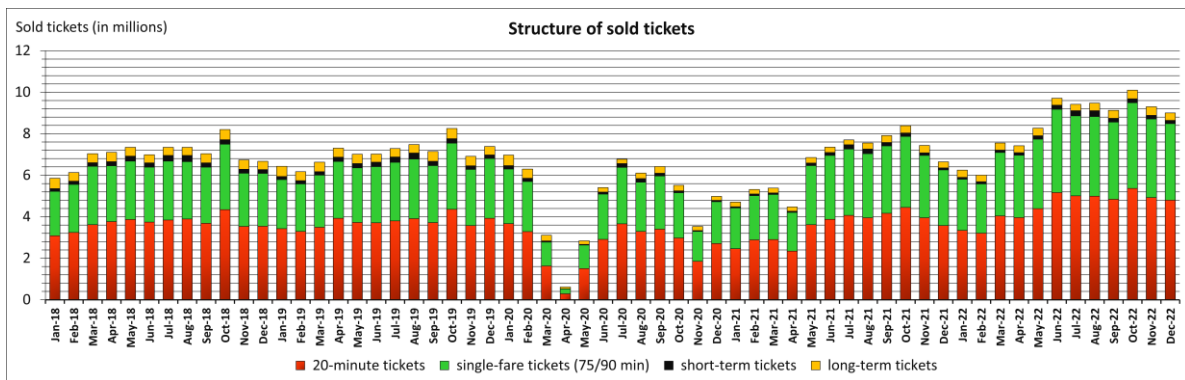


Fig. 1. Quantitative structure of tickets sold on Warsaw public transport

Then, a study was conducted on the changes in the total number of tickets sold. These sales amounted to: in 2018 - 6.98 million, in 2019 - 7.08 million, in 2020 - 4.88 million, in 2021 - 6.64 million, in 2022 - 8.47 million. Such high results translate into average annual sales of 6.81 million tickets. It is worth paying attention to the results from 2020 and 2022. They show the highest deviations from the arithmetic mean, which indicates the disruptions occurring at that time. The study showed that before the outbreak of the COVID-19 pandemic, there was an increasing trend in ticket sales by 29.86 thousand per month (Fig. 2a). Since the outbreak of the epidemic threat, the rate of change has increased significantly - to 196.49 thousand (Fig. 2b). In turn, in the period since the outbreak of the conflict in Ukraine, the largest increase in sales occurred - by 315.72 thousand per month (Fig. 2c). Therefore, in the years 2018 - 2022, the total number of tickets sold in Warsaw public transport showed an upward trend, with the pace of change varying depending on the specific period. Moreover, paying attention to the actual values in individual months and the characteristics of the models built, it can be concluded that the overall ticket sales depended on the crisis events considered. In terms of the COVID-19 pandemic, this is confirmed by the first months after the virus appeared in Poland, i.e. March and April 2020 (Fig. 2b). The impact of the war and the related influx of immigrants is shown in the period from February to July 2022 (Fig. 2c).

Table 2 presents the parameters of the exponential smoothing models of the total number of tickets sold, along with prediction errors. Parameters and determination coefficients for the established linear trends in individual periods are also presented.

Tab. 2

Parameters of smoothed models and linear trends for the total number of tickets sold

Period:	Pre-pandemic (a)	Pandemic (b)	Since the UA-RUS war (c)
Exponential smoothing models			
$\alpha$	0,1871	0,7484	0,8180
RMSE	578559,29	1141982,20	713804,97
MAPE	6,84%	22,08%	5,93%
Linear models (trends)			
form	$y = 29858x + 6 \times 10^6$	$y = 196492x + 3 \times 10^6$	$y = 315724x + 7 \times 10^6$
a	29858	196492	315724
$R^2$	0,63	0,75	0,80

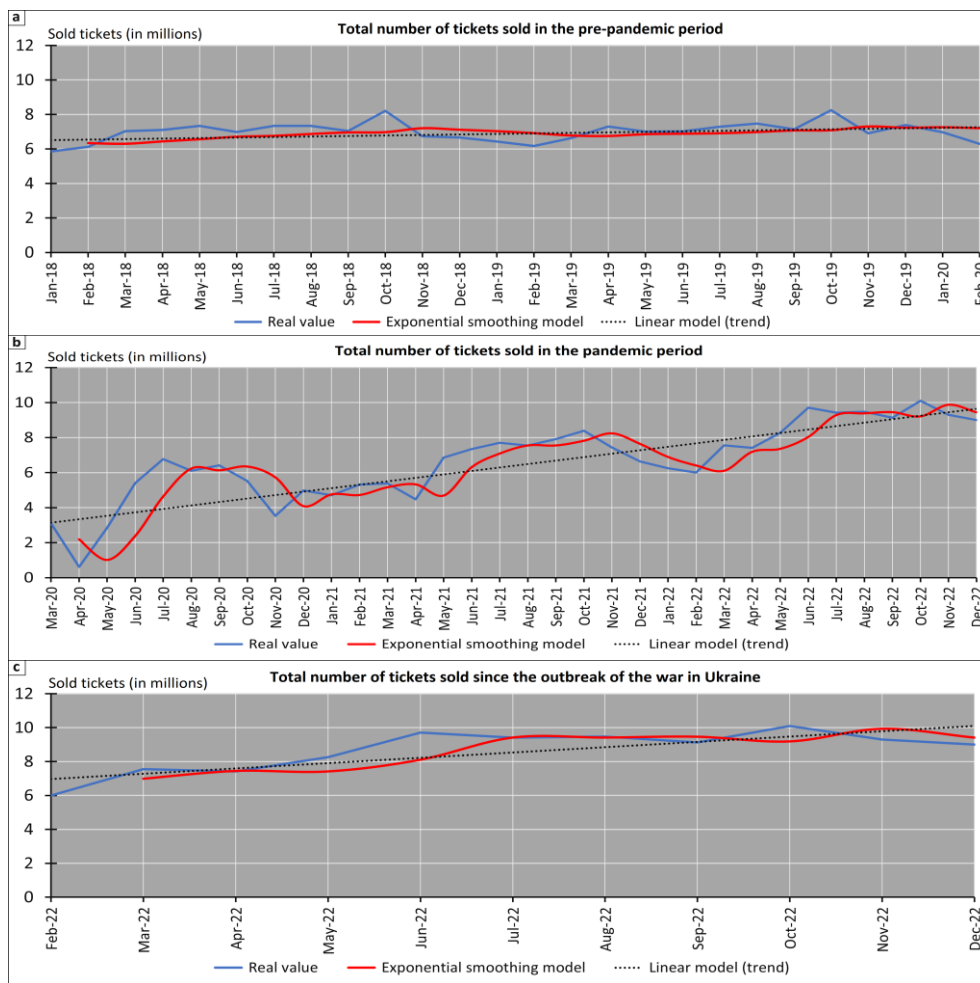


Fig. 2. Total number of tickets sold in the pre-pandemic period (a), pandemic period (b) and since the outbreak of the war in Ukraine (c)

The number of tickets sold on Warsaw public transport provides important information about the functioning of the transport system in terms of demand and availability of public transport among residents. However, it should be borne in mind that the sales indicator is subject to an error resulting from situations in which some passengers use public transport without having a ticket. Such phenomena not only have a negative impact on the financial condition of carriers, but also disrupt the reliability of data on ticket sales, and thus the flow of passengers and demand for transport. Although many residents still travel without a travel document, ZTM data from 2019 to 2022 optimistically show that Warsaw public transport is characterized by a low share of people travelling without a ticket, with an average of only 2.61% of all monthly passengers [21].

## 5.2. Transport performance

In passenger transport, one of the basic indicators is transport performance, which in the urban public transport system is expressed in vehicle-kilometres [VKT] and determines the length of the distance travelled by the vehicle in a specific time [21]. Warsaw public transport generated respectively: in 2019 - 231.623 million VKT, in 2020 - 195.398 million VKT, in 2021 - 188.087 million VKT, and in 2022 - 194.192 million VKT. This means that until

the outbreak of the COVID-19 pandemic (2019), transport means performed more transport than during the pandemic (2020 - 2022), and the result from 2022 is noteworthy, indicating a gradual return to pre-pandemic level. The study showed that before the outbreak of the COVID-19 pandemic, an increasing trend was observed by 113.85 thousand VKT per month (Fig. 3a). Since the spread of SARS-CoV-2 in Poland, there has been a change in the direction of development of the examined feature - a decrease of 15.14 thousand VKT per month (Fig. 3b). Since the outbreak of the war in Ukraine, an increasing trend in transport performance has been observed again by 100.1 thousand VKT per month (Fig. 3c). This shows that in the years 2019 - 2022, the examined feature showed variable directions of development, depending on the disturbances occurring at that time. It can therefore be concluded that the outbreak of the COVID-19 pandemic in Poland led to a significant decline in transport performance in Warsaw public transport. Moreover, the trend determined for the period since the escalation of the war in Ukraine shows that the level of implementation of transport processes in terms of vehicle-kilometres generated is gradually returning to the pre-pandemic state. This phenomenon is related not only to the development of the transport network, increasing the fleet of vehicles and changes in their frequency [20,21], but also depends on the demand for passenger transport, which, since the outbreak of the war, has been shaped not only by the needs of the inhabitants of the agglomeration but also by those immigrants settling in this area [7].

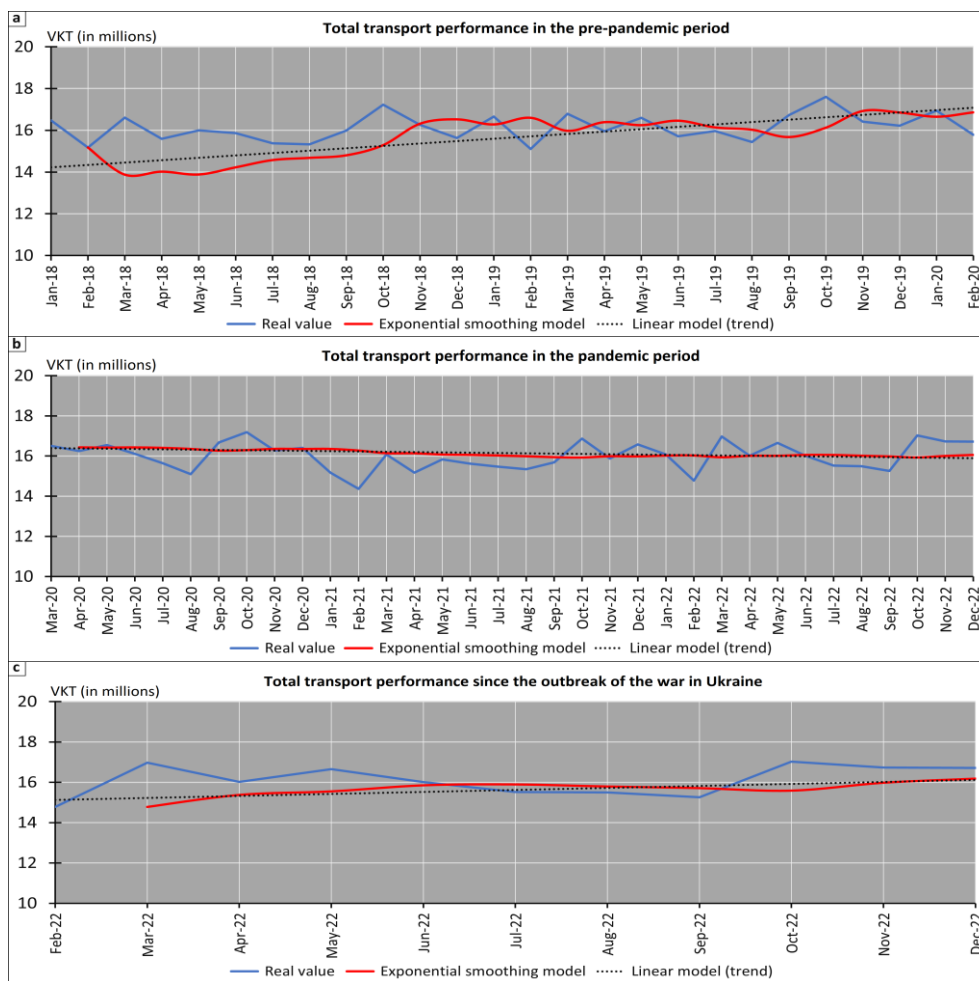


Fig. 3. Total transport performance generated by Warsaw public transport in the pre-pandemic period (a), pandemic period (b) and since the outbreak of the war in Ukraine (c)



Table 3 presents the parameters of the exponential smoothing models of transport performance along with prediction errors, which prove that the models fit the real data well. Parameters and determination coefficients for the established linear trends in particular periods are also presented.

Tab. 3

Parameters of smoothed models and linear trends for total transport performance

Period:	Pre-pandemic (a)	Pandemic (b)	Since the UA-RUS war (c)
<b>Exponential smoothing models</b>			
$\alpha$	0,4077	0,0672	0,2722
$\beta$	0,2987	-	-
RMSE	1159022,78	735102,68	989543,24
MAPE	5,90%	3,71%	4,79%
<b>Linear models (trends)</b>			
form	$y = 113854x + 1 \times 10^7$	$y = -15142x + 2 \times 10^7$	$y = 100105x + 2 \times 10^7$
a	113854	-15142	100105
$R^2$	0,69	0,73	0,61

### 5.3. Passengers carried

The number of passengers using public transport reflects the demand for transport services provided by public transport operators. This is a key indicator describing the implementation of transport processes, based on which it is possible to determine how the transport needs of residents of the Warsaw agglomeration have changed under the influence of crisis events. ZTM in Warsaw keeps only annual statistics on the number of passengers transported by public transport. From 2014 to the end of 2021, the values were estimated manually. From 2022, in order to increase the accuracy and reliability of statistics, the passenger counting method has changed as it is based on several data sources [21]. Therefore, apart from the crisis events considered, the number of people transported by Warsaw public transport will also depend on the passenger counting method.

Statistics from 2014 to 2023 were taken into account, showing that an average of 1,019.2 million people used Warsaw public transport annually [21]. Data from 2020 (726.1 million), 2021 (809.4 million) and 2022 (863.5 million) show the highest deviations from the arithmetic mean, which indicates the disruptions taking place then. The study showed that before the outbreak of the COVID-19 pandemic, the number of passengers increased by 15.86 million annually, which indicates the increasing importance of urban public transport. As a result of the outbreak of the pandemic and its consequences, the number of people transported in the Warsaw agglomeration decreased from 1,201.5 million in 2019 to 726.1 million in 2020, i.e. by as much as -39.56%. As a result, since 2020, there has been a decreasing trend in the number of people transported per year, at the level of -102.96 million, which only proves how serious the effects of the pandemic were on public transport. In 2022, the number of passengers transported increased by 54 million (+6.67%) compared to 2021, and in 2023 by 92.32 million (+10.7%) compared to 2022. As a result, in the period since the escalation of the Russian-Ukrainian conflict, we have been observing an increasing trend in the number of travellers, which shows that the influx of refugees to Warsaw also translated into an increase in passengers of the public transport. Considering the characteristic of the smoothed model and the growing trend for the period since the outbreak of the Russian-Ukrainian conflict, it can be assumed that in the future

the number of people using Warsaw public transport will continue to increase, which is a desirable phenomenon from the perspective of sustainable development of the city (Fig. 4).

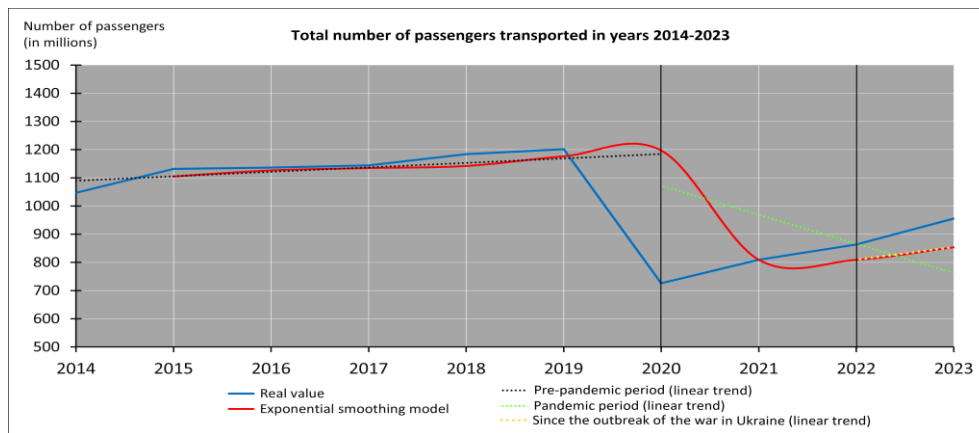


Fig. 4. Total number of passengers transported in the years 2014 - 2023

Table 4 contains parameters of the exponential smoothing model for the total number of passengers transported, along with prediction errors, which prove that the model fits the real data well. In addition, parameters and determination coefficients for the established linear trends in individual periods are presented.

Tab. 4

Parameters of the smoothed model and linear trends for the number of passengers transported

Exponential smoothing model			
$\alpha$	0,8231		
RMSE	162,7356		
MAPE	10,15 %		
Linear models (trends)			
Period:	Pre-pandemic	Pandemic	Since the UA-RUS war
form	$y=15,862x+1073,6$	$y=-102,96x + 1792,6$	$y = 44,457x + 409,31$
a	15,862	-102,96	44,457
R <sup>2</sup>	0,92	0,52	0,99

## 6. CONCLUSIONS AND RECOMMENDATIONS

Global threats from 2019 to 2022, such as the COVID-19 pandemic and the conflict in Ukraine, had an impact on the functioning of the urban public transport system in Warsaw. The significance of the impact of these events is confirmed by fluctuations in the indicators describing the implementation of transport processes, such as transport performance and the number of passengers transported. As a result of the disruptions, the transport needs of residents of the Warsaw agglomeration also changed significantly, as evidenced by the analysis of the structure and ticket sales. During the COVID-19 pandemic, a serious decline in the number of travellers and demand for passenger transport was observed, therefore it is reasonable to implement solutions that will increase the stability of transport processes in the event of similar threats in the future. It is recommended to:

- develop an action strategy for the operation of transport in a state of renewed threat, taking into account the levels (transition phases) of the epidemic and the corresponding specific restrictions;
- increase the sense of safety among passengers and employees, thanks to the implementation of system solutions with a clearly defined division of tasks between the authorities, the organizer and transport operators;
- develop and enforce safety standards and crisis response procedures with close cooperation between all entities of the public transport system;
- introduce additional solutions to reduce the risk of infection and maintain high quality of services provided (during the threat and restrictions in force);
- provide broader support to transport organizers in the implementation of preventive and control activities by sanitary services, law enforcement services and local government authorities (in the event of renewed threats and mobility restrictions);
- promote appropriate behaviour when using public transport, including appropriate passenger behaviour during the pandemic.

Referring to the conflict in Ukraine, the study shows that this event was not as important and direct in its consequences for Warsaw public transport as the COVID-19 pandemic. Moreover, from the perspective of process implementation and demand shaping, it brought benefits because the influx of refugees to Warsaw translated into greater demand for passenger transport and, as a result, also into higher ticket sales.

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