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FRAMEWORK PROPOSAL FOR SOLVING PROBLEMS IN RAILWAY TRANSPORT DURING THE COVID-19 PANDEMIC

Abstract. Since the beginning of 2020, the COVID-19 pandemic had a major impact on rail transport in the EU. The slowdown in the spread of the COVID-19 pandemic has been achieved by reducing the mobility of the population. The reduction in mobility has had an impact on passenger transport performance. The number of national rail passengers fell by as much as 90% during the first wave of the pandemic compared to the previous year. Several operators, especially new carriers, had to close down, while rail freight operators reported a dramatic drop in volumes as many sectors slowed or even stopped production as a result of the pandemic. The second wave of the autumn 2020 pandemic has forced many countries to take further restrictive measures regarding population mobility. The outbreak of the third wave of the pandemic has prevented a rapid recovery in rail transport, especially for passenger rail services. The paper focuses on the analysis of the impact of the pandemic and the measures put in place on the development of transport performance in rail transport in the Slovak Republic during the COVID-19 pandemic. The paper proposes operational and organizational measures against the spread of the COVID-19 pandemic in railway transport in the Slovak Republic.
Keywords: measures in railway transport, covid-19 pandemic, railway transport

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Introduction

Rail transport has a crucial role to play not only in the EU's strategy for a sustainable transport sector, but also in terms of economic and social cohesion. It contributes significantly to the mix of transport modes in the EU, while providing clean mobility and a high degree of efficiency. Following the outbreak of the COVID-19 pandemic, the volume of passenger and freight rail transport has fallen sharply due to constraints and lower demand for transport. Several players in the rail market had to close down. Rail operators have had to face a sharp decline in transport services. The effects of the measures introduced during the COVID-19 pandemic, which are related to transport, were addressed in his research by Zhang, et al (2021a). These authors developed a case study focused on the development of COVID-19 transport policy in six developed countries. The case study attempts to provide scientifically based evidence for proposing more effective COVID-19 policy measures in the transport sector. Ding & Zhang (2021) developed a case study focusing on the dynamic relationships between temporary behavioral changes caused by the COVID-19 pandemic and subjective assessments of policy-making.

They reveal the effects of risk perception in the use of public transport during a pandemic. Many researchers and organizations have investigated and reported on the negative impacts of COVID-19 on various aspects of public transportation. Most notably, many cities around the globe have experienced major reductions in public transit demand as a result of the substantially reduced economic activities. Work at home and online business became the new norm after the outbreak of COVID-19 (Zhang, et al., 2021b), contributing to reductions in passenger demand in the range of 80% – 95% (Vickerman, 2021). Modal preferences by commuters were also impacted by the pandemic. For essential out-of-home activities, it was observed that commuters preferred the private car, cycling, and walking over public transit (Gkiotsalitis & Cats, 2021). On the supply-side, many transportation agencies have cut service levels to reduce costs and meet government restrictions on service hours (Naveen & Gurtoo, 2021). Such reductions have consequently contributed to further decline in public transit ridership. It is thus obvious that the COVID-19 pandemic has adversely affected public transit ridership, both directly and indirectly. On the one hand, fewer people were commuting to work and school, and those who commuted were less likely to use public transit due to the perceived health risks while travelling (Tan & Ma, 2020). On the other hand, the restrictions enforced by governments and transit agencies have limited the public transit service levels, contributing to further decline in transit ridership (Marra, et al., 2022).

1. Impacts of the COVID-19 pandemic on railway transport in Slovakia

The impact of the COVID-19 pandemic on the rail passenger transport cannot be fully assessed as the pandemic situation still persists. Nevertheless, anti-pandemic measures are gradually being lifted. What is certain, however, is that the negative economic impact on transport is significant. The decline in the volume of performance of commercially motivated carriers and the consequent financial problems associated with it may result in a reduction in the level of quality of services provided, due to lower competition between carriers. The effects of the first wave of the pandemic were further exacerbated by the onset of the second wave in autumn 2020, when measures to reduce population mobility were reintroduced (European Commission, 2020). Due to the continuing pandemic of COVID-19, the curfew in 2020 and the reduced demand for train transport, the national carrier Železničná spoločnosť Slovensko, a. s. (ZSSK) started optimizing the supply of train transport on 7 March, based on the instructions of the Ministry of Transport and Construction of Slovak Republic, from the first changes to the train schedule diagram. Of the 34.4 million train kilometres planned for 2021, the 917,000 train kilometres will be lost (Ľupták & Pecman, 2021). Traffic in the vicinity of Bratislava was temporarily limited, where even after the reduction, a one-hour train cycle remained in the suburban transport area, which is concentrated during the rush hour to a thirty minute interval between trains. This meant a sufficient and high-quality transport supply due to reduced demand. On the Bánovce nad Ondavou - Veľké Kapušany line section, railway traffic was permanently stopped due to long-term public disinterest (8 trains). The reduction of the scope (or reduction) of transport services is the result of an agreement between ZSSK and Ministry of Transport and Construction of Slovak Republic. The aim was to optimize train supply and public transport expenditure so that the impact of the reduction on the public was minimal given the reduced demand. Ensuring smooth, high-quality and reliable public transport to work or schools by ZSSK trains is still fully implemented (ZSSK, 2020).

In 2020, the global health crisis caused by the COVID-19 pandemic affected the whole of the EU and also had a serious impact on passenger rail transport. In connection with the declaration of an emergency situation in the Slovak Republic, international train traffic with all neighbouring countries was temporarily stopped and the operation of IC trains was also stopped. The operation of all customer centres and the reservation workplace for personal equipment or selected points of sale was also suspended, the sale of national reservations was temporarily suspended and the ordering of restaurant, bed and lounger wagons and car wagons was also limited. These measures have negatively affected the management of the ZSSK and the consequences of the COVID-19 pandemic will continue to manifest itself in 2021 and beyond. Nevertheless, the ZSSK plans to continue ongoing projects in 2021 and to start new projects aimed at saving costs, increasing revenues and quality of services provided, and streamlining activities in the ZSSK (ZSSK, 2020).

2. Development of transport performance during the COVID-19 pandemic

The COVID-19 pandemic crisis has had a major impact on the supply, demand and economic performance of rail transport. The largest impact was recorded in the second quarter of 2020, from April to June. Passenger transport was more affected than freight transport, with international transport falling by an average of 85% in the second quarter of 2020, domestic transport falling by 18%, while freight transport fell by 14% in the second quarter of 2020. The reduction in rail transport in the first months of the crisis was a direct consequence of the public authorities' response to the COVID-19 crisis (restrictions on passenger mobility) as well as the impact of the global economic slowdown, which generally led to a reduction in transport demand. (Slovak Republic, 2020) The number of passenger trains within the public service operated in the network in the period from January to September 2021 is comparable to the number for the same period in 2019, while in 2020 it was by 7.8% compared to 2019 lower. However, the number of commercial passenger trains between January and September 2021 was still 21.5% lower than in the same period in 2019, which means that compared to the same period in 2020, when it was 23.3% lower in compared to 2019, there has been no recovery. The number of freight trains operating on the network was still 2.5% lower than in the corresponding period in 2019. Similar trends can also be observed when expressing the volume of traffic in train kilometres. From January to September 2021, the volume of passenger transport within public interest services expressed in wolf was 5.2% lower compared to the same period in 2019 (Slovak Republic, 2020). Figure 1 shows development of transport performance on Bratislava – Trnava line.

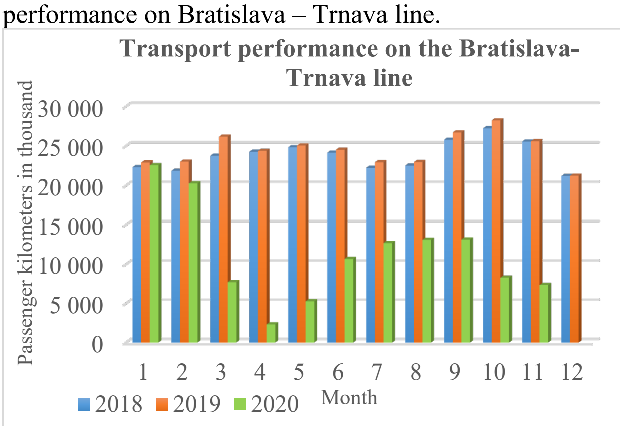

Fig. 1. Development of transport performance on Bratislava – Trnava line (Source: authors according to data from ZSSK)

Commercial passenger transport services expressed in wolf remained in 2021 compared to the same period in 25.6% lower in 2019, which is in line with the (low) level already reached in 2020. As regards the wagons of freight trains September 2021 remained 2.6% lower compared to the same period in 2019. It follows that the reduced level of rail transport caused by the COVID-19 pandemic still persists.

In passenger transport, performances were significantly affected by the pandemic, which results from the restriction of passenger transport trains, where it was set from 14 March2020 by changing the schedule of public transport, the so-called Saturday's performance regime. The highest decrease in output was recorded in April 2020. Output (train kilometres) in the given month decreased by 37.60% compared to 2019. In figure 2 we can see year-on-year change in transport performance on the Bratislava – Trnava line.

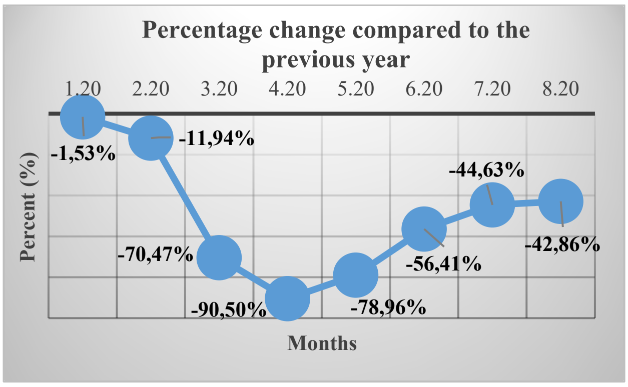

Fig. 2. Year-on-year change in transport performance on the Bratislava - Trnava line in 2020 (Source: authors according to data from ZSSK)

The largest percentage decline in output was in April 2020 and amounted to -90.50%. In May, transport performance began to rise slightly and reached a value of - 78.96%. Performance in passenger kilometres in rail transport also shows that the most significant decrease was recorded in April 2020. The loss of performance measured in passenger kilometres is a direct consequence of a significant reduction in the number of passengers in passenger transport in the period under review. Development of transport performance on Žilina – Čadca line we can see in figure 3.

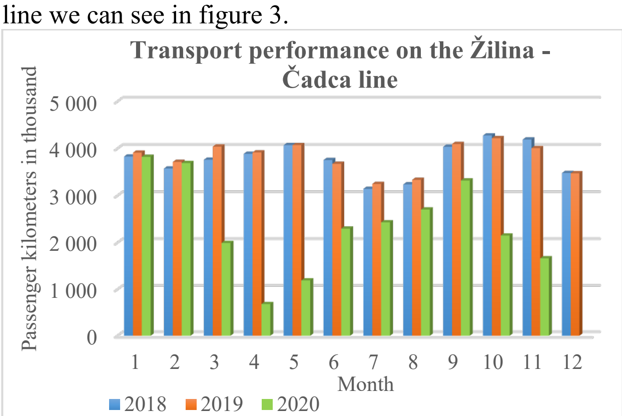

Fig 3. Development of transport performance on Žilina-Čadca line (Source: authors according to data from ZSSK)

Compared to 2018 and 2019, the decrease in transport performance on the regional railway line Žilina - Čadca in 2020 was considerable. April and May were the hardest hit again. After a slight recollection of the first wave of COVID-19, there was another decline in transport performance in November and December, caused by the second wave of the pandemic. Year-on-year change in transport performance on the Žilina - Čadca line in 2020 we can see in figure 4.

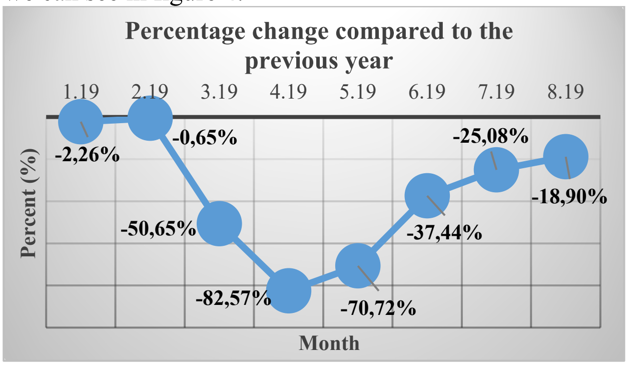

Fig 4. Year-on-year change in transport performance on the Žilina - Čadca line in 2020 (Source: authors according to data from ZSSK)

On the Žilina - Čadca line, the largest year-on-year change in transport performance was from March 2020 to May 2020, with the highest value reaching the month of April (-82.57%). Figure 5 shows development of transport performance on Košice – Humenné line.

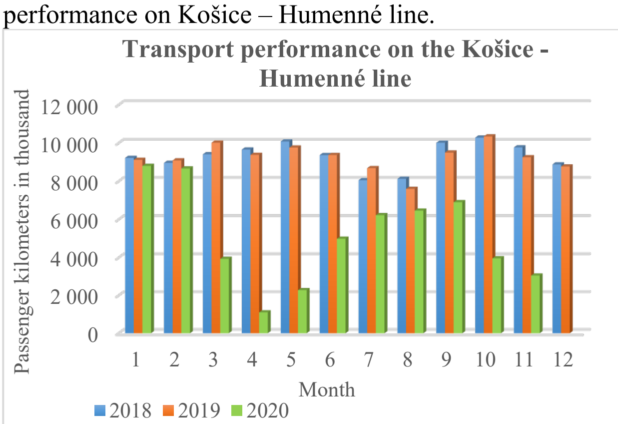

Fig. 5. Development of transport performance on Košice – Humenné line (Source: authors according to data from ZSSK)

In the figure 6 we can see Year-on-year change in transport performance on the Košice - Humenné line in 2020.

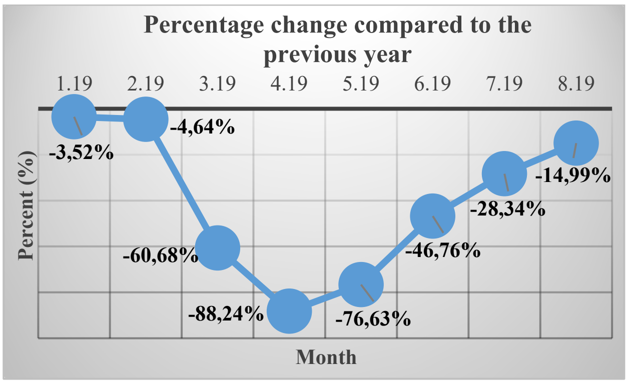

Fig. 6. Year-on-year change in transport performance on the Košice - Humenné line in 2020 (Source: authors according to data from ZSSK)

The largest year-on-year decline was recorded in April 2020 at -88.24% and in May (-76.63%). After these two critical months, transport performance began to rise again. Figure 7 shows the development of traffic performance on the Bratislava - Košice line in the years 2018 - 2020.

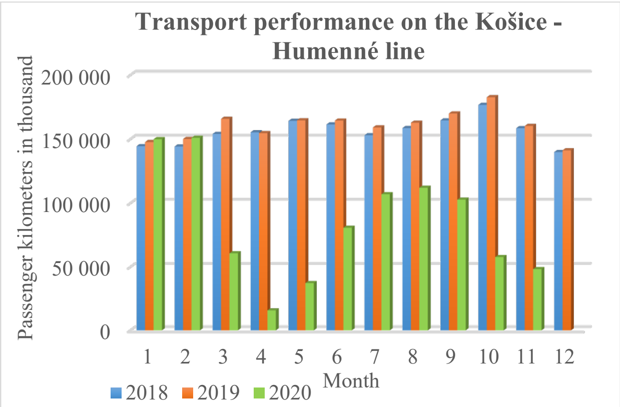

Fig. 7. Development of transport performance on Bratislava – Košice line (Source: authors according to data from ZSSK)

In the picture 7 we can observe transport performance on the Bratislava-Košice line during the years 2018 to 2020. The data show the increasing popularity of long-distance rail transport during 2019 and the first months of 2020. Regular monthly services range between 140 million during less popular months up to the border 180 million during October 2019. Figure 8 shows year-on-year change in transport performance on the Bratislava - Košice line in 2020.

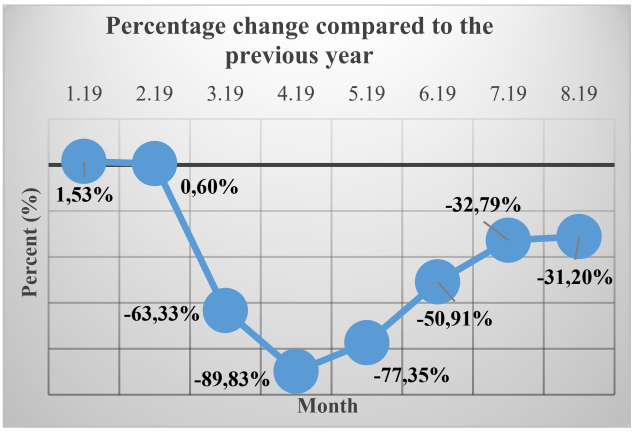

Fig. 8. Year-on-year change in transport performance on the Bratislava - Košice line in 2020 (Source: authors according to data from ZSSK)

During the first months of 2020, the trend of steady growth in transport performance continued. With the arrival of the pandemic in March, we can again observe a two-thirds drop in performance, reaching an absolute bottom in April 2020. The renewed trend is the same as the return trend, but transport performance remained 33% to 31% lower during the summer months by 2019, with passenger numbers only 25 to 22% lower. The reason for the lower performance may be the above-mentioned trend of longer trips during the summer, for example by students from Bratislava back to the east. As colleges remained closed during the first half of 2020, students traveling the entire length of the session remained at home and transport performance was higher. Table 1 shows change in transport performance compared to year 2019.

Table 1. Change in transport performance (passenger kilometres) compared to 2019 (Source: authors according data from ZSSK)

Track section		Bratislava - Trnava	Žilina – Čadca	Košice – Humenné	Bratislava – Košice	Average
Months	1.	2%	-2%	-4%	2%	-1%
	2.	-12%	-1%	-5%	1%	-4%
	3.	-70%	-51%	-61%	-63%	-61%
	4.	-90%	-83%	-88%	-90%	-87%
	5.	-79%	-71%	-77%	-77%	-75%
	6.	-56%	-37%	-47%	-51%	-46%
	7.	-45%	-25%	-28%	-33%	-30%
	8.	-43%	-19%	-15%	-31%	-25%

The COVID-19 pandemic also affected the management of the ZSSK in 2021. In the months of January and February 2021, compared to 2020 (January and February 2020 were not yet marked by a pandemic), we transported 7.9 mil. passengers less (-65.24%), which corresponds to a shortfall in revenues from passenger transport in the amount of 9.2 mil. EUR (-71.24%).

3. Proposal of measures against the spread of COVID-19 in railway transport

The proposed measures against the spread of COVID-19 can also be called operational-organizational measures. We methodically divided them into direct measures and indirect measures. These measures are characterized by the fact that they do not require high investment requirements and are not significantly demanding to implement. Proposal of direct measures shows in figure 9.

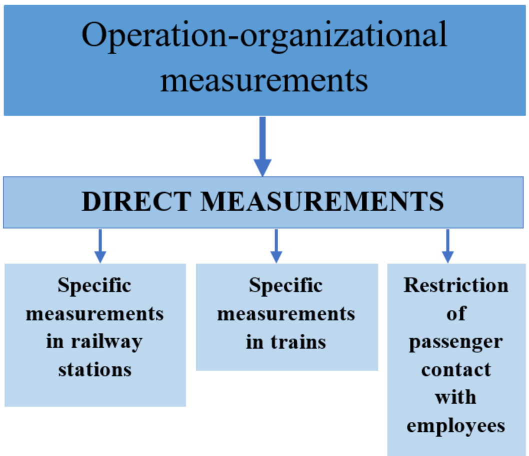

Fig. 9 Proposal of Operation – organizational direct measures (Source: authors)

Direct measures can be divided into specific measurements in railway stations, specific measurements in trains and Restriction of passenger contact with employees.

Figure 10 shows proposal of indirect measures in railway transport.

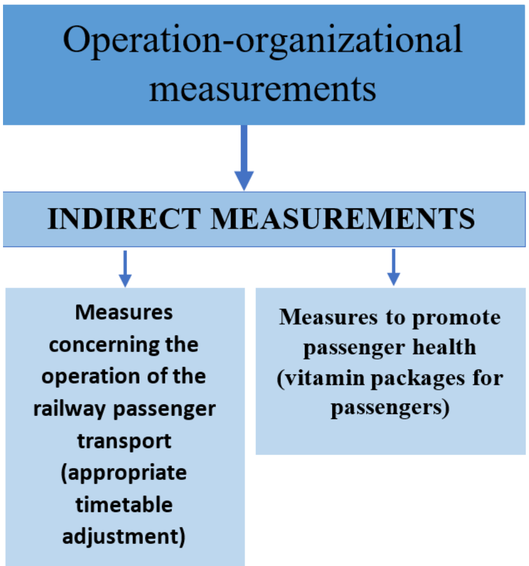

Fig. 10 Proposal of Operation – organizational indirect measures (Source: authors)

Indirect measures can be included Measures concerning the operation of the railway passenger transport and measures to promote passenger health.

3.1 Special free vitamin packages for passengers

As several studies in the field of virology have shown that regular use of the right vitamin composition has a significant effect on the body protection increasing against infections, including SARS 2-Covid-19 and significantly alleviates disease, relieves certain difficulties and accelerates recovery to offer passengers free packages, which will include:

- Vitamin C 250 mg,
- Vitamin D3 2000iu - 30 tablets,
- Selenium, Zinc Forte - 30 tablets,
- 200 ml hand cleansing gel,
- disposable mask (10 pcs/FFP2 type respirators 5 pcs).

These packages will be provided to passengers upon fulfillment of at least one of the following conditions, but not more than once a month:

- after traveling 300 km,
- for daily commuting by train to any distance (in the range of at least 15 calendar days per month).

Package delivery could be done:

- subject to strict anti-pandemic measures at pre-designated locations on or near railway stations (on the basis of a document presented where the passenger proves that he has met at least one of the above conditions, a package will be issued to him at that location),
- distribution to the passenger's specified address,
- distribution to another place (pharmacy in the place of residence), where this package will be issued free of charge on the basis of the submitted document.

The benefits of this operational-organizational measure will lie in particular:

- motivating passengers to make more intensive use of rail passenger transport,
- in motivating passengers to take greater care of their prevention against all viral diseases, which at the same time reduces the risk of their infection during regular train journeys and other means of public passenger transport.

3.2 Modification and disinfection of common areas in wagons and stations

The interior of the vehicle must be suitable for the health safety of the vehicle. This faultlessness is related to influencing the bacterial, viral and fungal microflora to make it as dangerous to humans as possible. Diseased bacteria and viruses enter the air through breathing, talking, but especially coughing and sneezing of passengers. Bacteria and viruses that attach to the wall surface:

- they can find a source of nutrients there,
- they may multiply there if their mass of the means of transport does not affect them,
- are directly destroyed by the mass from which the means of transport is constructed.

In order to ensure health safety, the third mentioned option is optimal, the mass of the means of transport must be adapted to be able to directly destroy bacteria and viruses or other effective measures must be provided that can eradicate these microorganisms quickly and effectively. It is therefore proposed:

a) ensure regular disinfection of toilets and common areas - the authorized employee will disinfect toilets and common areas also during train running at regular intervals (in long-distance trains behind each station / stop);

b) ensure that each passenger disinfects himself / herself in his / her own interest (on arrival and before departure) by means of a disinfection which could be located in each compartment and in each of the four seats in the case of centre wagons;

c) install an automatic air purifier (for example Daikin), which reduces the transmission of droplet infections, while removing common areas of dust, mites, bacteria and especially viruses, using patented Flash Streamer technology, which can destroy 99.93 in a certain area % of common influenza viruses and up to 99.98% of human coronavirus belonging to the same group as the current SARS-CoV2 virus;

d) install specific microbial destruction equipment, in particular Germicidal lamp, UV disinfection and UV surface disinfection.

The following special equipment could be located:

- at railway stations in common areas and waiting rooms,
- in the wagons of individual trains (in the case of open wagons with an aisle in the middle of 2-5 devices in the wagon; in the case of wagons with a compartment, it is necessary to consider whether it is necessary to place them in each compartment).

However, it may be necessary to manufacture specific types of these devices in order to be able to locate them appropriately.

3.3 Restriction passengers' contact with employees

It is strongly recommended to apply measures to passenger transport processes that limit passenger contact with carriers' employees. It is primarily a matter of limiting this contact at railway stations and on trains.

Measures at railway stations

They consist of limiting passengers' contact with cashiers at personal cash registers, which should be kept to a minimum in this case - this will motivate passengers to buy tickets online (via the internet or via a mobile application), which will also be more advantageous for them in that that they will not have to wait in lines at the cash desks at train stations, but they can comfortably arrive at the station just before the train leaves.

Another measure could be the introduction of turnstiles in the interior of railway stations, underpasses or platforms. These turnstiles would be located in reserved places and each passenger would have to go through them and would only be released after reading a valid travel document. In the case of the introduction of turnstiles, regular checks of travel documents by train drivers would not have to be carried out on trains, but only a random check by inspectors. It would also be appropriate to consider the installation of special devices that would be able to measure the body temperature of passengers before boarding the train, or identify other symptoms of COVID-19 or the possible degree of infectivity of the passenger to their surroundings. These operations could also be carried out at railway stations in the area before entering the underpasses or platforms or before entering the station building by means of a special device (something similar to frames at airports). Each passenger would pass through such a device, and this device would immediately measure his body temperature, or other indicators of his health and, based on the results, he would then be admitted to the platform and on to the train. An alternative solution could be to install a gel disinfection dispenser with body temperature measurement.

Measures in trains

They consist mainly in limiting contact with the train staff, which will also be due to the lack of train drivers in the ZSSK and. with reduced to a minimum. The control of travel documents will take place on the train in such a way that an automatic QR code reader of travel documents will be placed in each wagon above each seat, while the passenger will scan his travel document before the sitting in a specific seat. After the travel document has been scanned, a green light will illuminate above the place. If a valid travel document is scanned but in the wrong place, the light will turn yellow and if no travel document is scanned, the light will turn red. However, this progressive system can only be introduced in the case of mandatory local train connections. Subsequent checks will be carried out by an auditor or other authorized employee, and only in the case of such passengers, whose control indicator over their seat will not turn green. This measure could serve as an alternative to the introduction of turnstiles at stations.

3.4. Introduction of mandatory seats and limitation of the capacity of individual train connections

If certain measures are put in place to help reduce the mobility of citizens, and thus a reduction in passenger frequencies can be considered, it will also be possible to reduce the capacity of individual train connections. This measure could also only be implemented if mandatory train seats are introduced. The individual alternatives could be the following:

- limiting the capacity of wagons to 50% - filling every other seat in wagons with compartments (max. three passengers in one compartment) as well as in wagons with an aisle in the middle (max. two passengers in one "four");
- limitation of wagon capacity to 33% - occupancy of every third seat, applicable especially in wagons with compartment compartments (max. two passengers in one compartment);
- limitation of wagon capacity to 25% - occupying every fourth seat, applicable especially in wagons with an aisle in the middle (max. one passenger in one "four");
- as a last resort, limiting the capacity of wagons with compartments to 16.67% (max. one passenger in the compartment);
- the placement of a specific glass wall in compartment wagons, which would be mounted through the middle seat in both rows, thus achieving better protection for passengers and at the same time more space and privacy for them - in this case the capacity of these wagons could be limited to 66.67% (max. four passengers in the coupe);

- placement of a specific glass wall also in wagons with an aisle in the middle, between the individual fours, or pair of seats (in this case 50% of the capacity in these wagons would be recommended).

This measure can be applied especially in long-distance transport, in regional transport it is significantly more complicated. However, capacity constraints could also take into account the groups in which the passengers travel (whether the passenger is alone, a couple, or a family or a larger group). Based on this, coupe compartments could be reserved for families or groups of people.

The implementation of the most of the above proposed measures will have a major impact on employment in the rail passenger transport sector. As a significant reduction is considered, or absolute abolition of train managers and personal cashiers, it will be necessary for these staff to find an alternative job. They could find application, for example, as special inspectors on trains, checking only those passengers who did not read their travel document correctly (their indicator light would not turn green), and they could also help to disinfect trains and stations and to check passengers when crossing the turnstile, or body temperature measuring device. They could also work as operators who could assist in the electronic sale of travel documents and also in organizing the distribution of vitamin packages for passengers.

Another group of measures could be **construction and renovation measures** (see Figure 11). These measures are technologically, time and financially more demanding.

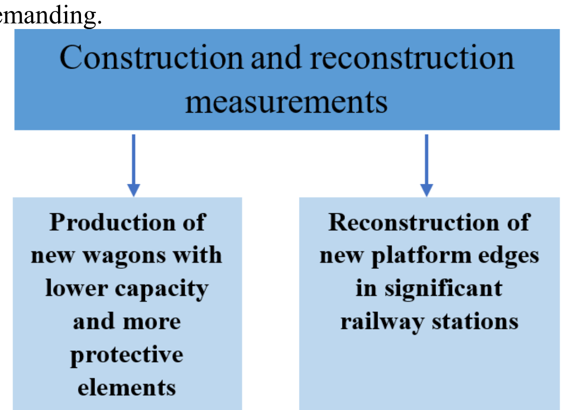

Fig. 11 Proposal of construction and reconstruction measures (Source: authors)

The proposal of construction and reconstruction measurements contains production of new wagons with lower capacity and more protective elements and reconstruction of new platform edges in significant railway stations.

Conclusion

During the first wave of the pandemic, rail transport in Slovakia suffered a significant drop in transport performance. With the declaration of the global pandemic and a state of emergency in the Slovak Republic in March 2020, we can observe an average drop in performance on all routes by 61%. The sharp decline in output continued until April, when it stopped at an average of 87%.

The positive effects on rail transport in the Slovak Republic have been evident for several years. The number of passengers grew every year before 2020 and it can be assumed that after the end of the pandemic, the growth trend will resume. Functioning railway connections within the Slovak Republic offer a suitable alternative to the individual car transport for transfer between regional cities. There is a presumption that with the resurgence of cars on the roads, potential passengers will find their way back to rail transport. The European Union's efforts to reduce emissions through the financing of greener modes of transport provided by rail can also contribute to long-term positive developments. With the gradual reconstruction of lines from sources partially provided by the European Union, the competitiveness of train transport in Slovakia may increase. The negative effects of the pandemic are more of a short-term threat to rail transport. Weakened passenger confidence in the sterility of trains and stations is unlikely to persist for more than half a year after the end of the pandemic. The transfer of passengers to the individual car transport, combined with the effort to avoid human contact, will no longer be an attractive option with a large number of cars returning to the roads and opening up the economy.

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IMPROVING EDUCATIONAL PROCESSES USING RESEARCH OF NEW KNOWLEDGE IN THE RAILWAY ENERGY EFFICIENCY MANAGEMENT SYSTEM

Abstract. At present, new knowledge about the physical nature and empirical phenomena in the field of distribution, losses, recuperation and consumption of electricity in railway transport is undergoing revolutionary changes. To date, the outputs of various types of traction electricity consumption on electric traction units (HEKV) and in the railway distribution network of the EU railway infrastructure manager (LDSŽ - Local Distribution System of Railways) have not been theoretically or practically analysed in available publications or on the scientific market. There are no empirical or experimental calculations and mathematical models at the level of mathematical approximation and intelligent prediction, i.e. at the level of preparation of technical specifications and documentation for expert software and effective ICT solutions to this problem. Research into new phenomena in the field of railway energy and research in the field of railway energy and research into expert systems and machine learning. The article describes the basic characteristics of determining the prediction of energy efficiency of traction electricity. Brings the results of the project "Research of new knowledge in the field of intelligent energy efficiency management system in rail transport using a modular neural network", which aims to innovate procedures in solving the problem and didactic transformation of scientific content to simplify them into a subject understandable to students as interpretive and application concept of didactics of professional subjects. Transform the curriculum into students' knowledge, attitudes and habits using teaching methods, organizational forms and material resources.
Key words: energy, carrier, prediction, algorithm, didactics, education

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Introduction

The current method of measuring energy consumption based on the application of the method of averaged specific electricity consumption (EE) in relation to the vehicle performance in a given train category. The price is based on the current value of the competitive price of power EE and its supplier, which is now secured through purchases through ŽSR for all carriers operating in the Slovak Republic. Prices for distribution system services are provided by ŽSR. As mentioned above, for each carrier, the amount of the corresponding traction EE costs and EE losses is calculated by the infrastructure manager. This method has the advantages that no EHV / EJ metering kits are required and thus easier data processing due to the actions of the infrastructure manager. During the use of the above billing, various deviations and outputs of different types of consumption at HEKV and the railway distribution network of the railway infrastructure manager (LDSŽ - Local Distribution System of Railways) were found in the calculation process, which has an impact on the payment for electricity consumed by carriers. For innovations in the procedures in determining the consumption of traction EE, we used research methods to model the predicted and actual consumption in the given selected sections of lines and monitored the standard deviation by setting up multidimensional regression models. At the same time, we tested the setting of random processes of the influence of individual monitored parameters on the total predicted electricity consumption using artificial intelligence and machine learning methods. The aim was to determine such a procedure that, in relation to the monitored parameters, would set the most energy-neutral ratio between consumption based on coefficients and consumption based on the estimation of real consumption according to the model and using machine learning.

1. Current methodology of traction EE consumption billing

The methodology of billing the consumption of traction EE between individual carriers is performed on the basis of a contract for the supply of EE for electric traction. This methodology is based on the basic assumption that the amount of EE entering the traction substation (TT) and traction converter (TM) is either consumed by the EHV / EJ, traction system losses and non-EE propulsion (eg preheating of exchanges, pre-heating of kits, safety device) which covers EE losses in this traction system. Therefore, the whole methodology in the first phase summarizes the total amount of EE collected at its input. According to the current procedure, this amount is evaluated for a calendar month:

$$A_{TPS} = \sum_{i=1}^{n} \left[A_{i\_input} \right] \tag{1}$$

A_{TPS} the total electrical work consumed in the given traction current system by unmeasured EE consumption from the electric traction for the evaluated period [kWh],
index i traction substation (TNS),
index n total number of TNS at the input of all traction current systems,
A_{i_input} electrical work measured at the TNS input by commercial measurement of the superior operator distribution system and adjusted by deducting measured non-traction consumption [kWh].

Then, for the evalated monitored period (one calendar month) the transport performance (work) performed by individual carriers is processed. The total EE consumption of all carriers for the evaluated period is determined according to:

$$A_{EXT\_C} = \sum_{j=1}^{n} \sum_{i=1}^{m} DV_{ji} * ms_{ji} \qquad (2)$$

A_{EXT_C} total electrical work determined by calculation for EE r of different types of trains from all carriers for the evaluated period [kWh]

DV transport performance of trains and EHV / EJ of the j-th carrier with a division according to the type of differentiated trains and traction vehicles in electric traction [thous. hrtkm trains]

ms determined specific consumption EE, for differentiated types of trains [kWh / thous. hrtkm trains].

index j value index for all carriers for the evaluation period

index i differentiated type of train (eg R, Os, Nex, Pn, Lv)

index n total number of external carriers

The total work calculated in this way is then used to allocate EE costs from the superior distribution system operator in the ratio of the specific carrier in the given period realized (reported) transport performance against the calculated total transport performance:

$$k_k = \frac{A_{TPS}}{A_{EXT\_C}} \qquad (3)$$

k_k correction factor taking into account the difference between the total amount of electrical work actually consumed in the traction current system and the total electrical work determined by the calculation for billing. With the help of this correction coefficient, individual EE losses are also distributed among the individual carriers, including the EE's own consumption of the traction system,

A_{TPS} total electrical work consumed in a given traction current system by unmeasured EE consumption from electric traction for the evaluated period [kWh],

A_{EXT_C} total electrical work determined by calculation for EE consumption of differentiated types of trains from all carriers for the evaluated period [kWh],

Based on the knowledge of the size of this correction coefficient, the corresponding amount of EE can be calculated for individual carriers depending on their transport performance (work):

$$A_{j\_EXT} = k_k \sum_{j=1}^{n} \sum_{i=1}^{m} DV_{ji} * ms_{ji} \qquad (4)$$

A_{j_EXT} total electrical work [kWh] consumed by the EE of the j-th carrier in electric traction for the evaluated period,

k_k correction factor,

DV transport performance of trains and traction vehicles of the j-th carrier,

Ms determined EE specific consumption for the given train type,

index j values for all carriers in the evaluated period,

index i differentiated train type (eg R, Os, Nex, Pn, Lv),

index n total number of external carriers.

2. Interpretation of achieved results

Within the evaluated period of the project, a model of prediction of energy consumption was created depending on the following parameters:

- train type (Os, R, NEX),
- type of power supply system (AC, DC), resistance power supply schemes,
- slope ratios, restrictions,
- average temperature and temperature fluctuations for a given period,
- technological consumption ratio,
- polygonization.

From the above, it is clear that each traction power system has not only its specific properties but also different energy losses. The first task was to define the criteria through which we will evaluate the individual variants of the solution and their ability, respectively. the possibility of meeting the defined criterion is expressed by the value of the cardinal rate of accuracy assessment. The value of the cardinal rate, ie the range of evaluation, defines the adjustable sensitivity of the method for self-learning algorithms. The greater the number of alternatives and the greater the number of factors, the greater the margin, the greater the cardiac rate and the possibility to err in the final estimate of future consumption. We evaluated the degree of fulfillment or non-fulfillment of the defined criterion in two ways:

- minimizing - the fewer points he earns from the cardinal rate, the better he meets the variant defined criterion,
- maximizing - the more points he earns from the cardinal rate, the better he meets the variant defined criterion.

The individual variants can be sorted from best to worst.

2.1 Methods for determining the weights of criteria

This step in the decision-making process requires attention when it is necessary to clarify what is optimal in a given situation. Multicriteria decision-making methods often require differentiation of individual criteria in terms of significance (importance). The more important the criterion, the greater its weight. The individual criteria are denoted by K_j and their criterion weight in $_j$, j = 1,2,3, ... n, where n is the number of all included criteria. Mutual comparison of criteria weights, calculated by different methods, is possible only after standardization to the same scale of standard weights w_j, which are calculated by the relation (BROŽOVÁ et al., 2003):

$$w_j = \frac{v_j}{\sum_{k=1}^{n} v_k}, \qquad j = 1,2,3 \ldots\ldots n \qquad (5)$$

The sum of standard weights is equal to number one and at the same time they are non-negative numbers. There are currently many methods for determining the weights of criteria during the decision-making process. These methods differ from each other in their structure as well as in the calculation algorithm. For a suitable choice of method, it is necessary to know the information that will serve as input data for the model.

It is not possible to determine in advance which method of determining the weights of the criteria is the most appropriate, as the determination of the weights is of a subjective nature. It depends on the evaluator the most. In order to achieve an optimal solution, it is appropriate if more evaluators are involved in the solution, as well as methods and averaging the obtained values. The model used is based on one evaluator, but using several methods. For this model, it is appropriate to use any of the methods for determining the weights of the criteria, as the stated standard weights are only small deviations.

2.2 Data collection and validation

Experiments and mathematical modelling of electricity consumption measurement were processed on the basis of data from the performance of the railway line in the Czech Republic and electricity measurement from 2018 and 2019. The collection of primary data was provided by current SŽDC systems. Operational data on train runs are processed (agreed and confirmed with carriers) in the KAPO application and from there transferred to the SŽDC data warehouse, from where they were drawn for modelling purposes. The second source of data is SŽE data on EHV. The third source of data is SAP, where data on the total consumed traction EE for a given month were drawn.

2.3 Calculation of electricity consumption for modeling purposes

The EE consumption of the carrier's unmeasured sub-trains is calculated by multiplying the total sub-train capacity (HRTKM) by the relevant measured consumption value, which is defined for the given period and train type. For DC traction, the calculation is made according to the relation:

$$EE_{dx}^{N-DC} = \sum_{k=1}^{n}(MS_t^{DC} * \sum_{v=1}^{m} HRTKM_t^{DC}) \qquad (6)$$

MS_t^{DC} specific consumption by type of train and season,

$HRTKM_t^{DC}$ train performance according to train type.

For AC traction, the calculation is made according to the relationship:

$$EE_{dx}^{N-DC} = \sum_{k=1}^{n}(MS_t^{AC} * \sum_{v=1}^{m} HRTKM_t^{AC}) \qquad (7)$$

MS_t^{AC} specific consumption by type of train and season,

$HRTKM_t^{AC}$ train performance according to train type.

Measured powers

The EE consumption of all measured EHV carriers is calculated by calculating for each EHV the total AC and DC traction consumption separately for the whole month:

$$ES_m^{DC} = \sum_{j=1}^{m} ES_{km}^{DC} - ES_{zm}^{DC} \qquad (8)$$

$$ES_m^{AC} = \sum_{j=1}^{m} ES_{km}^{AC} - ES_{zm}^{AC} \qquad (9)$$

ES_{km}^{DC} consumption meter consumption at the end of the month,

ES_{zm}^{DC} consumption meter consumption at the beginning of the month,

ES_{km}^{AC} consumption meter consumption at the end of the month,

ES_{zm}^{AC} electricity meter consumption at the beginning of the month.

The calculation of the value of recovered EE per month is analogous to:

$$ER_m^{DC} = \sum_{j=1}^{m} ER_{km}^{DC} - ER_{zm}^{DC} \qquad (10)$$

$$ER_m^{AC} = \sum_{j=1}^{m} ER_{km}^{AC} - ER_{zm}^{AC} \qquad (11)$$

ER_{km}^{DC} the state of the recuperation meter at the end of the month,

ER_{zm}^{DC} the state of the recuperation meter at the beginning of the month,

ER_{km}^{AC} the state of the recuperation meter at the end of the month,

ER_{zm}^{AC} state of the recuperation meter at the beginning of the month.

Summary evaluation of EE carrier's consumption

The summary evaluation of the carrier's EE consumption is performed as the sum of EE consumption of unmeasured traffic performance and combined traffic performance multiplied by the correction coefficient for unmeasured traffic performance and EE consumption measured by EHV multiplied by the correction coefficient for measured traffic performance.

Formula for DC traction:

$$EE_{dx}^{DC} = (EE_{dx}^{N-DC} + EE_{dx}^{K-DC}) * k_n^{DC} + EE_{dx}^{M-DC} * k_m^{DC} \qquad (12)$$

EE_{dx}^{N-DC} unmeasured EE consumption of the carrier,
EE_{dx}^{K-DC} combined EE of the carrier,
EE_{dx}^{M-DC} measured by the EE of the carrier,
k_{n}^{DC} the EE redistribution correction factor of the unmeasured EE,
k_{m}^{DC} EE redistribution correction factor measured by EE.

Formula for AC traction:

$$EE_{dx}^{AC} = (EE_{dx}^{N-AC} + EE_{dx}^{K-AC}) * k_{n}^{AC} + EE_{dx}^{M-AC} * k_{m}^{AC} \tag{13}$$

EE_{dx}^{N-AC} EE consumption of the carrier,
EE_{dx}^{K-AC} combined EE of the carrier,
EE_{dx}^{M-AC} measured by the EE of the carrier,
k_{n}^{AC} EE redistribution correction factor immeasurable EE,
k_{m}^{AC} EE redistribution correction factor measured by EE.

The value of the correlation coefficients is calculated as follows. We calculate the total value of consumed EE as the sum of unmeasured and combined consumption of EE of all carriers in DC traction:

$$EE^{N-DC} = \sum_{dx-1}^{n} EE_{dx}^{N-DC} + EE_{dx}^{K-DC} \tag{14}$$

$\boldsymbol{EE_{dx}^{N-DC}}$ unmeasured EE of the carrier,

EE_{dx}^{K-DC} combined EE carrier.

Next we calculate the value of measured consumption for all carriers in DC traction:

$$EE^{M-DC} = \sum_{dx=1}^{n} EE_{dx}^{M-DC} \tag{15}$$

EE_{dx}^{M-DC} measured EE consumption of the carrier.

Subsequently, the calculated value of EE, which was not redistributed among the carriers in the DC traction system, is redistributed. If the value is negative, more EE has been redistributed by the carrier than was delivered to the supply system. In this case, the value of the invoiced EE will be reduced as a result. Otherwise, the EE value will increase. Next, the volume of EE that should fall when redistributed to unmeasured and measured outputs is calculated. Divided is done proportionally. Here, it is possible to apply another redistributive mechanism, which may not be proportional, in order to support the achievement of strategic objectives. For example, the advantage of measured transport performance due to the positive motivation of carriers to install electricity meters in EHV. Based on these assumptions, we can determine the correlation coefficient of unmeasured (calculated) EE consumption in DC traction:

$$k_{n}^{DC} = \frac{EE_{for\,redistribution}^{N-DC}}{EE^{N-DC}} \tag{16}$$

In a similar way, we determine the coefficient of measured EE consumption in DC traction:

$$k_{m}^{DC} = \frac{EE_{for\,redistribution}^{M-DC}}{EE^{M-DC}} \tag{17}$$

Using the same procedure, we calculate the correlation coefficients of unmeasured (calculated) and measured EE consumption in AC traction. Correlation coefficient of unmeasured EE consumption in AC traction:

$$k_{n}^{AC} = \frac{EE_{for\,redistribution}^{N-AC}}{EE^{N-AC}} \tag{18}$$

Correlation coefficient of measured EE consumption in AC traction:

$$k_{m}^{AC} = \frac{EE_{for\,redistribution}^{M-AC}}{EE^{M-AC}} \tag{19}$$

2.4 Results of the calculation model

The resulting values of the calculation model, which takes into account the newly proposed coefficients, are given in Table 1.

Table 1. Coefficient of the ratio of prediction and actual values

Year	A month	AC	DC	AC + DC
2018	1	1,172769	1,008125	1,0490963
2018	2	1,225857	1.046376	1,0920424
2018	3	1,175634	1.026080	1,0640353
2018	4	1.074599	0.931263	0,9672279
2018	5	1.043723	0,918996	0,9514317
2018	6	1.044541	0.907914	0,9432329
2018	7	1.037953	0.921287	0.9519793
2018	8	1.054666	0,915023	0,9501713
2018	9	1,058274	0,925570	0.9590950
2018	10	1.077217	0,941558	0,9752794
2018	11	1,154284	0.982187	1.0248118
2018	12	1.210060	1,015888	1,0637304
2019	1	1,256596	1.033255	1,0889971
2019	2	1,180545	1,002329	1,0467483
2019	3	1,134260	0,972946	1,0123351
2019	4	1.077707	0,958669	0,9884608
2019	5	1.094745	0,949565	0,9850777
2019	6	1.057496	0,928887	0,9610675
2019	7	1.048406	0,917076	0,9494876
2019	8	1,039493	0,910217	0,9422012
2019	9	1,047638	0.908365	0,9412471
2019	10	1.070892	0.936791	0,9710768
2019	11	1,096886	0,962623	0,9970719
2019	12	1,172724	1,010554	1,0527104

Note: Values outside the 5% tolerance band are marked in red

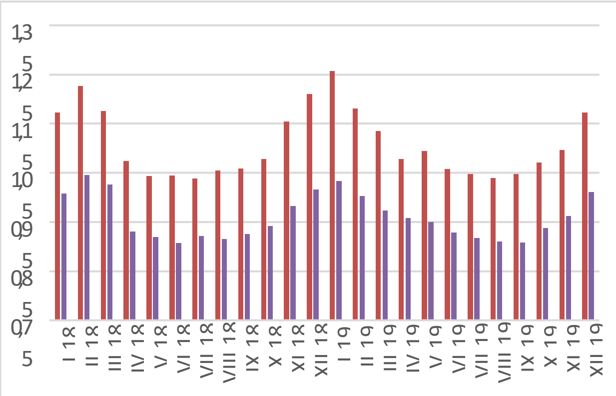

Fig. 1. Coefficient of prediction and actual values separately for AC and DC traction.

The following chart graphically shows the values of the total estimated balance coefficient in individual months. As can be seen from the graph, values falling within the tolerance band of +/- 5% were not reached in nine months. The partial results are good, but they do not reach the planned goal.

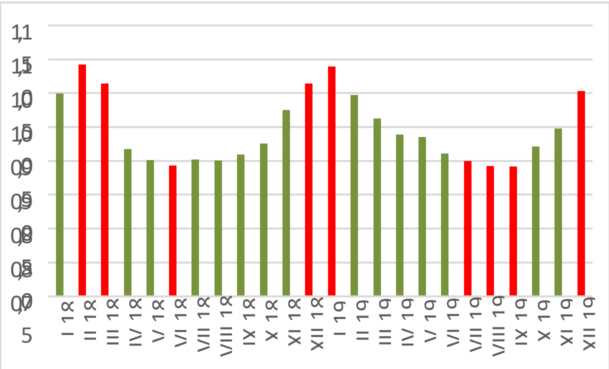

Fig. 2. Coefficient of estimation according to railway traction and individual months of measurement

Weighted coefficient, greens are values in the 5% tolerance band

3. Discussion of research results

The mathematical model for measuring electricity consumption on passenger and freight trains was tested and a purchasing model was developed based on data on rail transport performance in the Czech Republic and electricity measurement from 2018 and 2019. As part of the mathematical processing, the data were analyzed and evaluated from in terms of quality and quantity. Subsequently, the data were processed according to the methodology of hybrid billing of electricity consumption in the monitored period. In the evaluated part of the research, a computational model was developed for the purpose of determining and subsequent verification of new values of partial coefficients entering the computational hybrid model of billing electricity consumption in selected parts of the traction network to achieve a balanced energy balance. The proposal of new values of partial coefficients for the monitored data led to the achievement of very favorable values of the resulting coefficient of energy balance adjustment in individual months, when with two exceptions all values fall within the set tolerance band +/- 5%. Thanks to the use of mathematical algorithms developed in the research, for the calculations of the monitored coefficients and selectively set coefficients using the tested mathematical model, the total values for both tractions for the whole year 2019 in the amount of 1.0050946845 were achieved. Thus, only half a percent of the balance between consumption and supply of electricity, which is a satisfactory result. The individual values of the partial coefficients were also designed with regard to the future change in the ratio between measured and unmeasured traffic outputs, which was modeled using a scenario evaluating electricity consumption with the exclusion of measurement. In this scenario, a favorable value of the energy balance adjustment coefficient was also achieved, as most of the values fall within the set tolerance band.

4. Didactic interpretation of research results

We can use the research results for the interpretive and applied concept of didactics of professional subjects. Transform the curriculum into students' knowledge, attitudes and habits using teaching methods, organizational forms and material resources. From the point of view of managing the educational process at universities, it is very important to follow the most necessary didactic principles.

1. Principles concerning the content of teaching.
    a) what the student has to learn needs to be aligned with what he already knows
    b) ordered - the student learns the structured subject matter faster than unordered,
    c) teach the subject matter as a whole, but keep in mind that it is part of the whole,
    d) not to include knowledge that is not necessary in the given lesson,
    e) prepare didactic procedures that integrate students' activities with the content of teaching.
2. Principles of student motivation.
    a) motivation is more effective the more the student feels that the result depends on him,
    b) a positive attitude towards tasks increases the motivation to solve them,
    c) tasks arousing the student's curiosity and motivating them to fulfill them,
    d) are students for whom the main motivation is the need for acceptance by others,
    e) if the student considers the fulfillment of the task a success, his motivation increases,
    f) Motivation to complete a school task depends on the duration and strength of the tension that evokes the task or

circumstances.

3. Principles for the harmonization of pedagogical systems.
    a) when planning a lesson, it is necessary to take into account all the factors that make up the system and find a relationship between them,
    b) of particular importance for efficiency is the balance of objectives and opportunities, human and material,
    c) the planned or implemented system must be dealt with in relation to other systems,
    d) curriculum content, characteristics of students and teachers, aids, time, etc., these are all important factors that affect the proper management of teaching,
    e) the goal of every pedagogical system is to achieve the planned change in knowledge, skills and also in values.

Based on the above principles, it is necessary to create an optimal structure of the teaching unit, which is listed in Table 2. The optimal structure of the teaching unit is a condition for mastering the curriculum.

Table 2. Recommended Teaching Unit Structure

Stages of the teaching unit	**Teaching methods**	**Org. forms**	**Material resources**	**Duration**
Organizational part	an interview	mass	stationery, notebook	2 minutes
Objectives presentation	storytelling	mass	notebooks, writing utensils, blackboard	6 minutes
Motivation	motivational demonstration, problem as motivation	mass	Whiteboard, projector, PC, professional literature	10 minutes
Update of previously mastered curriculum	Question and answer method	mass	Whiteboard, projector, PC, professional literature, notebooks, writing utensils	10 minutes
Acquisition of a new curriculum	explanation an interview demonstration work with teaching material	mass	Whiteboard, projector, PC, professional literature, notebooks, writing utensils	35 minutes
Consolidation and deepening of knowledge	heuristic conversation problem solving	mass	Whiteboard, projector, PC, professional literature, notebooks, writing utensils	20 minutes
Homework assignment	storytelling	mass	notebooks, stationery, papers	2 minutes
Evaluation of the teaching unit and conclusion	an interview	mass	-	5 minutes

5. Conclusion

With regard to the implementation phase of the research project, new high-efficiency algorithms for highly efficient transport energy management were created to ensure market stability in transport and energy and to determine energy efficiency for potential customers of the rail logistics delivery-transport system. simulation, energy assessments and background materials on a sample of sensed traction electricity consumption. The achieved results give a precondition in further research tasks to achieve the main goal of research and to focus mainly on development a software tool for recalculation and forecasting of traction electricity consumption at HEKV and in the LDŠZ network, which will contain perceptron consumption prediction modules by which the multilayer and recurrent neural network will be the basis of artificial intelligence and machine learning to refine measurement and prediction of electricity consumption and loss.

A great benefit for the company is the development of the results of research tasks and their transformation into the curriculum at universities in the Slovak Republic in the development, implementation and use of modern digital technologies, including assistive technologies and the Internet. Developing students' habits, knowledge and skills to work with new digital technologies (digital competences) in exploiting the results of research tasks can help open education, which is also one of the goals of inclusive education. Open access to educational resources offers an opportunity to strengthen equality in education and to support the creation of educational. In this context, however, it is necessary to modify the goals, content, methods, forms, as well as staffing and material provision in educational processes at universities.

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COMPARISON OF CZECH AND SLOVAK RAILWAY INFRASTRUCTURE IN THE CONTEXT OF BASIC OPERATIONAL INDICATORS

Abstract. The level of development of railway transport is one of the indicators of the economic development of the state. If the state regularly invests in large volumes in railway infrastructure, it creates conditions for the operation of quality passenger and freight rail transport. Analytical comparison of railway infrastructures is key to understanding the increasingly abysmal differences between the quality of railway infrastructure in the two countries. The comparison will be made mainly from the Network Statement of both countries.
Keywords: railway infrastructure, SŽ, ŽSR, Czech republic, Slovak republic

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Introduction

Quality railway infrastructure is the basis for operating quality rail transport. Infrastructure wear and tear is one of the factors that reduces its quality. Extensive investment is needed not only in its maintenance and reconstruction, but also in the construction of new lines, which will create new connections for the transport of people and goods.

The comparison of railway infrastructures is carried out through various indicators. The trend today is to build high-speed railways that are designed for fast passenger transport. Article (Song & Zhai, 2011) compares the load indicators of high-speed lines, which are important for the overall safety of operation.

Each infrastructure produces costs and revenues. The optimal situation is when revenues are higher than costs. The infrastructure manager's revenues are mainly from the use of the railway infrastructure by the carriers. On the contrary, the costs are mainly associated with maintenance and renovation work. Article (Olson, Okland, & Halvorsen, 2012) compares the cost-benefit methodologies produced by the railway infrastructure in the countries of Northern Europe (Norway, Finland and Sweden).

The comparison of operational reliability based on station and track intervals was performed on the Žilina - Rajec line in the conditions of the ŽSR infrastructure manager in a conference paper (Čamaj & Dolinayová, 2018). This article dealt with the comparison of the calculation of intervals according to the new regulation of the infrastructure manager DP1, which entered into force in 2016.

From a historical point of view, comparisons from various points of view have already dominated the construction of railways. It was mainly about construction technology or political decisions. The construction of lines and related decisions are discussed in article (Fuchs, 2006).

The comparison of infrastructures between Slovakia and the Czech Republic is based on basic operational indicators (length, gauge, traffic management), as well as on the performance of individual carriers in passenger and freight transport. The comparison will be all the more interesting, as the management of the railway infrastructure is based on a common regulation from the time of the Czechoslovak State Railways, when the Czech Republic and Slovakia still formed one state.

1. Basic geographical indicators

To better compare the basic operating indicators of the two railway infrastructures, it is necessary to look at the basic geographical context of both countries. The basic geographical indicators are listed in Table 1.

Table 1. Comparison of geographical indicators of the Czech and Slovak republic (Sources: Statistical office)

Indicator/State	Slovak republic	Czech Republic
The population	5 449 270 inhabitants	10 701 777 inhabitants
Area	49 035 km^2	78 870 km^2
Number of regions	8	14
Number of districts	79	76
Population density	111.3 imhabitant/km^2	136 inhabitant/km^2

We can see from the table that in almost all indicators the Czech Republic is almost twice as high as Slovakia. An interesting paradox is the number of districts, which is higher in Slovakia by three districts, despite its smaller area. The data on the population refer to the year 2021, when the census took place in Slovakia and the Czech Republic, which takes place regularly every ten years.

Figure 1 shows the number of inhabitants in individual regions in Slovakia from 2019.

The comparative analysis of the railway infrastructure of the Czech and Slovak Republics contains a cross-section of operational and performance indicators of both railway networks. These indicators are available in the network statement of the infrastructure managers, which they are obliged to publish on their websites.

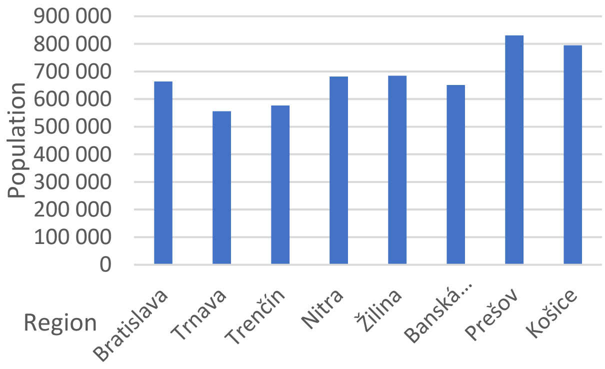

Fig. 1. Population in Regions of Slovakia in 2022 (Sources: Statistical office)

The most populous region is Prešov with a population of 831,000. On the other hand, it has the least population in the Trnava region with a population of 556 000. From the point of view of rail passenger transport, it is important to know the number of inhabitants, because the customer (Ministry of Transport and Construction) also decides on this indicator when ordering traffic performances.

Figure 2 shows the number of inhabitants in individual regions in Czech Republic from 2019.

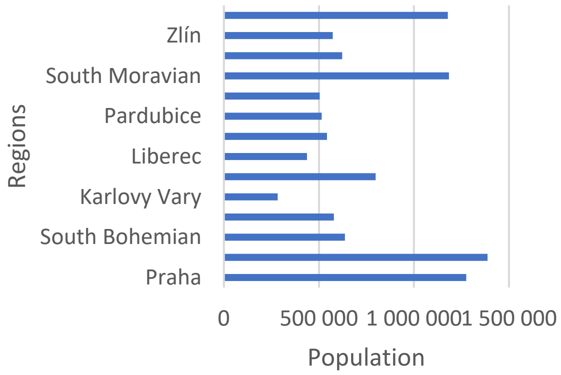

Fig. 2. Population in Regions of Czech Republic in 2022 (Sources: Statistical office)

The most populous region is South Bohemian Region (with capital city Praha) with a population of 1 386 824. On the other hand, it has the least population in the Karlovy Vary region with a population of 283 210. From the point of view of rail passenger transport, it is important to know the number of inhabitants, because the customer also decides on this indicator when ordering traffic performances. As in Slovakia, long-distance passenger transport is ordered by the Ministry of Transport, but regional passenger rail transport is ordered by individual regions. The regions must agree among themselves when financing regional trains between regions.

2. Analysis of the railway network in the Czech republic and Slovakia in the context of operational indicators

The following indicators are compared:

- method of origin,
- international railway corridors,
- track typologies,
- track gauges,
- connecting railway networks,
- power supply,
- train control systems,
- signalling systems,
- operating control points,
- railway undertakings performance.

Each of these indicators tells you about the infrastructure differences and the specifics of the infrastructure in a given country. Based on them, the current state of railway infrastructure in the countries being compared can be better understood.

2.1 Method of origin

Železnice Slovenskej republiky (hereinafter referred to as "ŽSR") was established in accordance with the Act of the National Council of the Slovak Republic No. 258/1993 Coll. of 30 September 1993 on Železnice Slovenskej republiky as amended by later regulations and has a special legal status.

Figure 3 shows the division of the Czechoslovak State Railways after the demise of Czechoslovakia since 1993 and the emergence of independent infrastructure managers in both countries.

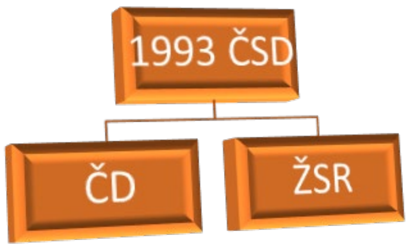

Fig. 3. The process of creating an infrastructure manager in Slovakia and the Czech Republic.

In accordance with Act No. 513/2009 Coll. On Railroads and on amendments of some acts as amended, Železnice Slovenskej republiky as the infrastructure manager, primarily provides for activities related to the operation of railways, traffic management and the operability of railways.

Správa železnic, státní organizace (hereafter „Správa železnic"), is a state organization under public law. It was established in 2003 and gradually from the then infrastructure manager of ČD, a. s. took over the competencies and components of the infrastructure so that it could be a full-fledged infrastructure manager in the context of the conditions for accession to the European Union. Správa železnic wishes to contribute to sustainable mobility within the European rail network in order to boost economic and social development in the Czech Republic. It is responsible for the operation, maintenance, and renewal of railway infrastructure, for the control and the safety of all train traffic as well as for participating in the development of the infrastructure. In Czech Republic, basic legal conditions for the construction of railways, the conditions for the operation of railways, the operation of railway transport on these railways, as well as rights and obligations of natural and legal persons associated with them are stipulated by the Rail Act and its implementing regulations, as amended, as well as directly effective regulations of the European Union.

Core activities of ŽSR and SŽ, s. o. in relation to applicants for infrastructure capacity and to railway undertakings shall comprise (Železnice Slovenskej republiky, 2021) (Správa Železnic, s. o., 2021)**:**

1. Management and operation of the railway infrastructure.
2. allocation of infrastructure capacity.
3. Provision of services to railway undertakings by means of:
    - minimum access package,
    - track access including access to service facilities,
    - services in service facilities,
    - negotiated additional service,
    - negotiated ancillary services.
4. Establishment and operation of railway, telecommunication, and radio networks.
5. Construction, repair and maintenance of railway lines.
6. Other business activities as incorporated into the Business Register.
7. Levying charges for access to the railway infrastructure.

This core business is basically the same for all infrastructure managers across Europe.

2.2 Railway corridors

The ten Pan-European transport corridors were defined at the second Pan-European transport Conference in Crete, March 1994, as routes in Central and Eastern Europe that required major investment over the next ten to fifteen years (Wikipedia contributors, 2022).

In 2010 the European Parliament and the Council laid down the rules for the establishment of a European railway network for competitive rail freight, consisting of international freight corridors (hereinafter referred to as "RFC") in order to meet the following goals:

- strengthening co-operation between IMs/ABs on key aspects such as the allocation of paths, deployment of interoperable systems and infrastructure development,
- finding the right balance between freight and passenger traffic along the RFCs, giving adequate capacity for freight in line with market needs and ensuring that common punctuality targets for freight trains are met,
- promoting intermodality between rail and other transport modes by integrating terminals into the corridor management process.

Table 2 contains a list of RFC corridors and their classification in the Czech and Slovak Republics

Table 2. Basic information about RFC corridors (Rail Net Europe, 2022)

Name RFC	Member states	Start of operation
Rhine-Alpine	NL, BE, DE, IT	10. 11. 2013
North Sea – Mediterranean	NL, BE, LU, FR, UK	
Scandinavian – Mediterranean	SE, DK, DE, AT, IT	10. 11. 2015
Atlantic	PT, ES, FR, DE	10. 11. 2013
Baltic-Adriatic	PL, CZ, SK, AT, IT, SI	10. 11. 2015
Mediterranean	ES, FR, IT, SI, HU, HR	10. 11. 2013
Orient – East-Med	CZ, AT, SK, HU, RO, BG, EL, DE	
North Sea – Baltic	DE, NL, BE, PL, LT, LV, EE	10. 11. 2015
Rhine – Danube	FR, DE, AT, SK, HU, RO, CZ	10. 11. 2020
Alpine-Western Balkan	AT, HR, SI, BG, RS	March 2020
Amber	SI, HU, SK, PL	January 2019

The RFC, which passes through Slovakia, is marked in green in the table, and the RFC, which passes through the Czech Republic, is marked in red in the table.

We can see from the table that a total of four RFCs pass through Slovakia and total of three RFCs pass through Czech Republic. Figure 4 shows the RFC map.

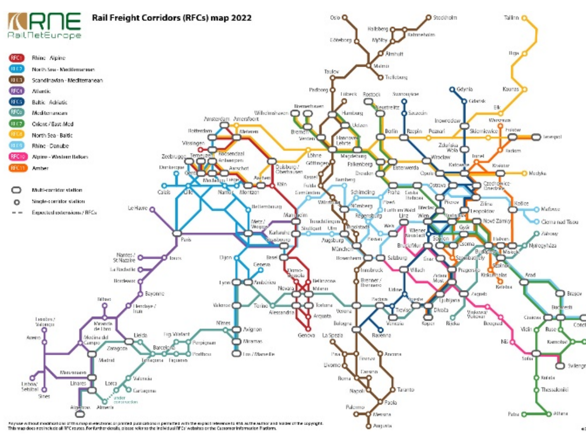

Fig. 4. Rail Freight Corridors (Rail Net Europe, 2022)

The dense network of freight corridors is intended to ensure competitive freight transport and ease the congested road network. Despite the efforts, the main problem in Slovakia is outdated infrastructure with a number of restrictions (temporary line speed restrictions, closures, non-functional diversion routes, etc.).

In the Czech Republic, the infrastructure, at least on the main corridors, is being reconstructed on an ongoing basis, but here (especially around Prague) there is a problem with the capacity of the tracks. Freight transport must wait, at peak times, at various intermediate station until heavy passenger transport has subsided.

2.3 Track typologies

Railway lines are numbered, separately for passengers and separately for railway staff. Table 3 shows the service numbering of lines on the ŽSR and SŽ network with the designation of areas (if they are divided).

Table 3. Service numbering of lines on the ŽSR and SŽ network (Železnice Slovenskej republiky, 2021) (Správa Železnic, s. o., 2021)

Country & infrastructure manager	Numeric range	The area
Slovak republic – ŽSR	101 – 130	-
Czech republic – SŽ	301 – 326	Moravia and Silesia
	501 – 548	Central Bohemia
	701-720	Western Bohemia

Železnice Slovenskej republiky and Správa Železnic, s. o. ensures serviceability of railway infrastructure in railway tracks, structures, and buildings.The railway lines managed by ŽSR & SŽ comprise the main and the secondary lines in terms of the Act on Railroads and this classification is published on the Ministry website www.mindop.sk (in Slovakia) and www.mdcr.cz (in Czech Republic) in the section "Ministry/Transport/Railway transport/State railway administration department/List of main and secondary lines". ŽSR & SŽ ensures serviceability of railway infrastructure in railway tracks, structures and buildings, bridges and tunnels, electrical and power engineering installations and signalling systems. The Company takes care of railway infrastructure maintenance and development in accordance with technical progress and requirements for safety and the fluidity of railway traffic. ŽSR ensures these activities by own capacities and also by contracted relationships with suppliers (Železnice Slovenskej republiky, 2021) (Správa Železnic, s. o., 2021).

Table 4 compares the basic operating indicators of the two railway infrastructures compared.

Table 4. Comparison of basic operating indicators (Železnice Slovenskej republiky, 2021) (Správa Železnic, s. o., 2021)

Railway tracks & structures	31. 12. 2021 in Slovakia	31. 12. 2021 in Czech Republic
Construction length of operated lines	3 580 km	9 358 km
Construction length of managed lines	3 627 km	9 254 km
Construction length of lines	6 866 km	11 358 km
Number of crossings	2 079 pc	7 734 pc
Number of switches	8 372 pc	25 458 pc
Number of bridges	2 326 pc	6 719 pv
Total length of bridges	52 544 m	154 845 m
Number of tunnels	76 pc	166 pc
Total length of tunnels	45.007 m	54 072 m

Given the size of the area, it was possible to assume that all operational indicators will be larger in the Czech Republic than in Slovakia.

2.4 Track typologies

In rail transport, track gauge is the distance between the two rails of a railway track (Wikipedia contributors, 2021).

In Slovakia, similarly to the Czech Republic, most railway lines are of normal gauge, 1435 mm. Figure 5 shows a comparison of track lengths in the Czech and Slovak Republics by gauge.

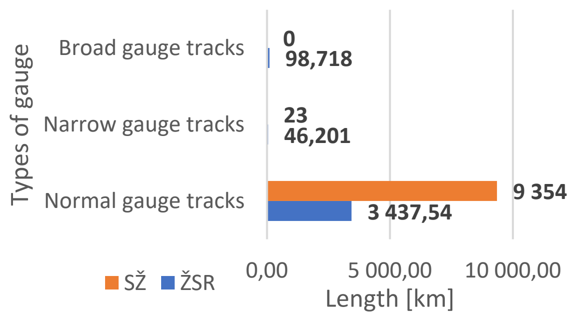

Fig. 5. Rail Freight Corridors (Železnice Slovenskej republiky, 2021) (Správa Železnic, s. o., 2021)

We can see from the graph that more than 90% of the lines in both countries are of normal gauge. At the same time, there are half as many narrow-gauge tracks in Slovakia as in the Czech Republic. There is also one wide gauge line in Slovakia, which leads from Eastern Slovakia to Ukraine. Table 5 shows the wide gauge and narrow-gauge lines in both countries under comparison.

Table 5. Comparison of basic operating indicators (Železnice Slovenskej republiky, 2021) (Správa Železnic, s. o., 2021)

Types of gauges	ŽSR	SŽ
narrow gauge tracks	Poprad – Štrbské Pleso (1000 mm)	Jindřichův Hradec – Obrataň (760 mm)
	Starý Smokovec – Tatranská Lomnica (1000 mm)	Jindřichův Hradec – Nová Bystřice (760 mm)
	Štrba – Štrbské Pleso (1000 mm)	Třemešná ve Slezsku – Osoblaha (760 mm)
	Trenčianska Teplá – Trenčianske Teplice (760 mm)	
broad gauge tracks	Haniska pri Košiciach – Užhorod (1520 mm)	

Operation on most narrow-gauge lines is year-round, mostly with passenger transport. Only freight transport is operational on the wide gauge line. Thoughts on the operation of passenger transport are still stopped.

2.5 Connecting railway networks

Border crossing stations form a liaison point between two neighbouring railway administrations. A border station is a railway station intended for communication with the railways of a neighbouring state. It is usually the last station before the state border. The primary difference between the border station and the border crossing station is that the handover and acceptance of wagon consignments is carried out at the border crossing station and the related operations are performed here. Which station is a border station and which station is a border crossing station is determined by the regime of border transport railway communication (Šperka, 2022). Figure 6 shows the number of border crossings on the ŽSR.

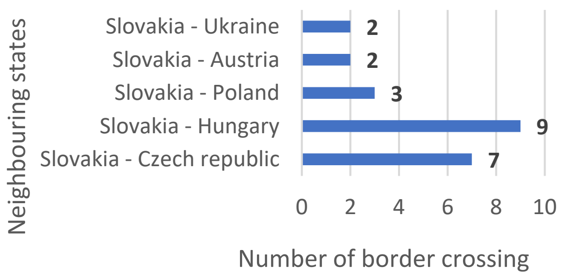

Fig. 6. Railway border crossings in Slovakia (Železnice Slovenskej republiky, 2021)

The main problem of cross-border transport in Slovakia is declining regional passenger transport. This can be seen especially in transports in the direction Slovakia - Hungary and back. Passenger transport is operated in year-round mode only at three border crossings. On others, only freight transport is operated, on some very sporadically. The gradual decline of regional passenger transport can also be seen at the border crossings between Slovakia and the Czech Republic.

Figure 7 shows the number of border crossings on the SŽ network with neighbouring railway infrastructures

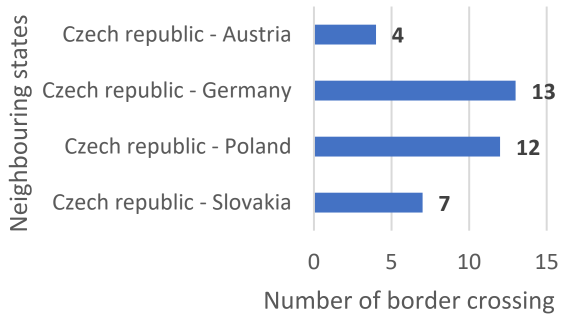

Fig. 7. Railway border crossings in Czech Republic (Správa Železnic, s. o., 2021)

SŽ and its foreign partners chose the exact opposite direction. In the last ten years, several border crossings with Germany have been renewed, and a new privileged transit traffic has been created. At the same time, passenger and freight transport is operated at almost all border crossings, at least to a satisfactory extent.

The border crossings between Slovakia and the Czech Republic are analysed in more detail in Table 6.

Table 6. Czechoslovak railway border crossings (Železnice Slovenskej republiky, 2021) (Správa Železnic, s. o., 2021)

Border crossing	Interchange station	Electrification
Čadca – Mosty u Jablunkova	Čadca	3kV
Kúty – Lanžhot	Kúty	25kV/50Hz
Lúky pod Makytou – Horní Lideč	Horní Lideč	3 kV
Holíč nad Moravou – Hodonín	Hodonín	25 kV/50Hz
Skalica na Slovensku – Sudoměřice nad Moravou	Skalica na Slovensku	-
Vrbovce – Velká nad Veličkou	Vrbovce	
Horné Srnie – Bylnice	Horne Srnie	

More than half of the railway border crossings are electrified by either a one-way or an alternating traction system. At the same time, passenger rail transport is maintained at most railway border crossings, at least to a limited or long-distance extent.

2.6 Power supply

Railway lines managed by ŽSR are divided into electrified and non-electrified and the extent is distinguished in different colour in figure 8.

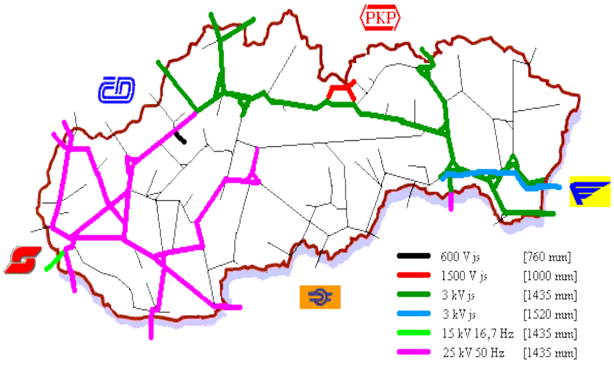

Fig. 8. Electrification of tracks in Slovakia (Kožuch, 2002)

Slovakia is dominated by a 3 kV unidirectional traction system (in the north and east of Slovakia) and an alternating traction system of 25 kV / 50Hz (center, south and west of Slovakia). In addition to them, there are also traction systems separately for the Tatra Electric Railway (1.5 kV) and separately for the Trenčín Electric Railway (750V). A short section from the Bratislava-Petržalka station to the Slovak-Austrian border is electrified by the Austrian 15kV / 16.7Hz AC traction system. A total of 1,585 km of railway lines are electrified in Slovakia.

In the Czech Republic, the dominant traction systems are the same. As described in Figure 8. In the Czech Republic, the dominant traction systems are the same. As described in Figure 9.

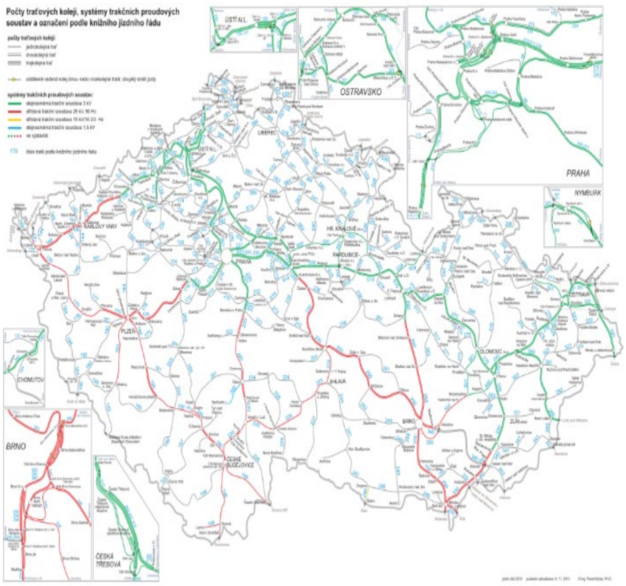

Fig. 9. Electrification of tracks in Czech Republic (Molek, 2015)

The same traction systems that dominate in Slovakia alternate to a lesser extent specific (1.5 kV on the Tábor - Bechyně track). The Austrian alternating traction system is also on a short section from Znojmo to the Austrian border. A total of 3 215 km of railway tracks are electrified in the Czech Republic.

2.7 Train control systems

The European Train Control System (ETCS) is the signalling and control component of the European Rail Traffic Management System (ERTMS). It is a replacement for legacy train protection systems and designed to replace the many incompatible safety systems currently used by European railways. This system has a total of three levels (Wikipedia contributors, 2021).

This system is not very widespread on the ŽSR network. Table 7 lists the sections where it is installed with the appropriate levels.

Table 7. Comparison of basic operating indicators (Železnice Slovenskej republiky, 2021)

Track section	Level ETCS
Bratislava – Rača – Púchov	L1
Považská Teplá (outside) – Žilina (outside)	L1
Žilina (outside) – Čadca	L2

We can see from the table that ETCS is installed on only three main tracks. It is very small out of the total number of tracks (Správa Železnic, s. o., 2021).

The use of ERTMS/ETCS system of Level 2 requires the use of encryption keys to encrypt useful data for radio transmission between the radio block central (RBC) and the ETCS mobile part. Encryption keys for ETCS mobile parts are issued at request of Správa železnic for RBC under its administration. Requirement for the application and detailed procedure are to be found in a separate Správa železnic document published on the Infrastructure Operation Portal (Správa Železnic, s. o., 2021).

On the Kolín – Česká Třebová – Brno – Břeclav state border Austria/Slovakia track section, a trackside part of the ERTMS/ETCS system of Level 2 in the version according to the set of specifications No. 1 of the TSI CCS (2.3.0d). The conditions for operating locomotives, control wagons and special traction vehicles with the enabled ETCS mobile part and controlled by this system are specified in the internal regulations of the railway operator (Správa Železnic, s. o., 2021).

On the sections Petrovice u Karviné st.hr. PL – Přerov – Břeclav (outside), Brodek u Přerova - Česká Třebová (outside), Český Brod - Praha-Běchovice - Praha-Malešice - Praha-Uhříněves a trackside part of the ERTMS/ETCS system of Level 2 in the version according to the set of specifications No. 3 of the TSI CCS (3.6.0) in system version 1.1 (allows operation of vehicles with the ETCS mobile part version according to specification set No. 1 [2.3.0d], No. 2 [3.4.0] and No. 3 [3.6.0] according to TSI CCS) (Správa Železnic, s. o., 2021).

Furthermore, the construction of the line part of the ERTMS / ETCS system is underway with commissioning before the entry into force of the 2022 timetable in the sections Hrušovany u Brna (outside) - Židlochovice and Hustopeče u Brna - Šakvice (outside), within which the ERTMS / ETCS level 2 system is implemented. in the version according to the specification set No. 1 (2.3.0d) according to the TSI CCS (Správa Železnic, s. o., 2021).

Furthermore, the construction of the line part of the ERTMS / ETCS system is underway and is being prepared with the expected commissioning before the entry into force of the 2022 timetable or during its validity in the sections Plzeň hlavní nádraží (outside) - Cheb (outside), Cheb - Cheb st. hr. DE, Beroun - Plzeň main railway station, České Budějovice - Votice (outside), Votice - Prague-Uhříněves (outside), Prague-Hostivař (outside) - Prague-Vršovice, Prague-Libeň - Prague-Malešice (outside), Prague-Malešice (outside) - Prague-Garden City, Kolín (outside) - Český Brod (outside), Prague-Běchovice (outside) - Prague-Libeň - Prague- Holešovice - Kralupy nad Vltavou (outside), Ústí nad Orlicí (outside) - Lichkov st. hr. PL, Přerov (outside) - Brodek u Přerova (outside), Prosenice - Dluhonice, Mosty u Jablunkova st. hr. SK - Dětmarovice (outside) / branch Závada (outside), Uničov - Olomouc main railway station (outside), within which the ERTMS / ETCS level 2 system is implemented in the version according to the set of specifications No. 3 according to TSI CCS (3.6.0) in system version 1.1 (Správa Železnic, s. o., 2021).

2.8 Signalling systems

Railway signalling (BE), also spelled railway signaling (AE), is a system used to direct railway traffic and keep trains always clear of each other. Trains move on fixed rails, making them uniquely susceptible to collision (Wikipedia contributors, 2021).

As there was a common rule based on both states, we present in Table 8 a comparison of the two neighboring states.

Table 8. Signalling systems in ŽSR and SŽ (Železnice Slovenskej republiky, 2021) (Správa Železnic, s. o., 2021)

Kind of signalling system	ŽSR	SŽ
Track signalling system – automatic block	478 km	874 km
Track signalling system – automatic block system	370 km	587 km
Track signalling system – semi-automatic block	714 km	1 045 km
Track signalling system – Line with telephone communication system	1 793 km	2 124 km
Station signalling system	513 pc	1 147 pc
Remote controlled signalling systems operated by dispatcher	396 km	600 km
Train signalling system	753 km	1 478 km
Crossing signalling system	2 079 pc	4 747 pc
Hump signalling systems	218 pc	396 pc

We can see from the table that the development of railway infrastructure in Slovakia is slower than in the Czech Republic. Old security devices prevail over modern technologies also on corridor railway tracks. At the same time, there is a so-called AVV (Automatic Train Control) system in the Czech Republic, which enables remote train control without the assistance of a train driver.

2.9 Operating control points

The operating control point is a specific point within the operation characteristic of a technical device (Šperka, 2022).

A comparison of the number of operating control point in the Czech Republic and Slovakia is shown in Figure 10.

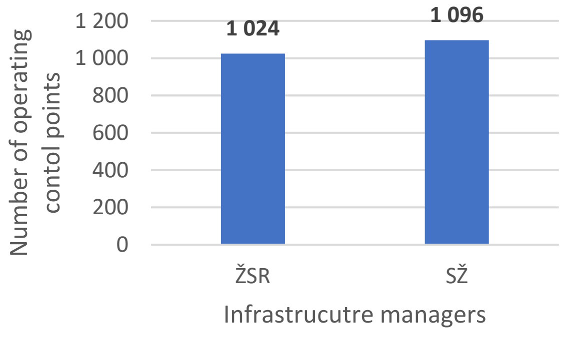

Fig. 10. Number of operating control points (Železnice Slovenskej republiky, 2021) (Správa Železnic, s. o., 2021)

Despite the area, the difference in the number of operating control point is not so great. There is a significant difference in remotely controlled operating control point, of which there are almost half of the transport in the Czech Republic in Figure 10.

2.10 Railway undertaking performance

A carrier is a legal person performing transport for someone else's own or own use on a railway line. To start providing services, a license is required, which is issued separately for passenger transport and separately for freight transport (Šperka, 2022).

From the year-on-year perspective, a decrease of 4,087 thousand train-km was recorded in transport performance, which was caused by the impact of COVID-19 measures. The decrease in total performance was largely on the side of passenger transport, where we record a year-on-year decrease of 2,998 thousand train-km. The decrease in rail passenger services was caused by a change in the Timetable – suspension of international passenger services, a significant decrease in domestic transport due to mobility restrictions. The largest decrease in transport performance by 2,169 thousand train-km reported Železničná spoločnosť Slovensko, a. s., while the carrier RegioJet recorded a decrease of 454 thousand train-km and, Leo Express s. r. o. reported decrease of 252 thousand train-km (Železnice Slovenskej republiky, 2021).

In freight transport, we record a year-on-year decrease in transport performance by 1,089 thousand train-km. The largest decrease of 996 thousand train-km reported Železničná spoločnosť Cargo Slovakia. For other railway undertakings, there was a year-on-year decrease in transport performance by 93 thousand train-km (Železnice Slovenskej republiky, 2021).

Figure 11 shows the performance of carriers for 2020 separately for passenger and separately for freight transport.

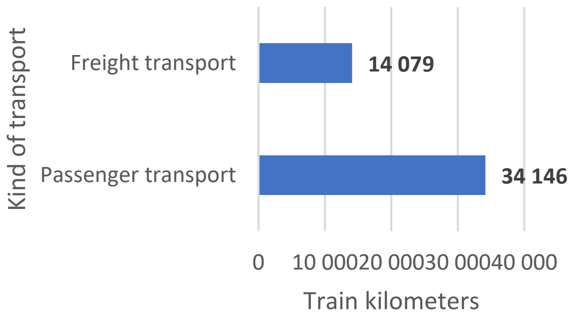

Fig. 11. Performance of carriers on the ŽSR network in 2020 (Železnice Slovenskej republiky, 2021)

It can be seen from the picture that passenger transport dominated in 2020, but for the COVID-19 pandemic, the performance is still lower than in previous years. At present, a total of 24 carriers in passenger and freight transport operate on the ŽSR network.

In the Czech Republic, the performance of carriers in train-kilometres is calculated as a percentage separately for passenger transport and for freight transport separately.

Figure 12 shows the performance of passenger transport in 2020 in train kilometres.

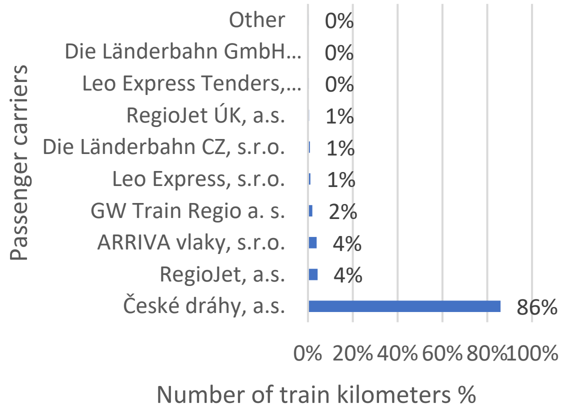

Fig. 12. Performance of passenger carriers on the SŽ network in 2020 (Správa Železnic, s. o., 2021)

Despite the drop in performance due to the liberalization of the passenger transport market, the state carrier remained in the first place. The shares of other carriers are significantly smaller.

Figure 13 shows the performance of freight carriers for 2020 as a percentage.

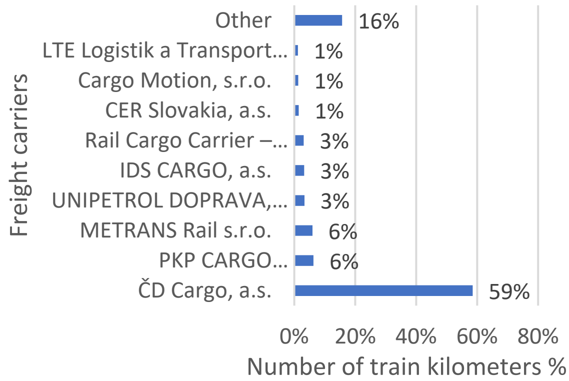

Fig. 13. Performance of freight carriers on the SŽ network in 2020 (Správa Železnic, s. o., 2021)

Due to the more developed liberalization of rail freight, the situation is different in this case. Although the carrier ČD CARGO, a. s., but several companies do business in freight transport and so its share is not as high as in passenger transport. The differences between the shares are also smaller.

The result of this analysis is the fact that the liberalized railway transport market is at a higher level in the Czech Republic than in Slovakia. This brings several benefits to the final consumer, i.e. the customer in freight transport and the passenger in passenger transport (price, time of transport, services provided by the carrier).

Conclusions

The aim of the presented analysis was to find out how much the operational indicators of railway infrastructure managers differ in the Czech and Slovak Republics.

The results led to the following conclusions:

- the railway infrastructure in Slovakia is significantly underfunded,
- repairs and maintenance are carried out only up to the amount of allocated funds, which is not enough in the long run,
- the infrastructure in the Czech Republic has undergone several major modernizations,
- carriers also complain about poor quality infrastructure in Slovakia,
- it is necessary to take the example of the Czech Republic and try to increase the amount of funds allocated to infrastructure managers and carriers in Slovakia

If these conclusions are fulfilled, the railway infrastructure may be of better quality and the differences between the railway infrastructure in Slovakia and the Czech Republic will no longer be so significant.

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