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Prediction of Transport Performance Development Due to the Impact of COVID-19 Measures in the Context of Sustainable Mobility in Railway Passenger Transport in the Slovak Republic

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Abstract: The disease COVID-19 negatively affected sustainable mobility, including public passenger transport, as it was necessary to take several measures to reduce the population's mobility. It also limited rail passenger transport. Railway operators suffered from a significantly reduced number of passengers. An analysis of the transport performance of railway passenger transport is conducted in a case study in Slovakia. Based on the decline in transport performance in railway passenger transport and the degree of measures introduced, a new methodology and procedure for introducing pandemic measures are proposed in the context of reducing the scope of rail passenger transport. The measures are proposed under the condition that it is necessary to monitor the roles and responsibilities of railway infrastructure managers and rail passenger operators. The proposed methodology includes a transport performance forecast according to the defined transport reduction measure level and the train traffic diagram variants on the model railway line in the case of levels of the implemented measures. These proposals will contribute to higher quality and more efficient railway transportation, including optimal use of railway infrastructure capacity during emergency situations. The novelty of the research lies in the new methodological procedure and its practical application.

Keywords: mobility; sustainability; COVID-19 measures; railway passenger transport

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1. Introduction

High-quality railway infrastructure is necessary for efficient railway operation and transportation. Only in such circumstances can railway passenger transport guarantee people's sustained mobility as the public passenger transport system's supporting mechanism. Public mass transit systems, however, are subject to a variety of outside influences that affect how well they function. An epidemiological danger may be posed as one of them. The global COVID-19 epidemic of 2020 had a major effect on both passenger travel and the global economy [1,2]. The transportation market's supply (the number of connections) and demand (the number of passengers) were impacted by numerous imposed regulations [3]. The most common limitations included limiting the number of connections, lowering the maximum number of passengers in a car, limiting the network of transportation connections, and similar measures [4]. Ensuring a suitable degree of safety during an epidemic poses a significant challenge because of the subjectivism of social members, their varied perspectives, and their life histories. In response, authorities everywhere released the requisite guidelines and legislation. Mobility styles were immediately and severely impacted by this. The economic and social effects of the COVID-19 outbreak on public transport go beyond service performance and health risks to financial viability, social equity, and sustainable mobility [5].

Circumstances related to the outbreak of the disease COVID-19 are beyond the control of railway undertakings, which face significant liquidity problems, large losses, and, in some cases, the risk of insolvency. To avoid the negative economic effects of the outbreak

of the disease COVID-19, railway companies may need financial support with the fees for access to the railway infrastructure. This option should be granted for the period during which the effects of the outbreak of the COVID-19 disease on the railway market have already been felt and during which they are expected to be felt. That is why the European Union decided to accept Regulation (EU) 2020/1429 of the European Parliament and the Council of establishing measures for sustainable rail markets in view of the COVID-19 outbreak [6].

Numerous nations have implemented diverse strategies to halt the transmission of COVID-19. Using social distancing to avoid touch is one of the most crucial of these strategies. Travel demand and activity participation are significantly impacted by a lack of social contacts [7]. Many nations quickly responded with effective accessibility limitations to stop the virus's spread and assure passengers that they were safe while traveling by train. Pandemic interventions mostly took the form of altered long-distance and regional transportation patterns, as well as a decrease in population mobility in public passenger transit [8]. The most common measure introduced by almost all EU countries was the introduction of an emergency [9]. Demand for travel saw an unprecedented overall decline, falling dramatically with peaks of 90–95% of public transport passengers. During the reopening phase, demand has gradually returned to pre-crisis levels, although some structural changes in travel behavior have been observed, and some restrictive measures are still in place to reduce the risk of contagion.

The basic background of the mentioned contribution and the established research is to contribute to a complex solution to the problem of public passenger transport during a pandemic. It will have a fundamental practical benefit for society, which will consist of increasing the quality and efficiency of rail passenger transport and providing safer conditions for passengers. There will also be a significant theoretical–scientific contribution, which will consist of enriching the science of transport processes with new progressive outputs. This paper analyzes the impact of the introduced pandemic measures on transport performance in railway passenger transport in the Slovak Republic and other EU countries. Based on a precise professional analysis of the current situation and problems, a methodical procedure is developed in which several scientific methods are used. The basic aim of the research is to propose a new system of pandemic measures that will be effectively applied in the railway system to increase the safety of passengers and maintain attractive railway passenger transport. Based on them, the dependence between the degree of measures and the expected development of transport performance is broken.

The proposed conceptual system of measures, including the established methodology in the context of the prediction of transport performance, will significantly contribute to sustainable mobility and sustainable development. It is very important to realize that sustainability is a social goal for people to co-exist on Earth for a long time. Therefore, society must be prepared to handle various threats and crises, and it is necessary to have a plan for solving such crisis situations. Therefore, the current research on the mentioned issue will partly contribute to the fulfillment of this common vision, specifically in railway passenger transport.

More specifically, this paper aims to (1) provide a structure for COVID-19 common policy measures and their impact on transport goals, (2) give an overview of findings in this area, and (3) synthesize the literature, discuss its policy relevance, and suggest avenues for future research. We review measures and their direct impacts (on mobility and activities) and indirect impacts on the economics of the transport system. We limit ourselves to passenger mobility and focus on the railway transport mode. The literature review in Section 2 focuses on the research outputs in the field of railway transport during pandemic measures. From a scientific point of view, we examined the procedures of the government, the dependence between the degree of the declared measure and the degree of reduction in transport performance in rail transport, and, subsequently, transport performance in the number of passengers. Section 3 first describes the methodology; Section 4 presents the results. Section 5 discusses the findings, and finally, Section 6 summarizes the main

conclusions and provides reflections on the transport policy implications and suggestions for future research.

2. Literature Overview

Public transport services, which are a vital link for many working people, were severely disrupted during the COVID-19 pandemic. As institutions gradually return to normal operations, it is important to understand and examine how the pandemic affected people's basic commute to work and what will be needed to ensure the effective recovery of transit traffic and increase the long-term resilience and equity of public transportation systems. A study [10] used focus group discussions with grassroots workers who were pre-pandemic commuters to understand how the COVID-19 pandemic affected their perceptions, experiences, motivations, and challenges of commuting and explore potential changes in their post-pandemic travel behavior. The COVID-19 pandemic brought about a significant change in urban mobility habits, leading to a significant decline in the use of public urban transport in many countries. This was only partially and unevenly reversed. In this context, many cities are still analyzing what factors hinder this recovery process. The intention is to propose measures to support sustainable mobility. The authors of [11] conducted research in the city of Almeria (Spain) and tried to analyze whether the main operational variables of the city bus network have an impact on the annual number of renewed users in 2022 compared to 2019. In [12], the authors analyzed the impact of the COVID-19 pandemic on mobility behavior and public transport strategy formulation after COVID-19.

Traveling by train during the time of the COVID-19 pandemic and the perception of safety with the support of political measures were addressed in the research [13]. To minimize the risk of contracting the coronavirus while traveling by train, the national government and the Dutch railway operator in The Netherlands adopted several policy measures. These included passengers being required to wear masks and instructions being issued for working from home and teaching online. In addition, other policy measures were considered, such as the introduction of a reservation system. The authors of [14] synthesized the latest status up to early June 2020 on key developments regarding public transport and the COVID-19 pandemic, including the various responses adopted by governments and public transport agencies around the world, and research on critical issues that minimize the risk of contagion in public transport in the so-called post-blocking phase. The range of less researched factors, such as attitudes and beliefs about train use, were examined [15], including the perceived risk of influenza-type infection, alongside more traditional factors that together influence decisions about whether to continue using the train. In [16], the authors focused on supporting policies and decision-makers in defining the most appropriate strategies to manage the COVID-19 crisis.

World governments have enacted and continue to enact many regulations and rules to minimize the level of risk to which the population is exposed. Most of them focus on ensuring social distancing of people, and in this context, the public transport sector plays a key role [17]. A study by [18] provides scientific evidence for designing more effective COVID-19 policies in the transport and public health sectors. The effectiveness of each policy is measured using nine indicators of infection and mobility corresponding to the three periods before and after the policy implementation. The purpose of the research in [19] was to examine the impact of COVID-19 on movement behavior with reference to public transport users in terms of their willingness to travel and their perception of safety criteria.

The pandemic measures were mainly manifested in the reduction in population mobility in public passenger transport [20,21] and in changes in mobility at the regional level.

In the Slovak Republic, this change manifested itself to varying degrees. The research teams of the University of Zilina published partial results of intensive research during the years 2020–2023 within the framework of the project "Identification and possibilities of implementation of new technological measures in transport to achieve safe mobility during

a pandemic caused by COVID-19", co-financed by the European Regional Development Fund. Transport-oriented researchers created a comprehensive study focusing on measures during the pandemic in all modes of transport. The changes in mobility at the regional level were assessed in research by [22]. The paper [23] deals with the impact of measures introduced in the first half of 2020 on railway passenger transport in the Slovak Republic to slow down the spread of the virus during the first wave of the COVID-19 pandemic. In other research [24], authors optimized timetables on the Bratislava–Zilina–Kosice route in the period after the end of the COVID-19 pandemic. In the paper [25], the authors focused their research on the analysis of the impact of the pandemic and implemented measures on the passenger rail transport sector in the Slovak Republic and on the development of rail passenger and freight transport during the pandemic. Their research defines the proposed measures against the spread of the COVID-19 pandemic in rail transport in Slovakia during the ongoing pandemic. The impact of the pandemic and the measures taken on the development of transport performance in rail passenger transport in Slovakia during the COVID-19 pandemic were examined in [26]. The authors propose operational and organizational measures against the spread of the COVID-19 pandemic in railway passenger transport in the Slovak Republic. However, the risk of transmission of the coronavirus disease (COVID-19) between individual train passengers remains unclear. The authors of the paper [27] quantified the risk of transmission of COVID-19 to passengers on high-speed trains. The authors analyzed the spatial and temporal distribution of COVID-19 transmission among train passengers to elucidate the associations between infection, spatial distance, and time spent traveling together. The authors of the paper [28] addressed the draft scope of public rail passenger transport during the COVID-19 pandemic. Paper [29] investigated the impact of pandemic measures on the scale of passenger rail transport with very partial results.

The research in [30] assessed the extent to which maintaining a one-meter distance between people in trains is sustainable for public transport companies. An optimization model for assigning seats in long-distance trains to ensure the spread of the SARS-CoV-2 disease was solved in their research [31]. The authors proposed a new seat assignment policy that aims to mitigate the risk of the virus spreading among passengers by reducing interaction between them.

Public transport, especially rail passenger transport over long distances and large areas, is the most potential risk source of a pandemic. This is also evidenced by the research of [32], who analyzed the relationship between the probability of contracting COVID-19 and the use of public transport through an analysis of survey data, taking Madrid (Spain) as a case study. This research uses a survey campaign with more than 15,000 responses that captures sociodemographic aspects, COVID-19 infections, daily habits, and mobility patterns at high risk of COVID-19 infection. Through a multilevel probit model, this paper examines the extent to which higher public transport use is associated with a higher probability of infection with COVID-19. The results suggest a relationship, although not very strong, between the probability of infection and the association between a higher frequency of use of metro services and the degree of overcrowding during the trip, while the use of bus services and travel time in the vehicle do not seem to be affected. Similar research was conducted by [33], who discussed that the resumption of public passenger transport operations during the pandemic was questioned due to the high risk of the spread of the COVID-19 disease in public transport vehicles and mass cases of this infection. The results of this study showed that there has been a significant decrease in the use of public transport modes, a trend that is likely to continue, given the preferences of the participants. While previous health crises such as SARS have affected the transport sector, the COVID-19 pandemic is unprecedented, resulting in exceptional impacts on the sector. Paper [34] analyzes the impact of COVID-19 on the transport sector and the subsequent consequences in selected cities around the world. The authors focused their research on public air transport, where traffic performance decreased by more than 71% during the pandemic. Authors of the paper [35] presented evidence in their research that the risk of

infection in humans can be extremely high due to the length of the exposure time window, transmission routes, and structural characteristics during travel or work. This can result in rapid spread of infection. Based on the characteristics of the transmission of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and the nature of public transport locations, we have identified comprehensive countermeasures for the prevention and control of COVID-19, including strengthening personnel management, personal protection, cleaning, and disinfection of the environment. Another proof is the increased risk of possible infection, and this problem was solved in [36]. Using focus groups and data collected through telephone interviews during the different phases of the pandemic, the authors investigated the current concerns of passengers regarding public transport and what measures would help alleviate their fear of using it again. The findings show that the pandemic has increased passengers' sensitivity to phenomena that they perceived negatively even before the pandemic, such as overcrowded vehicles, odors, or insufficient cleaning of vehicles. There are many other studies that dealt with the impact of COVID-19 on the mobility of the population in public passenger transport, for example, [37–43]. All the research cited indicates or seeks evidence that public passenger transportation (especially those with high occupancy rates) is a major source of contagion.

In rail passenger transport, real-name ticket checking can effectively track the path [44] and the spread of the pandemic, which is most important for the prevention of the spread of COVID-19. In [45], the authors first established an evaluation index system for checking the real name of a train ticket. The authors proposed a comprehensive evaluation model of the control of the real system, in which the normalized work of various indexes was carried out, and the key factors affecting the evaluation were determined.

To understand whether passengers will use rail transport during the COVID-19 pandemic, a logistic regression model was created based on 559 valid questionnaires from the three aspects of personal attributes, travel attributes, and perception of COVID-19. Authors of the paper [46] found that employment, commuting tools before the COVID-19 pandemic, walking time from residence to the nearest subway station, the possibility of getting infected in a private car, and the possibility of getting infected on public transport have a significant effect on travel for work by rail transport.

In [47], researchers addressed the impact of the COVID-19 pandemic on the operation of regional rail transport in the border areas of the Lower Silesian Voivodeship and the Liberec Region in the context of changes in the functioning of regional rail transport. The return to the level before the transport restrictions should be associated with encouraging passengers to use rail transport again. The assessment of rail transport capacity according to current regulations aimed at ensuring social distancing conditions against the COVID-19 pandemic was addressed in [48]. The authors proposed a methodology to optimize the operation of railway transport, thus satisfying the demand for mobility.

Overall, however, relatively few scientific articles covering the issue of COVID-19 and rail transport have been published in the world. Most were published between 2020 and 2022. The research [49] focused on modeling the variability of transport capacity during pandemic restrictions. The authors of the paper [50] evaluate the development of transport demand in Poland and other countries in the context of the end of pandemic measures and the subsequent increase in fuel prices after the crisis in Ukraine. Authors of the papers [4,51] proposed a policymaking support approach that is effective in evaluating the acceptance of anti-pandemic policies from the public's perspective, assessing the balance between policies and people's demands, and conducting the response analysis of a series of policy adjustments based on people's feedback. The case study suggests that the Wuhan COVID-19 transport anti-epidemic policies did not adequately consider the roles and interests of various segments of the public before the effective vaccine and medical aid were distributed. Moreover, public concerns mainly focus on the commuting of anti-epidemic-related staff, necessary travel for vulnerable groups in the community, information and communication mechanisms, disinfection of available travel tools, logistics and courier services, the safety of resuming production, and unstable policy decisions. This study also

used social media-based analytical methodology for the monitoring phase of policymaking. Within the mentioned and other current publications, there are many papers, scientific outputs, and studies where the issue of the COVID-19 pandemic is addressed in the context of the impact on transport, but always only from a certain point of view. In other contributions, this issue is applied only to selected specific countries, such as France [52], India [53], Indonesia [54], and Mozambique [55]. The ways in which the pandemic was solved in these specific countries, which political strategies were implemented, and how the measures in the field of transport were determined and accepted are described and analyzed. However, it is necessary to solve the mentioned problem comprehensively and to offer new challenges and generally applicable solutions throughout the world so that in the future, our society is better prepared for potential pandemics and can find a more suitable solution in the field of public passenger transport. This issue is partly addressed in [56], where certain post-COVID-19 challenges are also mentioned. Therefore, the research, models, and practical application presented in this research follow up on current bottlenecks that were not addressed in previous outputs.

From the aspect of research focus, it can also be stated that several scientific studies were created during the duration of the pandemic or just after its end, but after 2022, there are not many analyses focused on transport. It is obvious that the issue of the tasks of public transport using rail transport has not yet been comprehensively covered, and no recommendations have been established for the scope of transport during pandemic measures.

3. Materials and Methods

As countries across the world modify their travel in the face of the COVID-19 pandemic, the first casualty becomes the public transport sector. Worldwide transportation authorities have reported a 95% decrease in users at the COVID-19 peak, a fall in fare box income, and additional expenses for cleaning and putting in place physical distancing measures [57]. During the initial wave of the pandemic, domestic rail passenger numbers decreased by up to 90% compared to the prior year. Numerous carriers, particularly the more recent ones, were forced to cease operations. The second wave of the pandemic, which began in the fall of 2020, compelled many nations to enact additional restrictive policies pertaining to population mobility. The outbreak of the third wave of the pandemic prevented a rapid revival of rail transport, especially passenger rail transport [58].

In train kilometers, passenger transportation fell by 16.9% on average compared to the same month in 2019. The worst decline in performance happened in April 2020, when there was a 40.6% drop in passenger transport performance, similar to what happened in Slovakia. The second quarter of 2020, from April to June, saw the biggest impact. In the second quarter of 2020, domestic travel fell by 18%, while international travel fell by an average of 85%. Passenger travel was more severely impacted than freight travel. In the initial months of the crisis, the public authorities' response to the COVID-19 pandemic (passenger mobility restrictions) and the overall impact of the global economic slowdown, which generally resulted in a decrease in transport demand, directly contributed to the reduction in rail transport [59].

Between January and September 2021, there were almost the same number of passenger trains on the network as during the same period in 2019, but there were 7.8% fewer passenger trains in 2020 than in 2019. However, the number of commercial passenger trains between January and September 2021 was still 21.5% lower than the same period in 2019, indicating that there has been no recovery compared to the same period in 2020 when it was 23.3% lower than in 2019. Comparing the first nine months of 2021 with the same period in 2019, the number of passengers carried by public service trains was 5.2% lower. In terms of train kilometers, commercial passenger transport in 2021 was 25.6% lower than in 2019, which is in line with the (low) level already reached in 2020 [60]. Figure 1 shows the evolution of transport performance from 2019 to 2022.

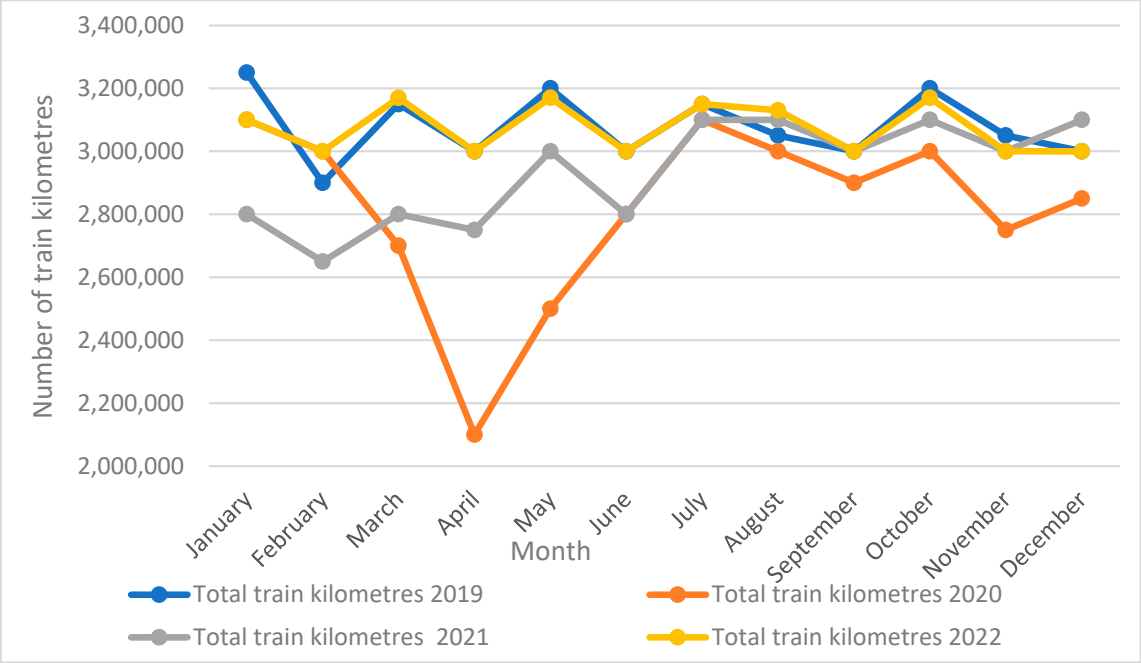

Figure 1. Comparison of transport performance in the period 2019–2022. Source: authors, according to [60].

The number of passengers transported by rail in Slovakia is another indicator of the shift in mobility. Figure 2 shows the growth in the number of passengers transported between 2019 and 2022.

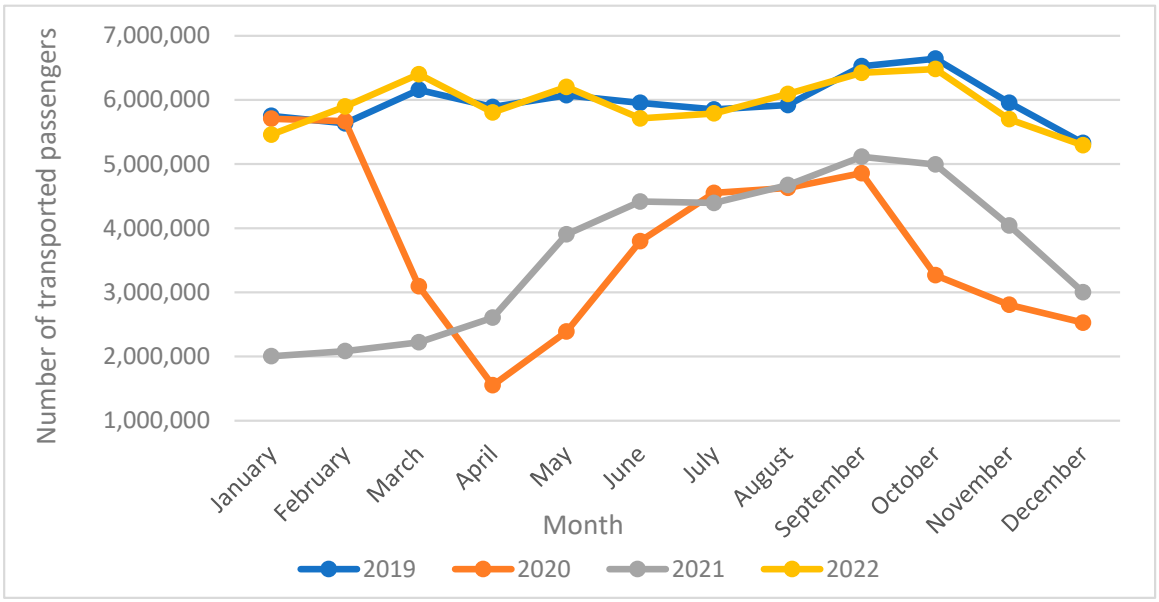

Figure 2. Comparison of total number of transported passengers by rail in Slovakia in the period 2019–2022. Source: authors, according to [60].

A significant decrease in the number of transported passengers per year can also be observed in the example of the specific regional railway line (Figure 3).

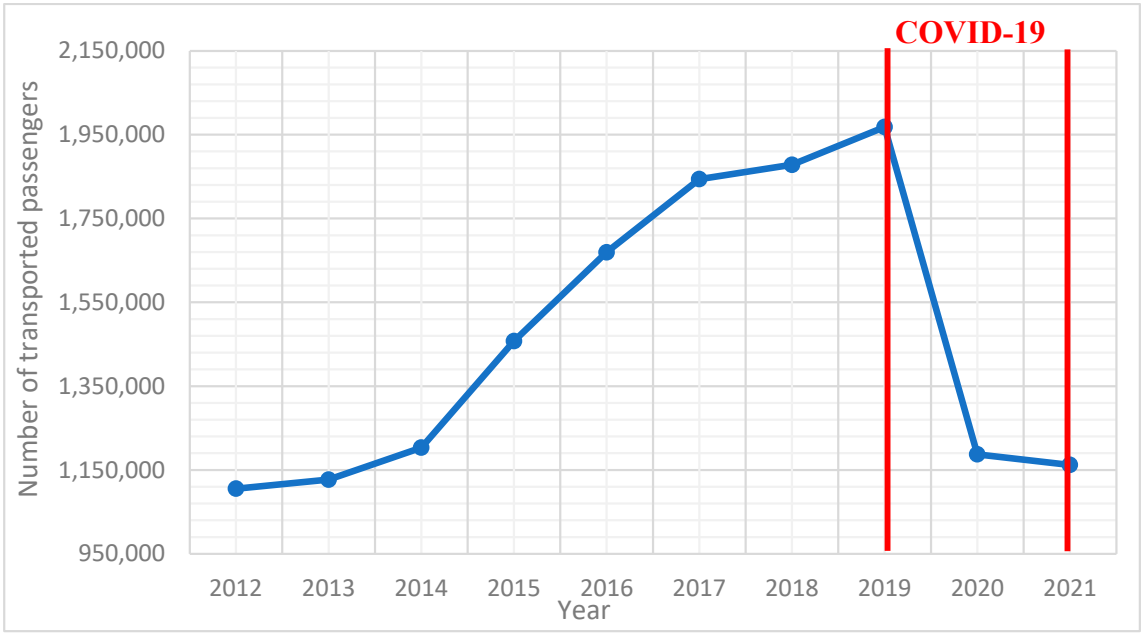

Figure 3. Comparison of the number of transported passengers per year on the specific regional railway line. Source: authors, according to [60].

Based on our research, we analyzed and evaluated all the pandemic measures introduced in the Slovak Republic and their impact on mobility in rail passenger transport according to the established 5-degree so-called COVID machine (Table 1).

Table 1. COVID machine for measures to restrict the movement of residents in Slovakia. Source: authors, according to [61].

Color	Risk	Description	Degree
White	No restrictions	Unlimited	0
Green	Monitoring	Unlimited	0
Orange	Vigilance	Unlimited; No visits to hospitals, welfare homes, services, prisons, all school field trips, events, shopping centers, churches.	0
Red	1st level of threat	Limited movement with exceptions from 9:00 p.m. to 5:00 a.m.; Curfew, except for traveling to work, for testing, stay in nature.	1
Burgundy	2nd level of threat	Limited movement with exceptions from 9:00 p.m. to 5:00 a.m.; Curfew with exceptions valid during holidays and Christmas.	1
Black	3rd level of threat	Extended curfew from 5 a.m. to 1 a.m.; inter-district travel ban; restricted movement with exemptions from 5 a.m. to 1 a.m.; measures were tightened while exemptions that applied during holidays and Christmas were removed. Orders from the Home Office included restrictions on visiting other people's homes, spending time only in the borough's parks and other natural areas.	2

The aim of this system is to ensure measures that are simple, understandable, predictable, targeted, feasible, safe, and in accordance with the legislation [61]. Throughout the period of validity of the specified type of COVID machine, this evaluation system provides information on the current risk associated with the applied measure at weekly intervals. In this study, the effect of COVID-19 measures on mobility in rail passenger transport in

Slovakia was assessed using the COVID machine system. As an example, we used the measure that had the greatest impact on the mobility of the population among all the measures implemented. The COVID machine for restricting residents' mobility is shown in Table 1, together with the COVID-19 measure. It lists the risk categories with which the color of the alleged warning (or threat) is associated. Each risk includes a description of the measures implemented and the level of infection risk associated with those measures. The method for evaluating the 5-degree COVID machine in relation to the recognized COVID-19 measures in the Slovak Republic is presented in Figure 4.

Region/week	2020																										
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Zilina	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	x
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	2	2	2	2	2	2	1	1	2	x
Region/week	**2021**																										
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	
Zilina	2	1	1	1	1	1	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	0	
	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	
	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	2	2	2	2	2	0	0	0	0	0	0	
Region/week	**2022**																										
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	
Zilina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Figure 4. Evaluation system of pandemic measures according to the 5-degree COVID machine in the Zilina region. Source: authors.

The quantitative research was focused on measuring and testing the data from the pandemic measures as well as transport performance in rail transport. There were tests of the causal relationships between variables, making predictions and generalizing the results to wider populations.

The literature review involved searches for academic literature (peer-reviewed journal papers only) performed on Scopus and Google Scholar, as well as searches for expert papers, news source information, and government analysis. This was performed mainly during the pandemic period between June 2020 and January 2022.

Keyword combinations used for academic and grey literature searches were used as follows:

(1) "Covid 19" OR "covid19" OR "COVID-19" OR "coronavirus" OR "SARS-CoV-2";
(2) "Measures" OR "response(s)" OR "roadmap" OR "intervention" OR "strategy" OR "strategies";
(3) "Recovery" OR "policy" OR "policy response" OR "phase-out";
(4) "Strategy" OR "exit strategy(ies)"; OR "lifting restrictions" OR "phased lifting";
(5) "Railway transport" OR "railway transportation" OR "mobility";
(6) "Impact" OR "behaviour" OR "travel" OR "travel behaviour" OR "perceptions" OR "transport";
(7) "Mobility" OR "mobility" OR "transport performance".

In each case, we searched for a combination of two or more of these strings. Due to the novelty of the topic, citations were not considered an important filter.

A search of websites was carried out using the Google IGO (International Governmental Organization) search engine [62]. A search of government websites of other international organizations for information on measures was conducted (e.g., European Commission/EU sites, UNECE, IRU, IMF, UNCTAD, UN-Habitat, UN-WTO, WTTC, the government of the Slovak Republic).

The application and impacts of COVID-19 measures are in the academic literature, catching up at some level, but impacts on railway transport are only a small range of published research (e.g., EU COVID-19 transport measures, COVID Mobility Works, UNECE).

Therefore, news websites or blogs were also searched as needed to create a more up-to-date picture of the experiences of the measures in different countries. Among all the sources mentioned, several research databases with records of the types of COVID-19 (transport) measures worldwide were found and searched.

In transport, the reductions in the scope of performance were influenced by political decisions limiting the mobility of the population, and subsequently, the operators of railway transport reacted with certain measures for the reduction in transport performance.

An important research procedure included the discussion of experts within the research team, which was created at the Faculty of Operation and Economics of Transport and Communications of the University of Zilina. As part of the solution to the COVID-19 project, the impacts and measures for all modes of transport were investigated.

The main brainstorming format was panel discussions with approximately 50 core researchers in transport from the University of Zilina as well as experts from the Ministry of Transport of the Slovak Republic, the railway infrastructure manager (Zeleznice Slovenskej Republiky), and railway operators operating passenger rail transport (Zeleznicna Spolocnost Slovensko Inc., Regiojet Inc. Czech Republic).

The quantitative research was conducted using brainstorming methods, the aim of which was to model measures in passenger rail transport. During the qualitative research step, we examined the opinions, behaviors, and experiences of experts in railway transport. They collected and analyzed data and findings in research papers. This research methodology was drawn from research topics at the faculty, which consists of experts in transport in all transport modes. Results and findings for railway transport are used in this paper.

To validate the findings and explain any unexpected results obtained, a mixed-methods research methodology was used to verify if the results observed using both methods were complementary.

Based on the mentioned methods, the authors proposed a universal methodology for the pandemic measures system in railway passenger transport. There were several useful scientific methods that are general and universal, but they are especially applicable to the given issue. The methodology consists of several steps, which are shown in Figure 5.

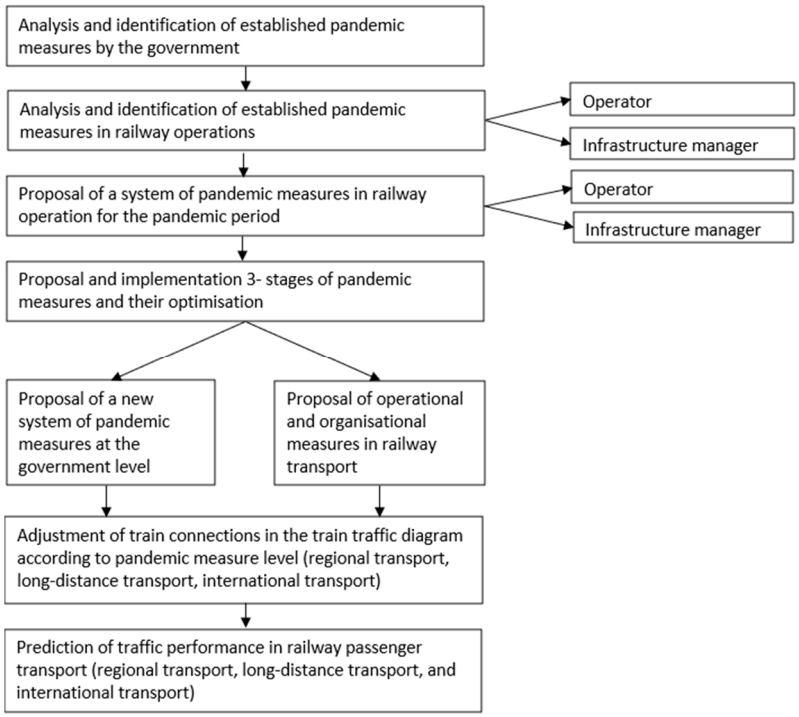

Figure 5. Proposed methodology of the pandemic measures system for railway transport. Source: authors.

Analysis and identification of established pandemic measures by the government—In this step, quantitative research was used for measuring and testing the data from the pandemic measures. The literature review involved searches for academic literature as well as news sources and government analysis. A search of the government websites of other international organizations for information on measures was conducted. Subsequently, these levels of measures were structured so that they could be more deeply analyzed and compared.

Analysis and identification of established pandemic measures in railway operations—In this step, quantitative research was used to measure and test the data from the pandemic measures in railway transport. The literature review involved searches for academic literature as well as expert papers. We acknowledge that there is some subjectivity in our choice of materials and that our literature list is bound to be incomplete due to the constant appearance of new publications about COVID-19. We think our analytical framework and conceptualization of links between measures are not sensitive to the selection of literature, but some of the empirical findings could be influenced to some extent.

Proposal of a system of pandemic measures in railway operation for the pandemic period—The system analysis method was used to improve an analyzed system of a variety of announced measures to create and implement a new system. The main activities in system analysis were problem definition, research, and analysis of affiliated systems, determining the method of solving the problem, and the introduction of a new structure. System analysis is a specific method for precise and empirically intuitive investigation of the basic properties and goals of simple and complex systems in various areas.

Proposal and implementation of 3 stages of pandemic measures and their optimization—On the grounds of information research and system analysis, a panel of experts in railway transport was organized. This contained forecasting based on input data and provided a vision or recommendations for future options and needs related to the examined transportation topic. The method involves approximately 30 to 60 experts who deal with the specific problem for a set amount of time (1 to 2 years). The basis is the development of final outputs based on joint compromises and joint scientific and professional research.

We propose to divide the measures into three levels according to the severity of the epidemiological situation. Within these levels, we will propose a set of new measures—operational and organizational measures—that will follow from the general measures adopted by the government.

Proposal of a new system of pandemic measures at the government level—A panel of experts proposed the new system of 3-stage pandemic measures at the government level, which is proposed conceptually for all economies in the region (country).

Proposal of operational and organizational measures in railway transport—A panel of experts proposed the new system of 3-stage pandemic measures at the railway transport sector level. In passenger transportation, there are conceptualized measures for infrastructure managers as well as for the railway operators operating passenger transport in all segments (regional, long-distance, and international).

Adjustment of train connections in the train traffic diagram according to pandemic measure level (regional transport, long-distance transport, international transport)—In the frame of quantitative research procedures, the key is the discussion of experts within the research team, which was created at the Faculty of Operation and Economics of Transport and Communications of the University of Zilina. The main brainstorming format was panel discussions with approximately 50 core researchers in the field of transport from the university as well as from practice. The percentage reduction in railway connections in regional, long-distance, and international transport was carried out based on previous pandemic experiences, scientific methods, and expert discussions from practice.

In addition, the SFMEA (System Failure Mode Effects Analysis) method was developed. It is a particular management technique that evaluates systems and subsystems early on (during the conceptual stage), focuses on the interconnections between systems and system elements, and then suggests improvement processes and procedures.

Prediction of traffic performance in railway passenger transport (regional transport, long-distance transport, and international transport)—The panel expert method was used for forecasting, which, based on input data, provided a vision or recommendations for future pandemic options and needs related to the examined transportation topic. The method involves approximately 30 to 50 experts who deal with the specific problem for a set amount of time (1 to 2 years). The basis is the development of final outputs based on joint compromises and joint scientific and professional research. In addition to predicting passenger flows in individual measures, it was important to establish the minimum value of traffic performance (number of train connections per day) during the strictest pandemic measures.

The individual parts of the research follow each other, and it is very important to preserve their hierarchy. In the case of the risk of the spread of a potentially infectious disease, it is necessary to analyze and correctly identify certain measures by the state, which will be applied in a comprehensive framework. Based on them, it will be necessary to adapt and adopt specific measures in railway operations at the level of the infrastructure manager and carriers.

This research in determining the size of the volume of traffic services provided during pandemic measures is prompted by the importance of precisely setting the functioning of the transport system during pandemic measures. For this, it is important to define the basic levels of government measures to limit mobility, for which the desired range of transport can be further explored. The goal is to prevent the waste of public resources on public passenger transport while maintaining a certain amount of basic transport service during the restrictions so that the operation of the national economy is not threatened.

The benefit and novelty of the proposed structure of measures lie in the fact that within them we can mutually establish current knowledge and experience in traffic processes, railway operation technology, and transport management for the needs of pandemic mobility. The system analysis method and SFMEA methods help to create a synergistic effect between these areas, which will result in a unique solution based on the proposal of a methodical procedure. The expert method panel significantly helps to propose systematic and professional solutions for individual parts of the methodological procedure and their appropriate practical application, including forecasts and predictions for the future.

All these methods will help to conceptually solve the issue, which will solve the current bottlenecks of current research in the field of the impact of the COVID-19 pandemic in the future. From the point of view of the complexity, specification, and uniqueness of our research, it was, therefore, most appropriate to use these methods. Other methods would not be able to adequately cover this issue.

An important scientific part of the support of the proposal is the setting of hypotheses, scientific research assumptions, or research questions. Within the conducted research, we have determined the following research questions:

(1) Does the number of transported passengers depend on the level of measures taken based on the current epidemiological situation?
(2) Is it possible to assume that a suitable conceptual and systemic setting of measures in railway passenger transport will not significantly reduce transport performance even during a worsening of the epidemiological situation?

Such a procedure for researching the impact of pandemic measures on ensuring mobility can be used in the future when restrictions are introduced. This will be possible according to prepared procedures with predictable impacts on the population and the economy.

4. Results

One of the strategies that successfully lessen the negative economic effects on passenger (and freight) transportation is the development of policies for a sustainable rail transport market. The use of these criteria by each member state needs to be transparent, unbiased, and free from prejudice. As part of EU initiatives for a sustainable rail transport market,

infrastructure managers should be permitted to determine market surcharges for the use of infrastructure or reduce, release, or postpone payment of infrastructure access costs. The infrastructure manager's operational and employee-focused COVID-19 preventive strategies are listed in Table 2. The goal of these tactics is to halt the virus's spread.

Table 2. Proposal of measures introduced by the infrastructure manager. Source: authors.

Infrastructure Manager Measures	
Employees	**Operation**
Provide safe and hygienic goods to staff members who interact with passengers.	Cleaning and disinfecting the surfaces, handles, handrails, armrests, tables, and other areas of the train station
Permit the infrastructure manager's staff to work from home if their line of work permits it.	Public education on how to stop the spread of the virus when using public transportation through pamphlets and information technology in stations
If the nature of the work and the working environment permit it, reduce the number of personnel present during the shift.	Making room for stopping trains or wagons in case of an emergency, introducing the use of an infrastructure manager/employee to mediate the sale of travel papers (contract)

Table 3 contains a list of the planned actions for train operators (railway undertakings) at the station and onboard the train. Passengers will be able to travel by train in comfort, safety, and responsibly by implementing air conditioning, higher cleanliness standards, and other crucial steps in the compartment.

Table 3. Proposal of measures introduced by the railway operator. Source: authors.

Operators Measures		
In the Station	**In the Train**	
	Passenger	**Operation**
Make seat reservations in long-distance trains (apart from passenger trains) mandatory.	Introduce the requirement to always wear a face mask or respirator while traveling on any of the carrier's trains.	Establish a daily inspection of the air conditioner's operation.
Introduce the sale of or requirement to buy travel papers in advance (through online stores, mobile apps, SMS tickets, etc.).	Limit client seating (every other table) in restaurant wagons to preserve the required distance.	Monthly filter replacement
Suspension of the storage room's luggage reception	Permit passengers to consume food to go or use an app to order food directly from their seat	Beyond routine cleaning, disinfection should occur at least once per day. Polymer disinfection should be done twice per week and last for 6–7 days.
Do not distribute and transfer objects that have been found on trains even after getting in touch with the person who lost them.	Permit passengers to purchase food from mobile bars	Increase the safety of all employees working for the carrier by placing disinfectants in all train wagon access areas.

The influence of the number of transported passengers on the degree of measures introduced in the period from March 2020 to February 2021 is shown in Figure 6, and in the period from March 2021 to February 2022 in Figure 7.

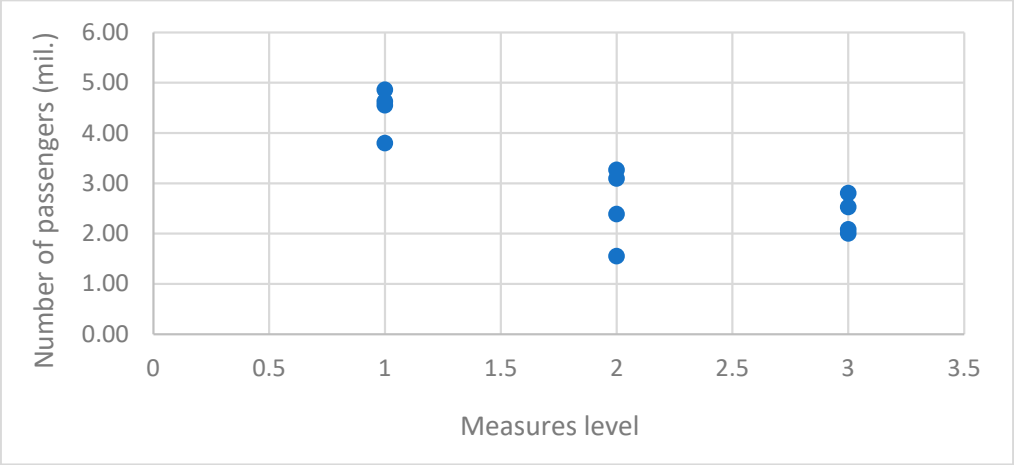

Figure 6. The influence of the number of transported passengers on the degree of measures in the period from March 2020 to February 2021. Source: authors.

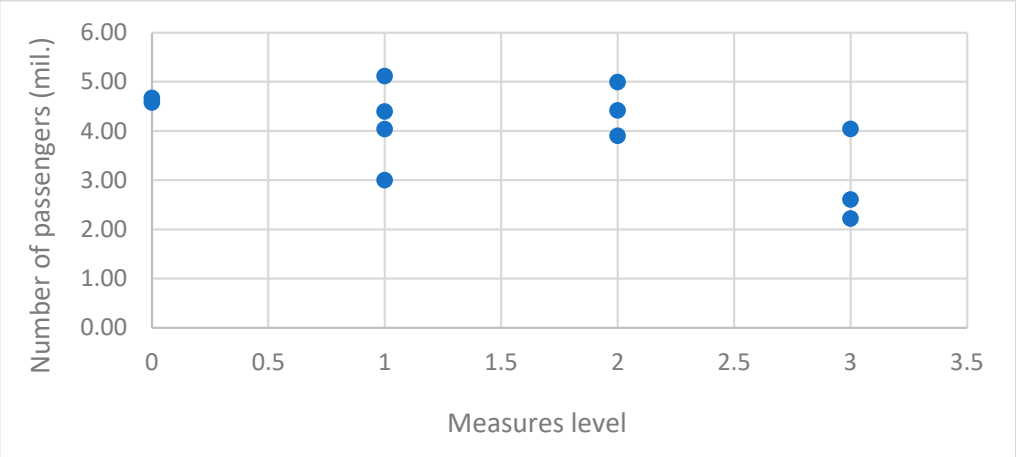

Figure 7. The influence of the number of transported passengers on the degree of measures in the period from March 2021 to February 2022. Source: authors.

As part of further research, the dependence of the train kilometers as well as the number of transported passengers on the degree of the implemented measure has been worked out (see Figure 8). The graph shows that the number of train kilometers was slightly reduced in the spring months of 2020 and the winter months of 2021. The number of transported passengers changed more significantly. A major drop was recorded in April 2020, but gradually these values began to increase in the following months, but from September 2020 until February 2021, they decreased again. In the spring and summer months of 2021, the number of transported passengers decreased, but from September to December, they once again decreased. In the course of 2022, there was an increase in their number and subsequent stabilization.

Based on previous measures that were introduced in the Slovak Republic, a new system of measures is proposed, the so-called COVID machine, which will be applied in railway passenger transport. For better clarity and efficiency, only three levels of measures are proposed. The individual levels will correspond to measures taken by the state, which are shown in Table 4.

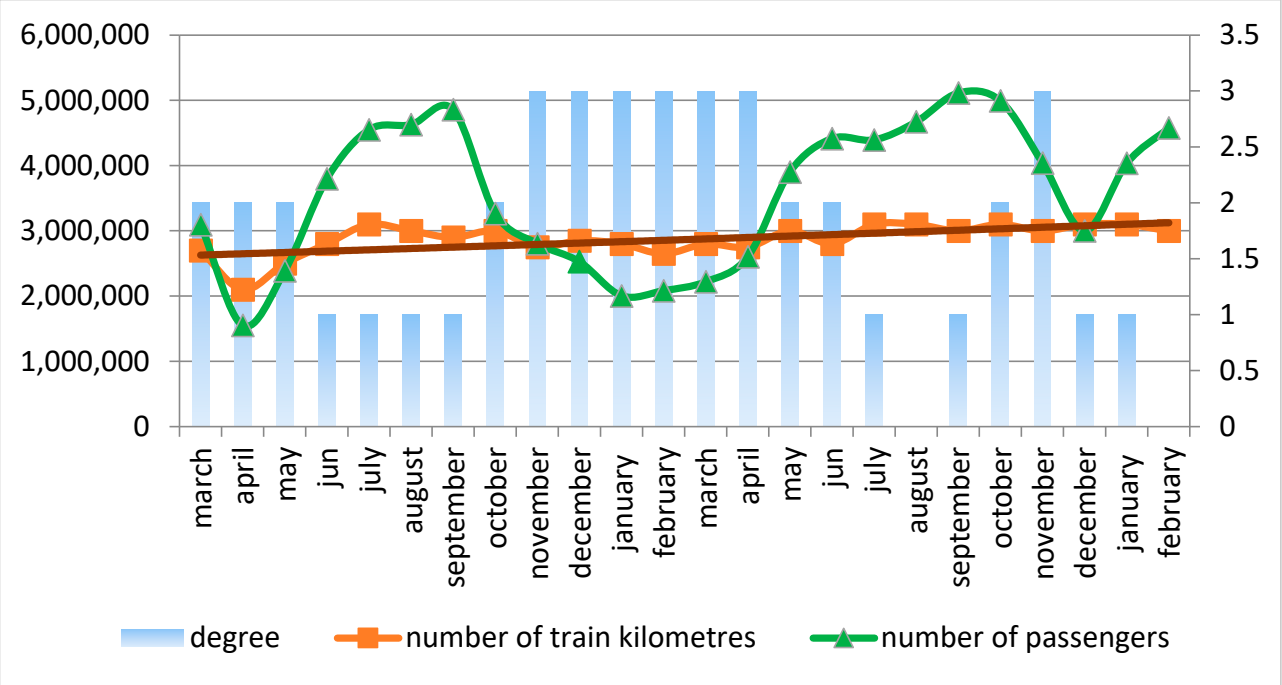

Figure 8. Dependence of the train kilometers transported passengers and degree of implemented measure (period March 2020–February 2022). Source: authors.

Table 4. New system of proposed anti-pandemic measures. Source: authors.

Level	Measures Introduced by the State within the Particular Level
1	Shops and establishments are open (possible small restrictions regarding the limitation of the number of customers); Home office introduced only in necessary cases in certain jobs; Universities are closed, secondary and primary schools are open (possibly with small restrictions); Capacity limitation at mass events; Slight restrictions on travel abroad; No curfews.
2	Certain shops and establishments are closed (possible restrictions regarding the limitation of the number of customers); Home office is recommended for most jobs; Universities are closed, secondary and primary schools are open (with strict restrictions); Certain mass events are closed, strict capacity limitations at other mass events; Certain restrictions on travel abroad, possibly in certain areas within the state; Possibly curfews in certain areas or regions.
3	Most shops and establishments are closed; Home office is required in most jobs (if possible); Close universities and secondary schools, possibly even elementary schools; All mass events are canceled; Travel restrictions or prohibitions abroad, possibly also between districts; Curfews at certain hours.

Table 5 contains the proposal of specific operational and organizational measures in the railway operator in the case of particular levels of the introduced measures.

Table 5. Overview of the proposed operational and organizational measures in terms of railway operator. Source: authors.

Level	Operational and Organizational Measures
1	Increased disinfection of trains, stations, and common areas, distribution of mini vitamin packages, preventive random temperature measurement of passengers, recommendation to purchase travel documents online (partial restriction of sale of travel documents at personal ticket offices).
2	Increased disinfection of trains, stations, and common areas, distribution of classic vitamin packages, installation of special equipment to identify symptoms of the COVID-19 disease (including additional hand disinfection), a strong recommendation to purchase travel documents online (significant restriction of sales of travel documents at personal cash registers), closure of customer centers.
3	Significant disinfection of trains, stations, and common areas, distribution of maxi vitamin packages, installation of special equipment to identify symptoms of the COVID-19 disease (including additional hand disinfection), possibility to purchase travel documents only online (sales at personal ticket offices suspended), closure of customer centers, provision of basic transport services only for critical infrastructure employees.

It is also critical to emphasize that, should the actions be implemented, fewer train connections will be made. Long-distance rail passenger transport, international rail passenger transport, and regional and suburban rail passenger transport must all be distinguished, nevertheless. Every one of the aforementioned varieties has unique characteristics and guarantees that the needs of other passenger groups are met. Table 6 displays the suggestion for reducing specific modes of transportation within the individual measure levels.

Table 6. Relative values of reduction proposal of train performance in train kilometers according to the measures level. Source: authors.

Level	Number of Connection Reduction		
	Regional and Suburban Rail Passenger Transport	Long-Distance Rail Passenger Transport	International Rail Passenger Transport
1	10%	20%	30%
2	20%	30%	50%
3	30%	50%	100%

Based on the proposal and data on transport performance in previous years in Slovakia (number of train kilometers), there is a possibility to create a prediction in the event of a reduction in regional and long-distance rail passenger transport. An example of prediction data is shown in Table 7.

Table 7. Train performance prediction in train kilometers, according to the measures taken. Source: authors.

Prediction in the Case of Introduced Measures (per Week)	Without Restrictions [Train Kilometers]	1st Level [Train Kilometers]	2nd Level [Train Kilometers]	3rd Level [Train Kilometers]
Regional and suburban passenger transport	495,238.97	445,715.08	396,191.18	346,667.28
Long-distance rail passenger transport	212,245.27	169,796.22	148,571.69	106,122.64

The prediction of total train kilometers per week in the case of introduced measures is shown in Figure 9.

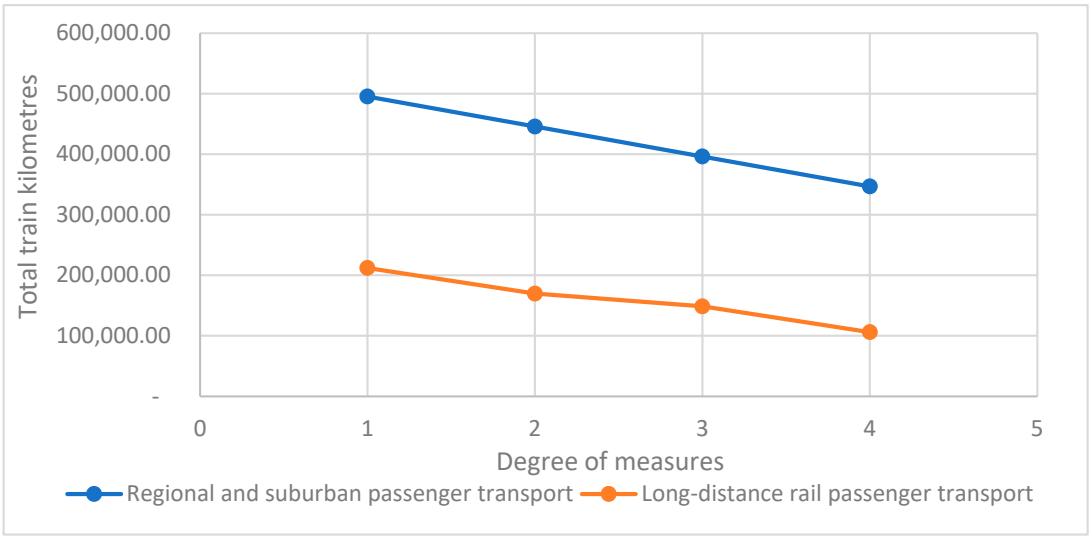

Figure 9. Prediction of the transport performance of the introduced measures. Source: authors.

The last part of the research is the proposal of the train traffic diagram, where the specific examples of the reduced number of train connections on the model railway line A–B are shown. The proposals are implemented according to the individual levels (1–3) and types of rail passenger transport. The number of trains is reduced by the value shown in Table 6. The circuits of the train set in the regional railway passenger transport are shown in Figure 10; the individual connections are marked in color.

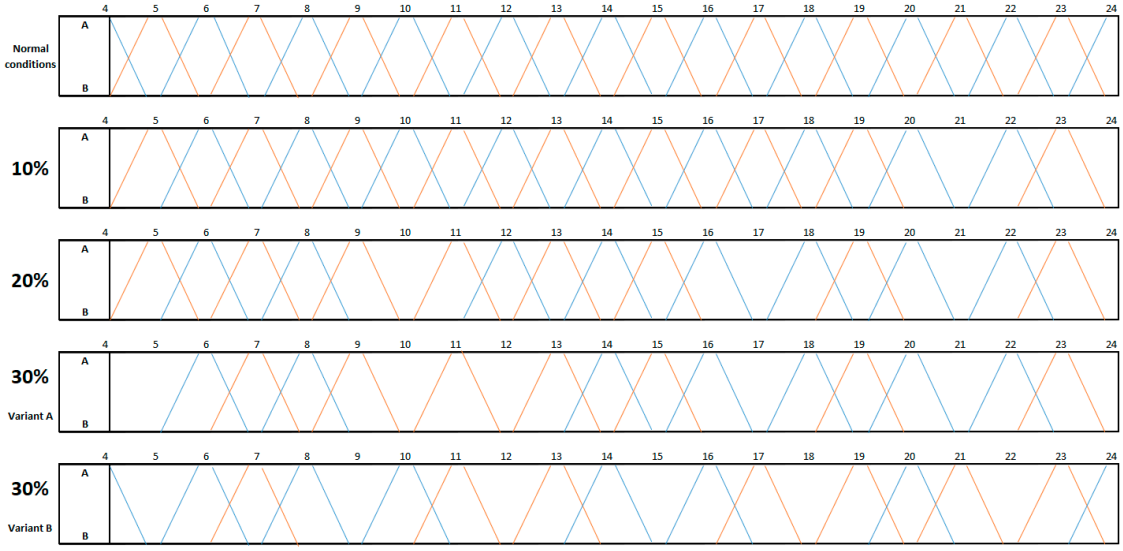

Figure 10. Impact of introduced measures on the regional railway operation. Source: authors.

On the model railway line, 20 pairs of regional trains operate in an hourly cycle. In the case of a reduction of 10%, two pairs of trains are omitted, namely the first morning train service on route A–B and three connections in the evening saddle. In the case of a reduction of 20%, two more pairs of train services are omitted in addition to the reduction of 10% (one pair in the morning saddle and one pair at the end of the afternoon rush hour). In the case of a reduction of 30%, two variants are proposed. In the first case, two extra pairs are reduced (one pair at the beginning of the morning rush hour and one pair at the beginning of the afternoon rush hour), and in the second case also, two extra pairs (one pair at the end of the morning rush hour and the other pair at the afternoon rush hour).

Also, one pair of trains in the evening saddle hour is removed, but in addition, the first morning connection on route A–B and the last evening connection on route B–A is added.

However, it is comprehensively true that even in the case of a reduced number of train connections, the train set circulation must be ensured as efficiently as possible, and basic transfer links to other railway lines must also be observed. In the case of the worst pandemic situation, it is necessary to pay attention to the increased disinfection of particular train sets. The circuits of the train sets in long-distance railway passenger transport are shown in Figure 11.

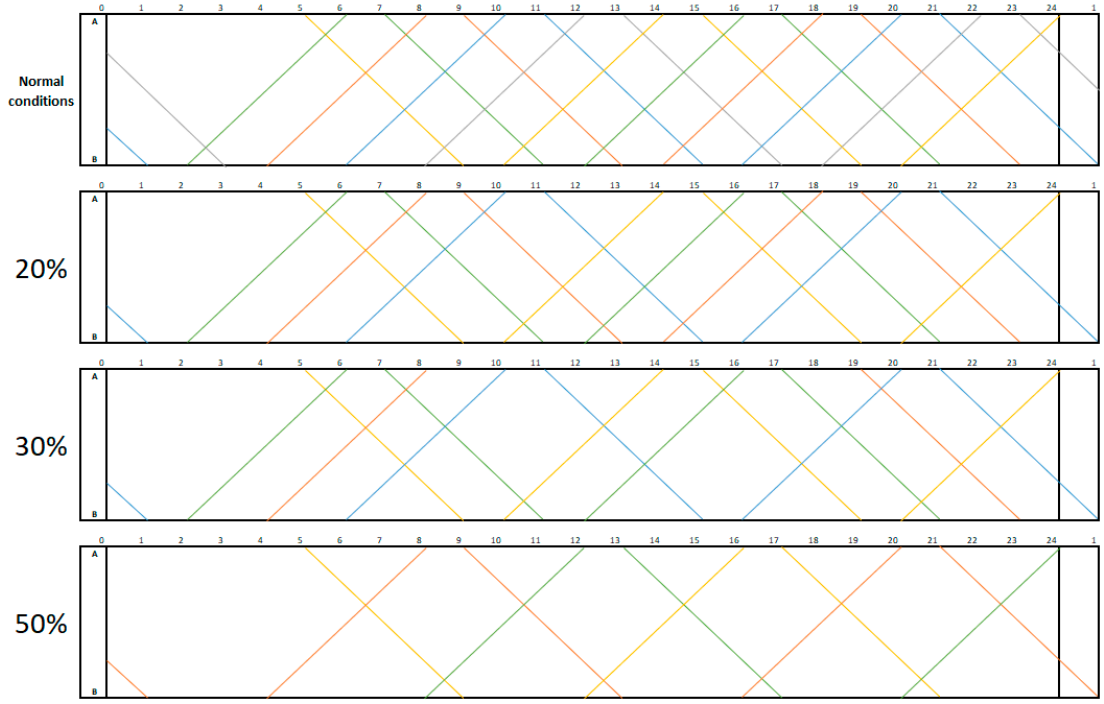

Figure 11. Impact of introduced measures on the long-distance railway operation. Source: authors.

In the case of long-distance transport, we are considering a basic transport operation of 10 pairs of long-distance trains on routes A and B in a two-hour cycle. In the case of a 20% reduction, two pairs of train connections are omitted, namely, the train set marked in gray. In the case of a 30% reduction, in addition to the grey set, one more pair is omitted, namely, the train set marked in red, which departs from station A at 9:00 a.m. and from station B at 2:00 p.m. In the case of a 50% reduction, five pairs of long-distance trains are proposed on the mentioned railway line in a regular four-hour cycle. The circulation of the train sets is subsequently adapted to this concept of operation. Longer stays of the train sets in the stations could be used for increased disinfection.

5. Discussion

In particular, a number of initiatives must be put in place to improve the effectiveness and allure of railway passenger transportation. The key goal will be to continue providing dependable, safe, sustainable, and high-quality public passenger transportation, even in extreme circumstances. Encouraging passengers to use public transportation as much as possible, even during an epidemic, is just as crucial as adequately protecting them from illnesses. Thus, the paper's central theme revolved around the specified core point. The analysis of transport flows and the current situation served as the foundation for the proposal's implementation. Its key theoretical contribution lies in the proposal of new systems and procedures in rail passenger transport in the event of a worsening pandemic situation. The key practical benefit lies in the provision of efficient and safe passenger mobility in the aforementioned emergency situation. Currently, there is no similar

methodical procedure and no crisis plan for dealing with similar emergency situations in railway passenger transport. Therefore, the proposed plan is one of the options to ensure more efficient functioning of railway passenger transport even during possible crises and emergency situations in the future.

Within the mentioned research, two research questions or hypotheses were also established. Research question 1 dealt with whether the number of transported passengers depends on the level of individual measures. Considering the results shown in the graphs in Figures 6–8, we can conclude that this dependence is significant, although the situation in the first, second, and third COVID-19 waves between 2020 and 2022 was slightly different. However, hypothesis no. 1 can be accepted. Research question 2 dealt with whether the conceptual and systematic setting of measures will not cause a significant reduction in transport performance even when the epidemiological situation worsens. The best answer would be detailed monitoring and analysis based on the current real situation in practice. However, the predictions in Figure 9 indicate that the individual levels of measures will cause a reduction in train kilometers, which logically can also cause a decrease in transport performance, but expert estimates indicate that this decrease will not be as significant as it was in the first and second COVID-19 waves when measures were taken by the state hastily and unsystematically. Therefore, based on the mentioned outputs and expert estimates, it is possible to accept this hypothesis as well.

The mentioned proposal and methodological procedure will contribute to the increase and efficiency of the operation of railway passenger transport, especially in times of crisis, when it is necessary to reduce the number of train connections. On a global scale, it establishes a systematic solution for the entire passenger transport sector. A functional transportation system is extremely important for a functioning economy, as well as other important sectors of the national economy. It follows that the practical contribution of the proposals is societal and has a significant impact on the development of society and sustainable development for people's lives in the long term.

The limitations of the proposed methodology lie in the correct linking of measures to limit public rail transport in the context of government pandemic measures. In the lessons learned from the crisis development and from the discussion within the research team, it is possible to clearly define the need to ensure a certain level of the scope of operation of railway transport, especially in regional transport. With the strictest pandemic measures, it is necessary to maintain this minimum range of performance in public transport. We consider two hours as the minimum interval between connections in suburban transport. The risk of achieving the optimal variant of the graph from the point of view of the economy is achieving a balanced circulation of sets with the necessary operational breaks for the necessary disinfection. Furthermore, the research should move in the direction of determining the safety of passengers from the point of view of preventing the spread of the disease. This will have the effect of reducing the population's fears of travelling by public transport and increasing the number of passengers, especially commuters.

6. Conclusions

The presented research in the contribution analyzes and describes the development trend of the selected indicators of railway passenger transport in the Slovak Republic in the period 2019–2022. Based on the available materials, analyzed indicators, and selected scientific methods, a new system and procedure for pandemic measures introduction has been elaborated with respect to supporting and developing public passenger transport during a pandemic period. The output of the complex research is, from a scientific point of view, the structuring of procedures for limiting mobility during a pandemic, the dependence between the degree of the announced measure and the degree of reduction in traffic performance in rail transport, and subsequently, transport performance in the number of passengers. To set traffic reduction measures depending on pandemic measures comes across as setting a minimum traffic service that should be guaranteed. The novelty of the research brings the new methodological procedure and its practical application.

These proposals provide a comprehensive tool for managing constraints in the railway passenger transport system, where both the railway infrastructure manager and the carrier have their roles. The development of the mentioned issue will be the subject of further scientific and research activities of the authors. Specifically, we will focus on increasing the attractiveness of railway passenger transport through deeper timetable optimization and introducing other measures to increase its efficiency. Current research, as well as possible future research, will significantly contribute to sustainable public mobility as well as cognitive mobility during a pandemic period that brings solutions for public transport.

The results of this study show that there has been a significant decrease in the use of public transport modes, a trend that is likely to continue, given the preferences of the participants. Such a shift in trends is not only a threat to the environment but also a major challenge to the global goals of sustainable development. Based on these trends, this study further makes recommendations to make the use of public transport safe and resilient in the long term. The findings of this study can be beneficial for transport planning during epidemics in the context of properly setting faulty mobility restriction measures and determining travel restrictions by considering people's travel motives and transport mode choices.

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