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INFLUENCE OF TIRE PRESSURE ON NOISE ROAD

Abstract. The article concerns the analysis of the influence of pressure on the noise generated by tires. The largest source of noise and vibrations is the cooperation of the wheels with the surface and the aerodynamic noise. For this purpose, seven winter tires, seven summer tires and one all-season tire were tested in the same region and same conditions. By changing the pressure in them in the range of 1-3 bar, the noise of the tires was measured. On the basis of the conducted tests, it can be concluded that with the decrease of tire pressure, the noise level of the tire decreases. The average noise drop recorded during tests for all types of tested tires is about 1.5 dB at a pressure drop of approx. 2 bar. The decrease in noise at reduced pressure is also dependent on the size of the tire and the softness of the mixture used for the production of tires. When operating the vehicle, follow the manufacturer's tire pressure recommendations.
Keywords: Road noise, Tire, Pressure

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Introduction

After 1990, the transport system in Poland was entering a period of transformation, including transport infrastructure, including road infrastructure. It mainly concerned quantitative aspects - length, density of the network. The quality side of the Polish transport infrastructure was much worse at the time (national pressures, practical capacity, internal and external integration of transport networks, surface quality, engineering solutions to improve safety and reduce environmental pollution departed from European standards).

The impact of negative qualitative characteristics of transport infrastructure, in particular road infrastructure, was limited as a result of low traffic levels. In the initial period only punctual infrastructural barriers to the work of road transport appeared (border crossings, bridges, especially on the Vistula, crossings through large agglomerations). Nowadays, we are collecting the harvest of twenty years of lack of major infrastructural investments, and even the lack of adequate replacement and maintenance measures in relation to our infrastructure (urgent repair requires a minimum of 35% of national roads).

In many places, road infrastructure becomes an obstacle to the efficient development of the region and efficient road transport. For example, an EU driver will drive an average of 9 km driving 800 km, and in Poland it is only around 500 km. Driving conditions, driving time and accompanying safety leave much to be desired. The necessity to raise the standards of Polish road infrastructure is a requirement set by the European Union. It stipulates that pressure standards should amount to 11.5 tons per axle, which currently only meets 450 km of Polish roads. At the same time, it must be stated that one 40-ton truck damages the road as well as 0.5 million passenger cars.

The number of vehicles traveling on Polish roads, roads in Wielkopolska and the whole country is growing year by year, as shown in Figure 1. For this reason, the condition of road infrastructure is very important, not only for drivers, but also for inhabitants of towns and villages. The condition of the road surface may cause increased noise. For this reason, the article analyses the influence of tire pressure on the generated noise. A similar problem was considered in the works (Gorzelanczyk, 2012, Gorzelanczyk, 2016, Gorzelanczyk, 2017, Gorzelanczyk and Kaczmarek, 2019, Gorzelanczyk and Michas, 2019, Gorzelanczyk and Sikora, 2019, Gorzelanczyk et al., 2018).

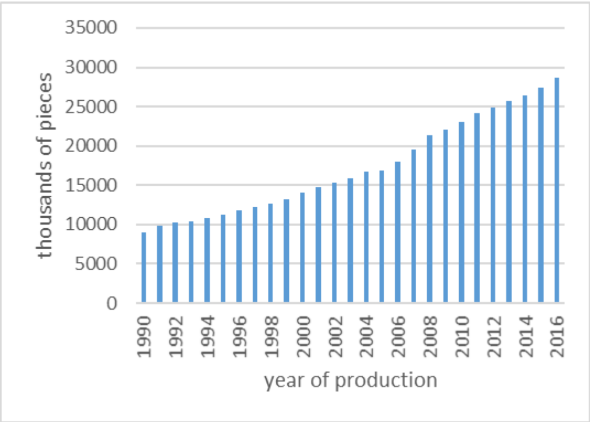

Fig. 1. The number of means of transport in Poland in the years 1990-2016 (Central register of vehicles and drivers 2019)

The problem of the impact of noise on the human body is complex and difficult. It refers to man as an intellectual unit and individuals of the social group, as well as all aspects of his life. For a long time, we have been striving to understand the impact of noise on health, and hence the functions of individual organs and its impact on productivity and quality of work. Equally important is the manifestation of subjective experiences and the individual relationship of the person and the entire society living in conditions of permanent impact of onerous sounds. Population, and all areas of their life are subject to the influence of noise, where the effects of this influence are negative. It is a problem of undoubted importance for both an individual and for the whole of society. The more so because the sources of noise are more and more, they occur in every space of human stay and become a threat to more and more people. Noise remained one of the key factors determining the quality of life of the society in large urban agglomerations. The intensity of noise, its origin, type and variability in time related to the essence of the place in question are determined by the acoustic climate (Gronowicz, 2004, Grzesik, 1975, Sadowski, 2001).

Communication noise is currently one of the most widespread and dominant among noise sources. In particular, road noise is becoming more and more important in view of the dynamic growth in the number of vehicles on Polish roads. At present, efforts are being made to reduce the noise of means of transport. Based on the noise measurement results collected by the Environmental Protection Inspection, it appears that the number of people at risk of noise in Poland is in the range of 13 -15 million, and the average equivalent noise level in urban areas is about 72.4dB (Kucharski, 1999). For this reason, measures should be taken to reduce and monitor traffic noise.

Motor vehicles consist of many systems and components. They are a complicated technical system. It contains, among others: engine, various gears, suspension, brake systems and exhaust system. Many elements of road construction are based on bearings, and all these elements are sources of noise (Gronowicz, 2004, Łaszkiewicz, 1992).

Currently, it is believed that the largest source of noise and vibrations is the cooperation of the wheels with the surface and the aerodynamic noise. The location of the main noise sources of the moving means of transport is presented using the acoustic map of the vehicle with the engine running in the wind tunnel (Figure 2)

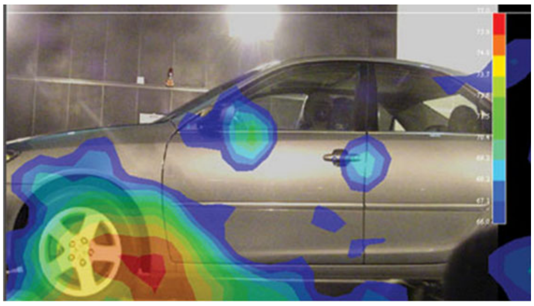

Fig. 2. Acoustic map of the vehicle with the engine running in the wind tunnel (Burdzik, 2012)

Traffic noise at the present time is a dominant and common threat, affecting the acoustic climate of many urban agglomerations. This is connected with the dynamically developing road network in recent years and a large number of means of transport moving on them. This situation causes intensive development of research into the recognition of phenomena that affect the propagation of sounds in the urban agglomeration (Gaja et al., 2003, Li et al., 2002, Morillas et al., 2001, Lipowczan, 1987).

2. Noise Generated by Tires

The last of the issues related to the road infrastructure of the Pila region is the noise generated by tires. It depends on the pressure in the tires as well as on the condition of the roads. Currently, the produced tires must meet the increasingly higher requirements of the consumer market. They must not only be very durable, but also have good adhesion and low rolling coefficient. Despite the use of more than 200 ingredients for the production of each tire, we can classify them into groups such as rubber, synthetic rubber, silica, carbon black, textile fibers, chemicals and metals. Despite such an extensive structure, tires are an element that does not undergo major changes (Oponeo, 2018). The construction of a car tire with the specified internal elements is shown in the Figure 3.

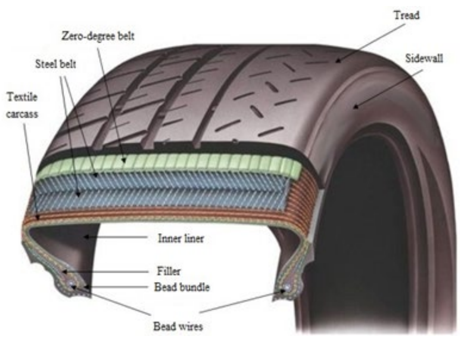

Fig. 3. Car tire (Oponeo, 2018)

We divide the tires due to their construction, application or specificity of the mixture from which they were made, due to the time of the year during which they best perform their task, whether the tread pattern and its depth. Diagonal and radial tires are the most popular. The diagonal tire is created by arranging several layers of cord arranged alternately in two directions at an angle other than 90°. With this design, higher stiffness is achieved than in radial tires. However, the radial tire was created by radially arranging the warp cord, which increases the flexibility of its side. Applying several layers of belting, we obtain a stiffening of the tire front. Such a construction solution increases the contact area of the tire with the surface. Compared to a diagonal tire, we obtain less angular deflection, less rolling resistance and lower resistance to mechanical damage (Andrzejewski, 2010, Jaworski, 1987.

3. Research Methodology

A The noise level generated by the tires was based on the sound level meter of motor vehicles AS-200 from SONOPAN (Figure 4). The meter is designed to measure the sounds produced by motor vehicles. It is also used to assess the volume of audio signals. After the measurements are completed, the meter can be connected to the computer to print a test report (AGK Partner, 2019). Noise measurement was carried out in accordance with applicable regulations, and the measurement set is certified by the Motor Transport Institute.

Fig. 4. SONOPAN AS-200 (AGK Partner, 2019)

The place selected for measurements is a section of an asphalt road about 500 m long located in the Pila region. Measurements were made only in such conditions that external factors would not have a greater impact on the results. The tests were carried out at a temperature of 6ºC to 20ºC, as well as in sunny weather or a slight cloud cover. The aim was to take measurements with low air humidity, and what is involved, on dry asphalt. The research covered cars with tires with a tread depth higher than 2.5mm measured from the TWI marker or higher than 4mm measured from the bottom of the groove between the blocks. The device has been selected for measurements due to its high accuracy, easy access and simple operation.

The test was carried out according to the following procedure, and the results are presented in the table and in the chart:

- The driver accelerates the car to a speed of 60 km/h,
- Turns off the ignition of the speeding car 20 m before the point of measurement,
- The AS-200 device placed at 1 m to 1.5 m from the car's path measures the volume of the passing vehicle,
- The result is saved on the measurement card,
- The driver lowers the pressure in the tires to make the next pass. The initial pressure is 3.0 bar and the final 1.0 bar. Reduction by 0.2 bar.

4. Research Object

The tests were carried out on 8 cars. Seven of them were equipped with winter and summer tires, and the seventh with all-season tires. The tires were made by different manufacturers and in different sizes. The data of the analysed tires are presented in Table 1.

Table 1. Vehicles and tires used to make measurements

Name and model	Year of production	Test summer tire	Test winter tire
Mercedes Benz E280 CDI	2006	Goodyear EfficientGrip 245/45 R18	BF Goodrich Winterg 215/55 R16
Chevrolet Lacetti	2005	Debica Presto 195/55 R 15	Sava Eskimo S3 185/55 R 15
Ford Mondeo	2008	Nokian zLine XL 225/45 R18	GOODYEAR Ultra Grip 215/55 R16
Volkswagen Passat	2001	Hankook PRIME3 205/55 R16	Debica Frigo 2 195/65 R15
Opel Insignia	2011	YOKOHAMA 225/35 R19	Vredestein WintracXtreme 255/35R19
Audi A4	2006	Pirelli CINTURATO ALL SEASON 205/55 R16 (all-season tire)	
Renault Laguna	2010	Vredestein Ultrac Sessanta XL 225/40 R18	Continental Wintercontact TS860 225/45 R18
Kia Pro'ceed	2008	UNIROYAL RAINSPORT 3 215/55R17	HANKOOK WINTER CEPT EVO2 215/55R17

5. Results

Based on the data from Table 2, it can be concluded that the noise generated by the tires is highly dependent on the pressure in them (Figure 5). The pressure drop reduces the external noise produced by the tires.

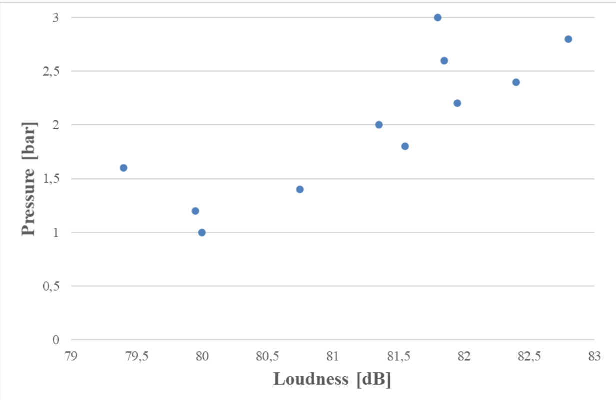

Fig. 5. The average noise value of all tested tires at different pressures

The average noise drop recorded during tests for all types of tested tires is about 1.5 dB at a pressure drop of approx. 2 bar. The decrease in noise at reduced pressure is also dependent on the size of the tire and the softness of the mixture used for the production of tires. The Goodyear EfficientGrip 245/45 R18 summer tire (81.70 dB) was the loudest of the tested tires. installed in the Mercedes Benz E280 CDI, while the winter tire Dębica Frigo 2 195/65 R15 (78.50 dB) installed in the Ford Mondeo turned out to be the quietest. The difference between the volume of the tested tires is over 3dB.

In most of the analysed tires, summer tires turned out to be louder than winter tires. Only in one case was the summer tire quieter for the Kia Pro'ceed. The tested all-season tire is a noisy tire. Among the summer tires the Uniroyal Rainsport 3 215 / 55R17 (80.43dB) was the quietest and the Goodyear EfficientGrip 245/45 R18 (81.70dB) was the loudest. The quietest winter tire was the Dębica Frigo 2 195/65 R15 (78.50 dB), which was the quietest tire in the Vredestein WintracXtreme 255 / 35R19 test (81.13 dB).

Table 2. Tire volume measurement results

Pressure [bar]	Mercedes Benz E280 CDI		Chevrolet Lacetti		Ford Mondeo		Volkswagen Passat		Opel Insygnia		Audi A4	Renault Laguna		Kia Pro'ceed		Arithmetic average
	Loudness [dB]		Loudness [dB]		Loudness [dB]		Loudness [dB]		Loudness [dB]		Loudness [dB]	Loudness [dB]		Loudness [dB]		
	Summer tire	Winter tire	Summer tire	Winter tire	Summer tire	Winter tire	Summer tire	Winter tire	Summer tire	Winter tire	All-season tire	Summer tire	Winter tire	Summer tire	Winter tire	
	Goodyear EfficientGrip 245/45 R18	BF Goodrich Winterg 215/55 R16	Debica Presto 195/55 R 15	Sava Eskimo S3 185/55 R 15	Nokian zLine XL 225/45 R18	GOOD YEAR Ultra Grip 215/55 R16	Hankook VENTUS PRIME3 K125 205/55 R16	Debica Frigo 2 195/65 R15	YOKOHAMA 225/35 R19	Vredestein Wintrac Xtreme S 255/35R19	Pirelli CINTURATO ALL SEASON 205/55 R16	Vredestein Ultrac Sessanta XL 225/40 R18	Continental Winter contact TS860 225/45 R18	UNIROYAL RAINSPORT 3 215/55R 17	HANKOOK WINTER CEPT EVO2 215/55 R17	
3	82,3	81,3	81,7	81	82,1	80,8	81,4	78,7	82,5	81,7	81,7	82	81,9	80,7	81,7	81,35
2,8	83,2	82,4	80,6	79,8	81	80,4	79,8	79,5	82,2	82,1	81,9	81,3	82	81,1	81,6	81,16
2,6	82,9	80,8	81,9	78	82,4	78,8	81,8	78,2	82,7	82,3	81,7	81,5	80,6	81	81,2	81,01
2,4	82,2	82,6	80,4	79,8	80,8	79,4	80,9	79,1	81,8	81,2	82	81,4	80,9	81,3	80,8	80,82
2,2	82,6	81,3	81,4	77,9	81,1	78,9	80,9	78,1	80,9	81,3	81,3	81,3	81	80,8	81,2	80,70
2	80,1	82,6	80,6	79	81,6	79,2	81,4	79,2	81	80,1	81,6	82	81,2	80,5	81	80,72
1,8	82,7	80,4	81,6	77,6	81,6	78,6	81,8	78,2	80,8	81,3	81,8	81,2	81	80,7	81,1	80,42
1,6	79,4	79,4	79,9	78,6	80,8	78,7	80,8	78,3	81,1	80,8	81	81,8	80,8	80,1	80,7	80,19
1,4	82,3	79,2	81,1	78,4	81,2	78,2	80,2	77,9	80,7	80,9	81,1	80,9	80,9	80,1	80,5	80,11
1,2	79,4	80,5	80,7	78,3	81,2	78,4	81,2	78,3	80,8	80,3	79,9	80,8	80,7	79,3	80	79,96
1	81,6	78,4	80,3	78,6	81	78,1	80,1	78	80,2	80,4	80,7	81,2	81	79,1	80,3	80,29
Average	81,70	80,81	80,93	78,82	81,35	79,05	80,94	78,50	81,34	81,13	81,34	81,40	81,09	80,43	80,92	80,65

Conclusions

Based on the data presented in the article, it can be concluded that the noise level of the tested tires decreases with the decrease in tire pressure. The summer tires turned out to be the loudest, and the winter ones were the quietest. The difference was very big as it exceeded 3 dB. The all-season tire was in the upper range of the tested tires. However, despite the results presented above, they should not be considered, but only the vehicle should be operated at the pressure recommended by the car manufacturer.

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POSSIBILITIES FOR INTRODUCING A NEW NIGHT TRAIN CONNECTION IN MIDDLE EUROPE

Abstract. Liberalisation of the rail transport market is the main aim of the European Union in the field of transport policy. Open access on the market allows railway undertakings to provide their services, but it also requires to compete with each other. In recent years, night train services have experienced a renaissance, especially in west-Europe countries. A development of this type of services is important to achieve the goal of carbon neutrality in EU, especially in context of affordable air transport. The aim of this study is to analyse current night train services in middle Europe and find opportunities for their further development. In this article we have proposed new night train connections between Hungary, Slovakia, Czech Republic, and Germany, provided by railway undertaking in open access mode, with a detailed cost calculation. This is necessary to assess the economic efficiency of introducing new connections. Results of the cost calculations form the basis of the price for transport on newly introduced routes.
Keywords: Open Access; Railway transport market; Night train services; Middle Europe; Cost calculation; Economic efficiency

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Introduction

The share of international long-distance passenger rail transport has been constantly declining compared to the air transport in recent years. The development of low-cost companies had a significant impact to make air transport available for general public. Railway transport on conventional routes with a length more than 1 000 km has become less flexible, and the travel time and fares have become uncompetitive. This situation led railway undertakings in Europe to reduce international long-distance connections, especially night connections, due to their low profitability.

Despite these facts, in las few years several night train connections have been re-estabilished, especially in Austria, Germany, Switzerland and Sweden. There are several reasons for gradual increase in this segment. Liberalisation of rail transport market has introduced open competition and allowed market access for all undertakings. Also, efforts to protect the environment and to reduce the negative effects of the climate crisis affects the behaviour of society. Railway transport as the most ecological-friendly mode of public transport can play an important role in achieving the carbon neutrality of the EU. However, to achieve this aim, it is necessary to increase competitiveness of long-distance rail transport for example through efficient pricing and providing added value for the passenger.

In literature we can find several studies dealing of the issue of night train connections. Manthei (2005) presents an up-to-date overview of the European night train services comprising of 180 scheduled train services in 15 countries. Author also presents a concept for a combined passenger train car that could be used for day as well as night train services. Gunkel et al. (2007) proposed and compared in their research two new approaches to support queries for night train connections. Its purpose is to find all train connections which are attractive from a costumer point of view. Li et al. (2019) dealt with analysis and prediction of passenger flow of high-speed night train in China. Their study result can provide certain data support to the reasonable operation of high-speed night train under network condition.

1. Analysis of current night train connections in Europe

Night trains in Europe are provided mostly by domestic railway undertakings or undertakings consisting of two or more incumbents. Predominance of incumbents in this sector can be seen especially in East and South part of Europe. There are also several private railway undertakings providing mostly seasonal night connections, like Swedish company Snalltaget on the route Berlin – Malmö operated during the summer months. The largest reduction of the night trains took place in the west part of Europe (France, Germany). After the termination of night connections operated by German incumbent Deutsche Bahn under the brand City Night Line (CNL), the service on some CNL routes was replaced by ÖBB Nightjet services. ÖBB Nightjet as a subsidiary of Austrian state incumbent ÖBB is currently the biggest railway undertaking providing night trains services in Europe. Its trains are operated in Austria, Germany, Switzerland, Italy, Belgium and in partnership with other domestic incumbents also in Slovakia, Czech Republic, Poland, Hungary, Slovenia and Croatia. Network of ÖBB Nightjet night connections operated in year 2020 can be seen at figure 1 (nightjet.com, 2021).

The development of night connections is also visible as well in Sweden. Domestic incumbent SJ provides inland trains from south of the country to nord, and one pair of international connection from Stockholm to Narvik in Norway (named as Arctic Circle Train). Other companies operating night trains across Europe are Thello (consisted of Italian and France incumbents) on the route from Milan to Paris, Snalltaget and domestic incumbents in another European countries. Most of them provides also inland night connections or trains to neighboring countries (railguideeurope.com, 2021).

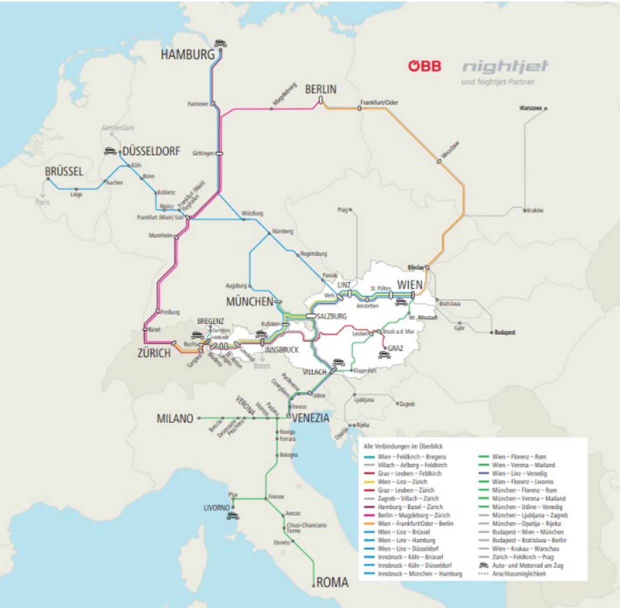

Fig. 1. Network of ÖBB Nightjet night train connections in year 2020 (Source: www.railguideeurope.com)

Situation in the middle Europe countries has been in recent years similar to the global scale. Most countries excluded night trains from PSO contracts, which resulted in a reduction of these connections that were economically unprofitable. Fast development of low-cost air transport undertakings has made these trains less flexible and more expensive for passengers. One of the biggest disadvantages of long-distance international trains in middle Europe is long travel time due to outdated infrastructure. This can be in the segment of night transport compensated by value added services and developing passengers' environmental awareness.

For the purposes of this study, we have analysed night connections between V4 countries - Slovakia, Czech Republic, Poland, Hungary and also from these countries to the west part of Europe. From Slovakia to Czech Republic are night trains services provided by incumbent České Dráhy (ČD) and Železničná spoločnosť Slovensko (ZSSK) and also by private Czech railway undertakings Regio Jet and Leo Express. The most frequented route is between Prague and Košice, the second biggest city in Slovakia situated in east part of the country. The average travel time between these two cities is 9 hours and 13 minutes. ČD and ZSSK nowadays operate one pair of night trains on route Prague – Košice – Humenné, Regio Jet one pair of trains on route Prague – Košice and Leo Express also one pair of night trains between Prague and Prešov. There was gradual reduction of night trains provided by incumbents, from three to one pair per day, but at the same time development of connections operated by private railway undertakings. This means, that the demand of passengers on this route is high, however services provided by incumbents are not attractive for them. Compared to private undertakings, there is an absence of effective pricing and the amount of operating costs is higher.

ÖBB Nightjet in cooperation with domestic incumbents operate one pair of night train on the route Wien – Břeclav – Bohumín – Wroclav – Berlin, with direct wagons from Budapest and Bratislava. In the direction from Slovakia and Czech repubic to Poland, domestic incumbents provide their services on several routes, for example Prague – Warsaw, Žilina – Gdynia and seasonal connections from Bohumín to Baltic destinations Hel, Świnoujście and Kołobrzeg (nightjet.com, 2021).

In table 1 we can see current night train connections from Middle Europe (Slovakia, Czech Republic, Poland, Hungary) with their frequency during the week and total travel time from the station of departure to the arrival station.

Table 1. Current night train connections in Middle Europe

Route	Number of night trains	Operator	Travel time
Košice - Praha	1 pair	incumbents	10 hod
	1 pair	Regio Jet	8 hod 41 min
Prešov - Praha	1 pair	Leo Express	9 hod 19 min
Budapest - Berlin	1 pair*	incumbents	11 hod 2 min
Budapest - Warszawa	1 pair*	incumbents	14 hod 2 min

* Direct wagons in cooperation with OBB Nightjet

(Source: authors by zssk.sk, cd.cz, regiojet.cz, leoexpress.com)

Most of this trains are operated by incumbents (ZSSK, ČD, MÁV and PKP IC). Private railway undertakings provide their night services on the route from Košice / Prešov (the second and third largest cities in Slovakia) to capital of Czech Republic Praha. Travel time of Regio Jet night trains on this route is an hour and 19 minutes shorter than in the case of incumbents. If we compare the services provided in these trains, Leo express offers only seat wagons, Regio Jet seat and sleeping wagons and incumbents offer all types of night services (seat, couchette and sleeping).

2. Theoretical background and methods

In case of proposing a new rail connection, it is necessary to evaluate their economic efficiency. The methodology for determining the price for transport when introducing a new connection consists of these main steps:

- demand analysis,
- market analysis,
- analysis of customers,
- transport characteristics,
- set of wagons,

- set of locomotives,
- determination of the required number of locomotives and wagons,
- deciding on the lease or purchase of rolling stock,
- preparation of rolling stock circulations and determining the number of required vehicles,
- preparation of staff shifts and determining the number of locomotive and train crew members,
- formation of technology of transport,
- costs calculation,
- setting the price for transport (Dolinayova et al., 2018).

The most important step for our study and evaluating the economic efficiency of proposed trains is the cost calculation. This process also forms the basis for determining the price for transport. The first step is to quantify total costs for each route and for the different expected train occupancy. Then we can quantify the unit costs per unit volume (usually per passenger, train kilometre or passenger kilometre).

Total costs consist of direct and indirect costs. *Direct costs* can be calculated per specific unit of volume (operational performance, transport performance) and are related to the operation of the train connection. In general, direct or operational cost can be divided into:

- locomotive costs C_L– calculated as a product of the average kilometre run of locomotives (lkm) and the avarege cost rate per locomotive kilometre (C_{RL}). The cost rate includes depreciation, maintenance and repairs costs and costs spent on certification of the locomotive and annual insurance.

$$C_L = C_{RL} * lkm \quad (1)$$

- wagon costs C_W - calculated as a product of the average kilometre run of wagons (wkm) and the avarege cost rate per wagon kilometre (C_{RW}). The cost rate includes depreciation, maintenance and repairs costs and costs spent on certification of the wagon and annual insurance.

$$C_W = C_{RW} * wkm \quad (2)$$

- personal costs C_P - calculated as a product of the average employee hours (eph) and the avarege cost rate per employee (C_{RP}). The cost rate includes the wage, social and health insurance costs, diet, accommodation, education costs and other costs as ensuring the work clothes and protective equipment. we can distinguish two basic groups of this cost item – costs of locomotive crew and train crew.

$$C_P = C_{RP} * eph \quad (3)$$

- infrastructure costs – represent price for the use of railway infrastructure, which is usually regulated. This cost item must be calculated separately for individual parts of route in different countries. Methodology for the determination of price for the use of railway infrastructure is set by the infrastructure manager in each country. The amount of the charge is dependent on various factors, mostly on train-kilometres, train weight, route allocation method, category of the railway route or parameters of vehicles.
- energy costs C_E – calculated as a product of the operating performance in gross tonne kilometres (gtkm) and the average cost rate per energy unit (C_{RE}). This cost rate depends on unit price of the traction energy (kWh in case of electric trains, litres of fuel in case of diesel trains) and energy consumption of the locomotive/multiple units.

$$C_E = C_{RE} * gtkm \quad (4)$$

(Dolinayova, Nedeliakova, 2015)

Indirect costs or overhead costs form a cost item, that cannot be directly attribute to a unit of volume. This includes operational, administrative and sales overheads. Their amount can be determined based on different methods of calculating indirect costs, as division calculation, by mark-up or using activity-based costing (ABC). In this study, we will calculate indirect costs as a percentage of the total costs of the railway undertaking for operation of specific service (Dolinayova, Nedeliakova, 2015).

Unit costs represent the amount of total costs expressed per unit of performance, most common operating performance (train km) or transport performance (passenger km). The amount of unit costs depends also on the expected train occupancy.

3. Proposal of new night train connections in middle Europe

Based on current night train connection offer and demand between European capitals and major cities, we have proposed new trains in central Europe countries, including a detailed cost calculation, which forms the basis for determining the possible amount of fares. The proposed trains would run on these lines:

- Budapest – Hamburg – one pair of night trains,
- Košice – Budapest – one pair of day trains (which need arose in order to maintain the effectivity of trainset circulation),
- Košice – Pardubice – one pair of night trains with direct wagons to Hamburg.

Table 2 represents approximated timetables of all trains. Departure and arrival times were estimated considering the infrastructure parameters in each country and sufficient length of sleep for passengers from all metropoles, like Budapest, Bratislava, Košice, Brno, Berlin and Hamburg. Trains are also usable for passengers from Praha in direction to Germany as day connection.

Table 2. Timetables of proposed trains (Source: authors)

Station	IC 190 arr.	IC 190 dep.		IC 191 arr.	IC 191 dep.
Košice		12:00	Budapest Keleti		12:00
Miskolc	13:20	13:23	Hatvan	13:05	13:07
Fuzesabony	13:58	14:00	Fuzesabony	13:40	13:42
Hatvan	14:33	14:35	Miskolc	14:17	14:20
Budapest Keleti	15:40		Košice	15:40	

Station	EN 482 arr.	EN 482 dep.	Station	EN 483 arr.	EN 483 dep.
Košice		20:29	Pardubice hl. n.		2:10
Kysak	20:41	20:48	Olomouc hl. n.	3:35	3:45
Poprad-Tatry	21:39	21:49	Ostrava hl. n.	3:51	4:00
Štrba	22:09	22:15	Bohumín	4:06	4:36
Liptovský Mikuláš	22:41	22:50	Čadca	5:26	5:33
Ružomberok	23:07	23:13	Žilina	5:55	6:05
Žilina	23:56	0:06	Ružomberok	6:49	6:54
Čadca	0:28	0:38	Liptovský Mikuláš	7:11	7:16
Bohumín	1:28	1:40	Štrba	7:42	7:47
Ostrava hl. n.	1:46	1:55	Poprad-Tatry	8:07	8:17
Olomouc hl. n.	3:01	3:10	Kysak	9:09	9:14
Pardubice hl. n.	4:35		Košice	9:26	

Station	EN 474 arr.	EN 474 dep.	Station	EN 475 arr.	EN 475 dep.
Budapest Keleti		18:50	Hamburg Altona		17:30
Gyor	20:10	20:15	Hamburg Hbf	17:40	17:50
Rajka	20:50	20:55	Berlin Hbf	19:50	20:10
Bratislava Petržalka	21:12	21:20	Dresden Hbf	21:55	22:02
Bratislava N.M.	21:35	21:43	Děčín	22:52	22:57
Bratislava hl. st.	21:50	22:00	Ústí nad Labem	23:12	23:20
Břeclav	22:50	23:10	Praha - Holešovice	0:20	0:30
Brno hl. n.	23:40	23:50	Pardubice hl. n.	1:30	2:40
Pardubice hl. n.	1:20	5:13	Brno hl. n.	4:10	4:20
Praha - Holešovice	6:13	6:20	Břeclav	4:50	5:25
Ústí nad Labem	7:20	7:25	Bratislava hl. st.	6:15	6:25
Děčín	7:40	7:45	Bratislava N.M.	6:32	6:42
Dresden Hbf	8:35	8:40	Bratislava Petržal	6:55	7:02
Berlin Hbf	10:25	10:35	Rajka	7:19	7:22
Hamburg Hbf	12:35	12:45	Gyor	7:57	8:02
Hamburg Altona	12:55		Budapest Keleti	9:22	

Decision on rolling stock set for suggested performances was made taking into account the need for an interoperable locomotive eligible for operation in all countries, sufficient capacity of wagons and differentiation of standard services for night trains (especially sleeping and couchette cars). For every trainset we have chosen a uniform form, in order to ensure efficient rolling stock circulation. The final form of the trainset consists of:

- 3 modernized open-space seat wagons with AC (Bmpz);
- 1 modernized couchette wagon with AC and section for immobile passengers (Bcmz);
- 2 modernized sleeping wagons with AC (WLABmee).

The total capacity of each trainset is 252 seats in the seat section, 52 in couchette section and 52 in sleeping section. Night train on the route Budapest – Hamburg in the section from Pardubice to Hamburg and back will consist of two connected trainsets with a given capacity. Figure 2 presents the trainset circulation, divided into 4 days cycles. The total need is 4 trainsets with average daily run of each 1095 km. The total need of locomotive park is 3+1 backup multisystem locomotives Traxx MS3, with average daily run of each 1460 km.

The first step of the cost calculation is to quantify the performance indicators for the period of one year and then to calculate the average cost rate related to a specific indicator. For locomotive cost we select train kilometres, for wagon costs wagon kilometres, for personal costs train kilometres and for energy costs gross-ton kilometres. Calculation of the infrastructure charges depends on the currently valid national methodology, but as a general the individual parts of the fee are charged in relation to train and gross-tone kilometres. Cost rates have been calculated according to the methodology in theoretical part of this article. Resulting rates are summarized in the Table 3. The wagon cost rate we calculated separately for seat wagons in the personal ownership of the railway undertaking, and for couchette and sleeping wagons which the RU leases from the leasing company. A higher amount of these rates is caused mainly by the special equipment and configuration of wagons, as well as the increased maintenance requirements of this equipment. Locomotive and train crew cost rates were calculated separately for middle Europe countries (Slovakia, Czech Republic, Hungary) and Germany, due to the different standard of living and labour costs in these two parts of Europe.

Table 3. Calculated cost rates (Source: authors)

locomotive cost rate		0,93 EUR/lockm
wagon cost rate	seat	0,52 EUR/wagkm
	couchette	0,75 EUR/wagkm
	sleeping	0,73 EUR/wagkm
locomotive crew cost rate	SK+CZ+HU	0,48 EUR/trainkm
	DE	0,55 EUR/trainkm
train crew cost rate	SK+CZ+HU	0,33 EUR/trainkm
	DE	0,40 EUR/trainkm
traction energy cost rate		0,005 EUR/grosstkm

The amount of total costs we quantified for each route at different expected train occupancy (from 30 % as a lower limit to full occupancy). Results are summarized in Table 4, for the most important routes between major cities on the train path. Unit costs are calculated for one passenger on the specific route, depending on the total amount of passengers in the train at different train occupancy. The amount of unit costs is presented in Table 5. It also forms the lower limit of the price for transport.

By setting the price for transport, the railway undertaking must take into account the risk of non-utilization of the train, or different utilization due to uneven passenger flows during the week or day (peak and off-peak days/time).

Table 4. Total costs in EUR (Source: authors)

occupancy	30%	40%	50%	60%	70%	80%	90%	100%
Budapest - Košice	2 625,30	2 695,66	2 766,02	2 836,38	2 906,75	2 977,11	3 047,47	3 117,84
Miskolc - Košice	1 180,73	1 204,42	1 228,11	1 251,81	1 275,50	1 299,19	1 322,88	1 346,57
Košice - Pardubice hl.n.	5 344,48	5 495,41	5 646,34	5 797,27	5 948,19	6 099,12	6 250,05	6 400,98
Poprad-Tatry - Pardubice hl.n.	4 582,14	4 704,68	4 827,22	4 949,76	5 072,30	5 194,84	5 317,37	5 439,91
Žilina - Pardubice hl.n.	3 517,89	3 600,80	3 683,70	3 766,61	3 849,51	3 932,42	4 015,32	4 098,22
Budapest - Bratislava hl. st.	4 579,46	4 642,34	4 705,23	4 768,12	4 831,01	4 893,90	4 956,78	5 019,67
Budapest - Brno hl. n.	5 622,58	5 721,19	5 819,80	5 918,40	6 017,01	6 115,62	6 214,22	6 312,83
Budapest - Praha Holešovice	7 978,24	8 152,89	8 327,54	8 502,20	8 676,85	8 851,50	9 026,15	9 200,81
Budapest - Berlin Hbf	13 046,56	13 380,50	13 714,44	14 048,37	14 382,31	14 716,25	15 050,19	15 384,13
Budapest - Hamburg Hbf	16 787,20	17 235,15	17 683,10	18 131,04	18 578,99	19 026,94	19 474,88	19 922,83
Bratislava hl. st. - Praha Holešovic	6 102,64	6 214,41	6 326,17	6 437,94	6 549,70	6 661,46	6 773,23	6 884,99
Bratislava hl. st. - Berlin Hbf	11 170,96	11 442,01	11 713,06	11 984,11	12 255,17	12 526,22	12 797,27	13 068,32
Bratislava hl. st. - Hamburg Hbf	14 911,61	15 296,67	15 681,72	16 066,78	16 451,84	16 836,90	17 221,96	17 607,02
Brno hl. n. - Berlin Hbf	9 802,79	9 929,78	10 056,76	10 183,75	10 310,73	10 437,72	10 564,70	10 691,69
Brno hl. n. - Hamburg Hbf	13 201,42	13 328,40	13 455,39	13 582,37	13 709,36	13 836,34	13 963,33	14 090,31
Praha Holešovice - Berlin Hbf	7 772,18	7 931,46	8 090,75	8 250,04	8 409,32	8 568,61	8 727,90	8 887,18
Praha Holešovice - Hamburg Hbf	11 512,82	11 786,12	12 059,41	12 332,71	12 606,00	12 879,29	13 152,59	13 425,88

Table 5. Unit costs in EUR (Source: authors)

occupancy	30%	40%	50%	60%	70%	80%	90%	100%
Budapest - Košice	34,54	26,69	21,95	18,66	16,42	14,74	13,42	12,37
Miskolc - Košice	15,54	11,92	9,75	8,24	7,21	6,43	5,83	5,34
Košice - Pardubice hl.n.	49,95	38,43	31,72	27,09	23,79	21,40	19,47	17,98
Poprad-Tatry - Pardubice hl.n.	42,82	32,90	27,12	23,13	20,29	18,23	16,57	15,28
Žilina - Pardubice hl.n.	32,88	25,18	20,69	17,60	15,40	13,80	12,51	11,51
Budapest - Bratislava hl. st.	42,80	32,46	26,43	22,28	19,32	17,17	15,44	14,10
Budapest - Brno hl. n.	52,55	40,01	32,70	27,66	24,07	21,46	19,36	17,73
Budapest - Praha Holešovice	49,71	38,10	31,19	26,49	23,17	20,71	18,77	17,23
Budapest - Berlin Hbf	81,29	62,53	51,36	43,76	38,40	34,42	31,29	28,81
Budapest - Hamburg Hbf	104,59	80,54	66,23	56,48	49,61	44,51	40,49	37,31
Bratislava hl. st. - Praha Holešovice	38,02	29,04	23,69	20,06	17,49	15,58	14,08	12,89
Bratislava hl. st. - Berlin Hbf	69,60	53,47	43,87	37,33	32,72	29,30	26,61	24,47
Bratislava hl. st. - Hamburg Hbf	92,91	71,48	58,73	50,05	43,93	39,38	35,80	32,97
Brno hl. n. - Berlin Hbf	61,08	46,40	37,67	31,73	27,53	24,42	21,96	20,02
Brno hl. n. - Hamburg Hbf	82,25	62,28	50,39	42,31	36,61	32,37	29,03	26,39
Praha Holešovice - Berlin Hbf	36,32	27,83	22,73	19,28	16,85	15,03	13,62	12,48
Praha Holešovice - Hamburg Hbf	53,80	41,35	33,87	28,81	25,26	22,60	20,52	18,86

Risk is defined as the opportunity for something that has an impact on the objectives. It is measured by consequences or an estimate of the probability. It is necessary for the railway undertaking to calculate the costs of transport at different occupancy of the train. The final total costs of one seat in the train is an important basis for the tariff formation with the result of eliminating the previous risk and increasing the RU´s revenues (Černá et al., 2016). One of the risk elimination options in our case is the determination of the price as the average amount at different train occupancy. The railway undertaking providing this type of services may also face these additional risks:

- financial risk of interest rate increase (if the rolling stock is purchased on credit);
- the risk of capping the amount of compensation for social discounts in the Czech Republic (children, students and seniors are entitled to a 75% discount);
- compensation risk within the meaning of Regulation (EC) No 1371/2007 (compensations for train delays).

An important means of competition in the market is the acquisition activity of the railway undertaking. With providing the night train services are associated additional services, especially couchette and sleeping services. For determination of the price for additional services is important to know the technological process of the service and the share of costs incurred for its provision. The costs need to be expressed using analytical formulas per calculation unit, in our case per 1 passenger. The following direct costs are included in the additional service sleeping ticket:

- bed sheet costs;
- breakfast package costs;
- employee live labour costs;
- material and other equipment costs.

$$C_S = \frac{C_{BS} + C_{BP} + C_{EL} + C_M}{p * n * c} \tag{5}$$

The formula determined by us is as follows:

where:

C_s – sleeping service costs,

C_{BS} – bed sheet costs,
C_{BP} – breakfast package costs,
C_{EL} – employee labour costs,
C_M – material costs,
p – period or lifetime,
n – number of trains per day,
c – passenger occupancy of one wagon.

The price for transport and additional services is formed as a sum of costs and the reasonable profit. For evaluating the economic efficiency, it is necessary to estimate the expected revenues. In our model, we set the price bottom as an average amount of costs by different train occupancy with the reasonable profit of 10 %. In Table 6, we can see calculated price based on average costs and profit by different train occupancy.

Table 6. Profit by different train occupancy (Source: authors)

	average costs	price	profit 30%	profit 50%	profit 60 %	profit 100%
Budapest - Košice	19,85	21,84	-12,71	-0,12	3,18	9,46
Miskolc - Košice	8,78	9,66	-5,88	-0,09	1,42	4,32
Košice - Pardubice hl.n.	28,73	31,60	-18,35	-0,12	4,51	13,62
Poprad-Tatry - Pardubice hl.n.	24,54	27,00	-15,83	-0,12	3,87	11,72
Žilina - Pardubice hl.n.	18,70	20,57	-12,31	-0,13	2,96	9,05
Budapest - Bratislava hl. st.	23,75	26,13	-16,67	-0,31	3,85	12,03
Budapest - Brno hl. n.	29,44	32,38	-20,16	-0,31	4,73	14,65
Budapest - Praha Holešovice	28,17	30,99	-18,72	-0,20	4,50	13,76
Budapest - Berlin Hbf	46,48	51,13	-30,16	-0,23	7,37	22,32
Budapest - Hamburg Hbf	59,97	65,97	-38,63	-0,26	9,48	28,66
Bratislava hl. st. - Praha Holešovice	21,36	23,49	-14,53	-0,20	3,44	10,60
Bratislava hl. st. - Berlin Hbf	39,67	43,64	-25,96	-0,23	6,31	19,17
Bratislava hl. st. - Hamburg Hbf	53,16	58,47	-34,43	-0,26	8,42	25,50
Brno hl. n. - Berlin Hbf	33,85	37,24	-23,84	-0,43	5,51	17,21
Brno hl. n. - Hamburg Hbf	45,20	49,72	-32,53	-0,67	7,41	23,34
Praha Holešovice - Berlin Hbf	20,52	22,57	-13,75	-0,16	3,29	10,09
Praha Holešovice - Hamburg Hbf	30,63	33,70	-20,10	-0,18	4,88	14,84

The lower limit of profitability is 60 % occupancy of the train. The railway undertaking must adjust its acquisition activity in such a way as to maintain at least this occupancy of the train. Setting the price with higher amount of reasonable profit can ensure the profitability at lower occupancy but may also cause but it can also lead to an outflow of passengers to competition.

Conclusion

The liberalised railway transport market offers more and more options for railway undertakings to provide their services on competitive environment. In these conditions it is necessary to be able to estimate the demand for this service, detailed transport technology and form a methodology for calculating the price for transport. Expanding night connections connecting Europe's major cities is also one of the means of achieving carbon neutrality.

The aim of this article was based on analysis of current night train connections to introduce possibilities for new night trains in middle Europe. We focused on connecting important cities in Slovakia, Hungary, Czech Republic, and Germany, and ensuring competitive night connections on international corridor routes. In the article, we proposed timetables, trainset circulations, calculated expected costs and identified possible risks during the provision of this type of services. Based on the costs calculation, we evaluated the economic efficiency of proposed connections and estabilished a methodology for determining the price for additional services, especially couchette and sleeping services.

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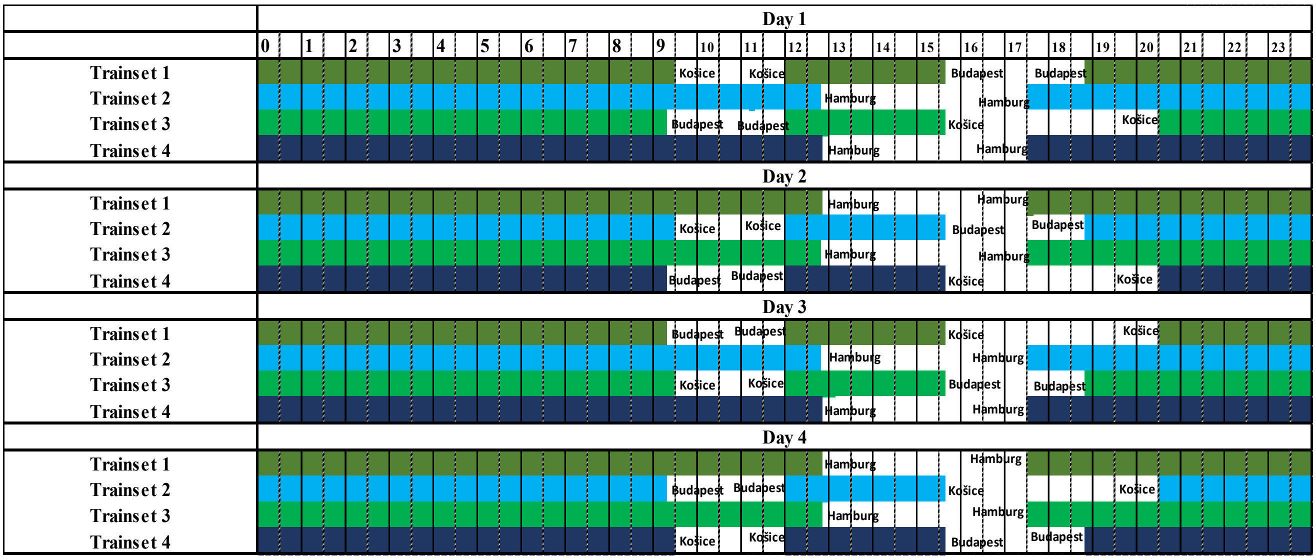

Fig. 2. Trainset circulations (Source: authors)

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EVALUATION OF THE IMPACT OF INTERNATIONAL TRADE USING REGRESSION AND CORRELATION MODELS

Abstract: The connection of international economies in the world represents an important role for the development of modern economies of countries. This phenomenon is known as globalization. The article describes in more detail the dependence of the Slovak Republic on the economies of East Asia, where mathematical research was performed on macroeconomic indicators of imports and exports. The Slovak Republic is experiencing an increase in GDP for the entire reference period. The growth of economic indicators in the Slovak Republic is ensured mainly due to the strong integration of our economy into international logistics chains and the strongly developed automotive industry. However, assuming the COVID-19 crisis, several studies suggest a sharp decline in economic indicators, as international trade has had to be significantly reduced for some time. The countries we examined in the article have a significant impact on these areas, so our research was focused on the main sectors of the Slovak economy. The automotive industry, the metallurgical industry and the electronics industry were evaluated. Data from world statistics were evaluated using mathematical and statistical models. The result of the study was the confirmation of dependence in all the categories.
Kľúčové slová: International trade, Gross Domestic Product, Export, Import, Macroecnomoics

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Introduction

The impact of globalization on the country's economic indicators is increasing every year. In order to secure global trade, it is also necessary to address the issue of functional and economically efficient logistics chains that will ensure the distribution of goods in the world evenly and at optimal costs.

At present, maritime transport is irreplaceable in transcontinental transport from Asia to the EU. The volume of transport carried out by this mode of transport cannot currently be replaced by any other mode of transport. Likewise, unit costs per unit of output represent only a fraction compared to other modes of transport.

On the other hand, it is important to note that the price or. the costs incurred per unit of transport do not mean that they are taken as a top criterion. Consumers are often willing to increase costs many times in order to ensure a faster and more efficient flow of materials or products for their business.

For the appropriate use of the railway network, it is necessary to select suitable types of goods that could be transported using the logistics chains of the railway networks. In terms of profitability, at such distances, the railway is able to halve the delivery time compared to maritime transport, which represents a possibility of more dynamic supply and, at the same time, the possibility of reducing costs.

Foreign studies show that rail transport can be suitably used as a complementary system for supplying the engineering, electrical and automotive industries in the event of a maritime supply outage. Therefore, we decided to test the two East Asian countries that are most affected by the dynamically developing manufacturing sectors. We will test partial indicators using regression analysis and their impact on the participation of the overall indicator.

1. Evaluation of the impact of international trade using regression and correlation models

The task of regression and correlation analysis is a mathematical description of systematic circumstances, which are accompanied by statistical dependencies. Specifically, we chose to examine the impact of foreign trade and imports of goods from Asia, and to find out whether the level of international trade with the countries of East Asia has risen to such a level that they become, for example, key trading partners for the Slovak Republic.

The aim of using regression models in research is to penetrate deeper into the essence of the observed phenomena and processes in a particular area. When solving, we get to the so-called causal links. A causal relationship between two phenomena is a state where the existence of one phenomenon is related to the existence of another phenomenon.

Our goal will therefore be to use such analytical models of dependence, which could lead to deeper research. For example, reassessing the economic benefits of switching from maritime to rail transport within logistics chains and optimizing supplies for production on the Iron Silk Road, which connects eastern Asia and Europe.

Such models are initially represented by a function of the dependence of factors that give us an insight into whether this direction of research is relevant for the next steps and for the direction of our research activities. These mathematical functions are called regression functions. The aim of regression analysis is to bring the empirical regression function as close as possible to the hypothetical regression function.

Before starting the research, it is necessary to perform several partial actions that require a certain degree of analytical thinking and gather them into complete blocks of information, which we can then formulate more clearly.

- Collection and mathematical formulation of the idea of the nature of the regression function,
- Formulate our ideas about the overall effect of unconsidered statistical features,
- Estimate the empirical regression function based on statistical observations,
- Assess the quality of the empirical regression function in terms of the reason and goal of the statistical survey.

2. F-test

To determine the dependence between the observed phenomena, the so-called F-test. An F-test is any static test in which the test statistic has a distribution of F assuming the validity of the null hypothesis. It is most commonly used to compare statistical models that have been estimated from a data set in order to identify the model that most closely matches the population from which the data were collected. Exact F-tests arise mainly when the models were estimated using the least squares method.

If the tabular value of the F-test is less than the calculated value, it can be stated that the investigated quantities are dependent. However, if the tabular value of the F-test is greater than the calculated value, it can be stated that the investigated quantities are not dependent. We will use the following relation to calculate the F-test value (Hindls 2006).

$$F = \frac{\frac{R^2}{k}}{\frac{1-R^2}{n-k-1}} \tag{1}$$

Where:

R^2 – is coefficient of determination

n – amount of observations in treatment

k – number of classes

3. Data mining and its interpretation

Gathering information from the perspective of international trade research, it is important to determine which indicators will be best for us to evaluate the market using mathematical models.

Another important fact is that information for market research is often difficult to access and therefore needs to be supplemented in some way in the form of analytical calculations, which may lead to possible deviations, but for projection, graphical representation and interpretation.

The main indicator currently used by most economists and analysts is the country's assessment of gross domestic product. Gross domestic product (at market prices), gross domestic product (at market prices), abbreviated GDP) or domestic product is the value of all final products and services produced by resident units of the observed territory (usually the state) during the observed period (usually per year). It corresponds to the so-called gross value added of the whole economy at market prices (Dolinayova 2016).

We also decided to continue by comparing the value of gross domestic product with the values of total exports and imports. To examine our dependencies, we will focus on the import curve, as Slovakia is not one of the top exporters to the PRC, and the value of imports is many times higher than the value of exports for this destination. The trend of the curves of GDP, imports and exports at first sight have common features, which at first glance changed, that their connection resp. testing of our indicators will be roughly comparable in terms of.

The basic features that have these curves the same are the local maxima and minima at certain time periods and, of course, their generally growing trend.

It can be seen from the graph that the largest increase in exports and imports for the Slovak Republic is in 2004, when Slovakia joined the EU as a member. By joining the EU and the Schengen area, we gained benefits such as duty-free contact with all EU member states, which greatly helped the overall growth of interstate transactions. The year 2009 represents the most significant decline, such a sharp fall may be related to the adoption of the new € currency, this change has often accompanied other countries in the past and causes smaller revenue shortfalls. After the stabilization of our economic growth in 2011, the overall growth of the economy of the Slovak Republic also slowed down.

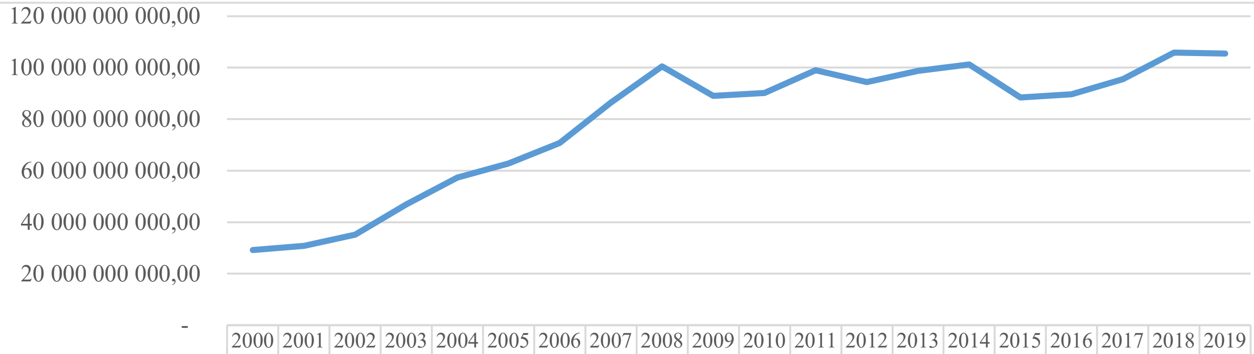

Fig. 1.GDP in Slovakia in USD (source: worldbank.com)

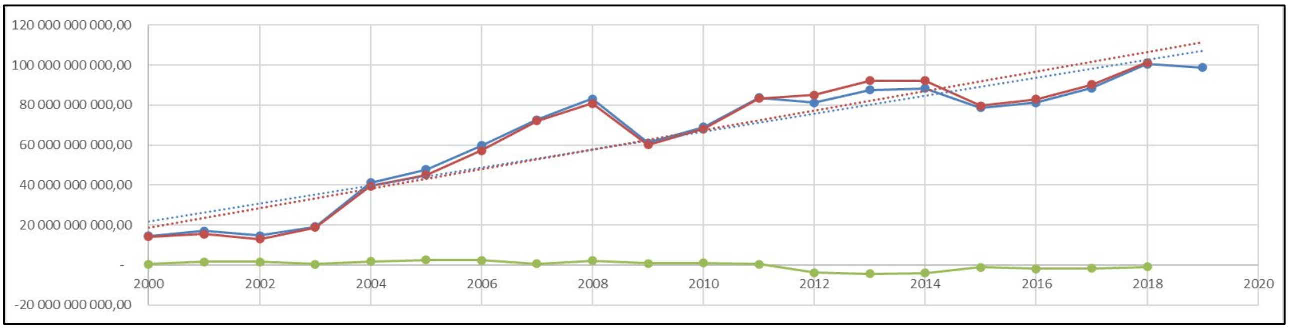

Fig. 2. Value of total Exports and Imports of the Slovak Republic for the observed period 2000-2020 (source: OEC.world)

The overall impact of the COVID-19 crisis is currently not yet described, but the models entrusted in several economic studies suggest a significant drop in 2020, which will be carried over to the near future.

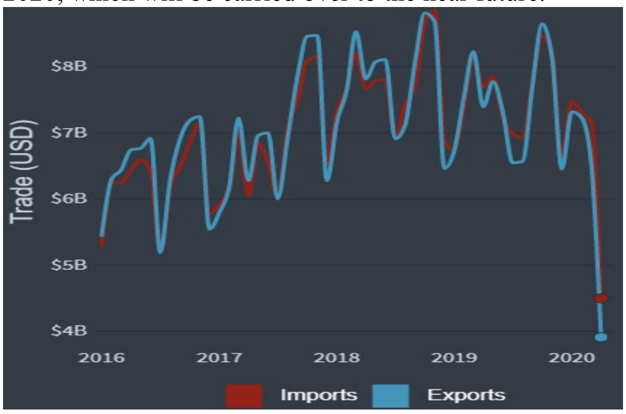

Fig. 3. An example of an OEC model in an international trade agreement for 2020 (source: OEC.world)

For further investigation, we decided to examine precisely the dependence of imports from East Asian countries. We have chosen the two largest suppliers for the Slovak Republic, namely the PRC and South Korea. By comparison, these countries are interesting in terms of connection to the European market, as China has access to Europe by sea but also by continental rail networks that cross the continent and are becoming increasingly important in terms of international trade.

On the other hand, due to the political situation for its neighboring state, South Korea has very limited opportunities in terms of the use of transcontinental rail links, and therefore South Korea's entire international trade is highly dependent only on maritime transport. The political situation between the two countries has not improved in recent years.

In picture no. 3 shows the share of the total international imports of the Slovak Republic for the countries of China and South Korea. There is approximately a comparable amount of volume throughout the period considered, except in 2012, when the difference between imports from

South Korea and China was almost two billion USD. We see the acceleration of international trade just after 2004 and 2005, when we became part of the European union. The increase in imports from South Korea supported the arrival of the car manufacturer KIA in 2007.

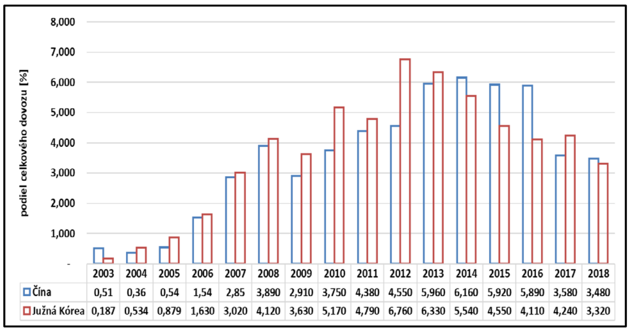

Fig. 2. Comparison of imports from the PRC and South Korea during the period considered (source: OEC.world)

3.1. Peoples republic china import

The PRC's impact on the local markets of individual member states has increased rapidly. The approach of technology, the expansion of electronics and current smart devices is visible daily. A significant amount of household-owned electronics is made in China. for this reason, we decided to test the main commodities that are most common in our region. In terms of international trade, we mainly import LCD displays from the PRC, which are used in several companies that produce consumer electronics, but at the same time their occurrence is increasingly being promoted in sectors other than automotive.

The blue color shows the engineering industry, and the components that were produced by machine production. Imports of these commodities often result due to lower prices, respectively. that the production of these components in our region would be expensive, and so the manufacturing capability of the PRC is used. el. transformers, electric motors, car parts or bearings.

For our research, we have selected industries or products that match as closely as possible the import comparisons of a competing country in South Korea. In our test, we chose the import of LCD displays, parts intended for the automotive industry, the import of gasoline engine units, computers, metallurgical material, and we also included the import of textiles and clothing industry, as our company is strongly influenced by this commodity.

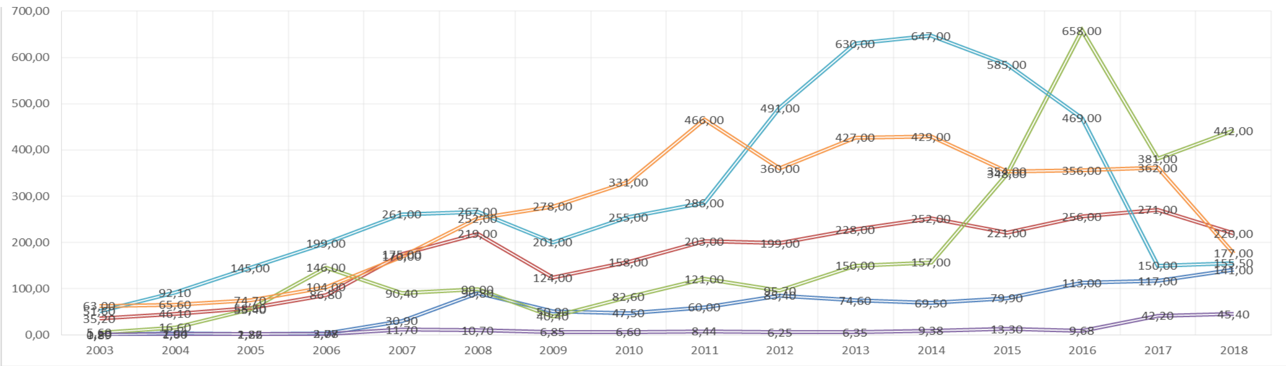

Fig. 5. Year-on-year increase in import volumes from the PRC in USD over the period considered (Source: OEC.world)

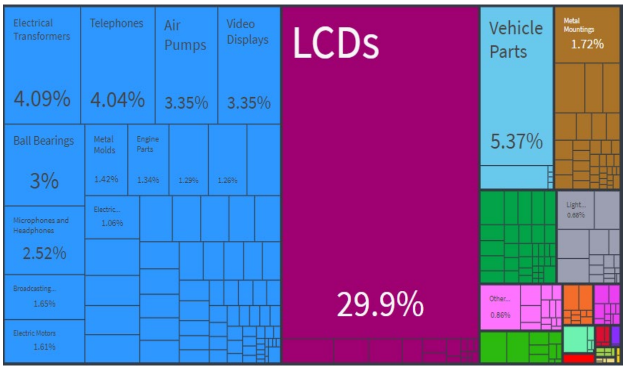

Fig. 6. Overview of imported groups of goods from China in 2018 (source: OEC.world)

Figure 6 graphically shows the course of imported goods from China for our period under review according to selected categories. An interesting trend is going through the metallurgical products sector, whose imports have caused severe complications for ironworks in the EU, with the consequences of regulating the release of externalities into the air, which has increased production. The opportunity for the growth of metallurgical material imports was stopped only by the EU anti-dumping duties, which were

Figure 5 graphically shows the course of imported goods from China for our period under review according to selected categories. An interesting trend is going through the metallurgical products sector, whose imports have caused severe complications for ironworks in the EU, with the consequences of regulating the release of externalities into the air, which has increased production. The opportunity for the growth of metallurgical material imports was stopped only by the EU anti-dumping duties, which were adopted in 2017, which resulted in a decrease in demand.

Imports of LCD panels began to rise sharply after 2014, when these displays spread to all sectors of production, from car production and the inclusion of their use in the middle and lower class car and, of course, in the electronics industry. Currently, every smart device includes at least some form of LCD display for simplified interaction with its user.

3.2. South Korea import

South Korea has been the second largest partner in international trade relations. Imports from South Korea are currently around 5%. The strongest year was 2012, when general trade with South Korea has been on a declining trend. The reason why we chose South Korea for this comparison is also that in the Slovak Republic and the surrounding countries there are large conglomerates such as. Samsung, KIA or Hyundai and others. The largest items of imports are mainly engineering production, imports of electrical equipment and components and vehicles resp. automotive. Other categories include products of the metallurgical industry and the chemical industry. The year-on-year growing items are electric motors and batteries for automotive or e.g. also optical fibers.

For the purposes of our survey, we have selected commodities that match imports from the competing People's Republic of China, and we have also chosen other products and industries that are closely related to the economic sectors of the Slovak Republic.

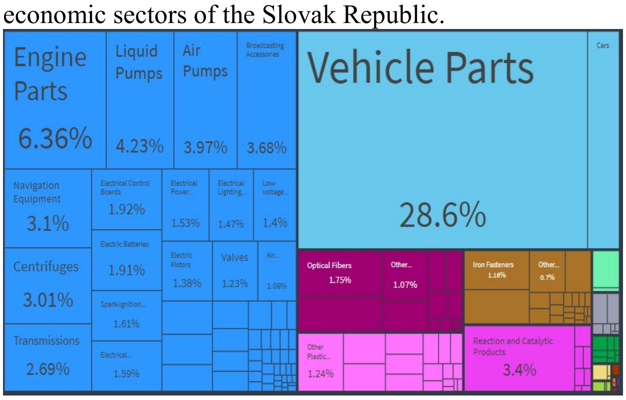

Fig. 7. Graphical representation of the largest commodities of imports from South Korea in 2019 (source: OEC.world)

Imports of products from South Korea focus on key items such as imports of displays and parts for the automotive industry. The rapid growth in the value of imported displays is related to their implementation in various devices. The decline in the volume of imported displays is probably related to the relocation of the main production of the SAMSUNG and LG conglomerate to China, where the vast majority of modern display devices began to be produced. Such steps are taken by all

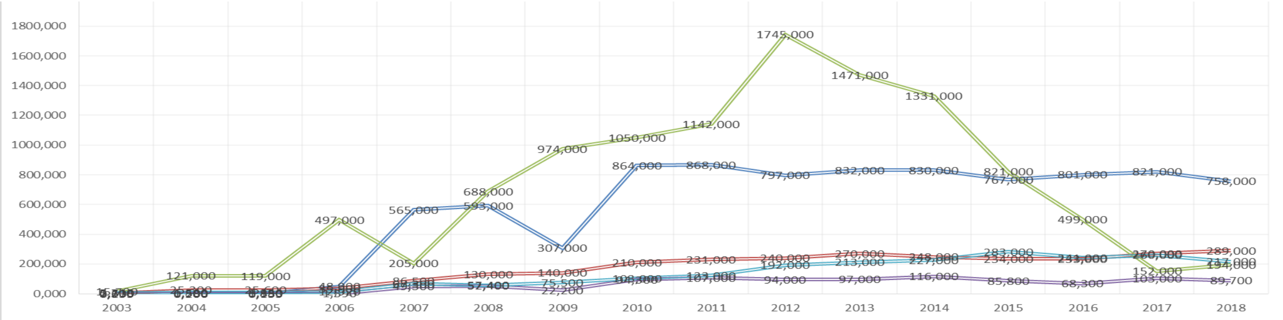

Fig. 8. Year-on-year increase in import volumes from the South Korea in USD over the period considered (Source: OEC.world)

technology companies in order to reduce the cost of their production.

Imports of goods related to the automotive industry are shown by the Autodiely curve, which recorded its first sharp increase in 2007 due to the construction of the KIA car plant in Žilina. As a result of its supply, imports of car parts from South Korea have stabilized at around USD 800 million (Oec.world 2021).

4. Testing of statistical hypoteses for the monitored commodities of the selected sountries

For decision-making in testing, we determine the result of the test in the form of hypotheses, which we either reject or accept. These hypotheses are listed in the following table.

Table 1 Decision table for statistical hypotheses

H_0	The GDP of the Slovak Republic depends on the import of commodity XXX. From the People's Republic of China
H_1	The GDP of the Slovak Republic is not dependent on the import of commodity XXX. From the People's Republic of China
H_0	The GDP of the Slovak Republic is dependent on imports of commodity XXX. From South Korea
H_1	The GDP of the Slovak Republic is not dependent on imports of commodity XXX. From South Korea

4.1 People's Republic of China hypotheses testing

When examining the impact of imports of textile industry products from the PRC on the GDP of the Slovak Republic, we chose a polynomial dependence, as equation R2 was the highest in this function. The drawn model is based on the data of picture no. 1 and figure no. 5. The graphical representation of the dependence is shown in Figure no. 6

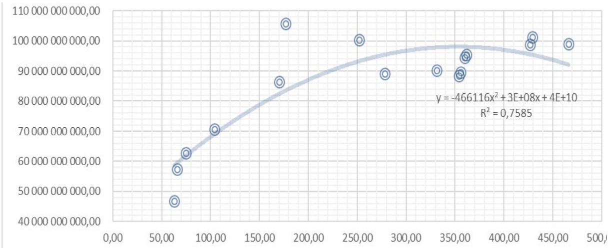

Fig. 9. Dependence of imports of textile industry products on the GDP of the Slovak Republic (source: author according to oec.com)

To verify the dependence, it is necessary to compile a table where the individual variables on the basis of which the dependence will be verified, resp. independence of the factors examined. This verification is in Table 2.

Table 2. Factor dependence verification table

R^2	0,7585
k	2
n	16
n – (k + 1)	13
F	20,41511387
F_{TAB}	3,806

From the table 2 we can see that the calculated value of the F-test is larger than the table value. Based on this fact, it can be concluded that it is possible to accept hypothesis H0 and reject Hypothesis H1.

The textile industry has been growing relatively steadily throughout the period under review. Its rising nature copies the GDP curve and therefore the level of reliability is around 0.7585.

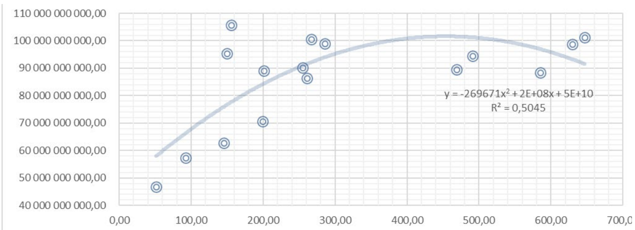

Fig. 10. Dependence of PC imports on the GDP of the Slovak Republic (source: Author according to oec.com)

To verify the dependence, it is necessary to compile a table where the individual variables on the basis of which the dependence will be verified, resp. independence of the factors examined. This verification is in Table 3.

Table 3 Factor dependence verification table

R^2	0,5045
k	2
n	16
n – (k + 1)	13
F	6,618062563
F_{TAB}	3,806

From the table 3 we can see that the calculated value of the F-test is larger than the table value. Based on this fact, it can be concluded that it is possible to accept hypothesis H0 and reject Hypothesis H1.

Imports of personal computers from China is a rapidly growing market. The confidence level is around 0,5, which means a not very reliable indicator.

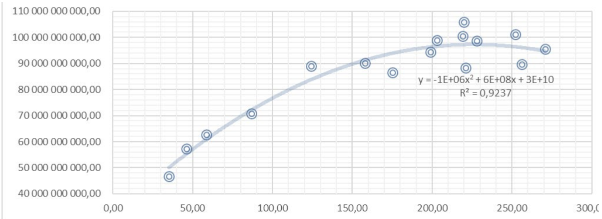

Fig. 11. Dependence of imports of metallurgical industry products on the GDP of the Slovak Republic (source: author according to oec.com)

To verify the dependence, it is necessary to compile a table where the individual variables on the basis of which the dependence will be verified, resp. independence of the factors examined. This verification is in Table 4.

Table 4. Factor dependence verification table

R^2	0,9237
k	2
n	16
n – (k + 1)	13
F	78,69003932
F_{TAB}	3,806

From the table 4 we can see that the calculated value of the F-test is larger than the table value. Based on this fact, it can be concluded that it is possible to accept hypothesis H0 and reject Hypothesis H1.

The metallurgical industry and its imports from the PRC are at a level of reliability of up to 0,92, which means that imports of steel and steel products from China may be closely linked to the national economy.

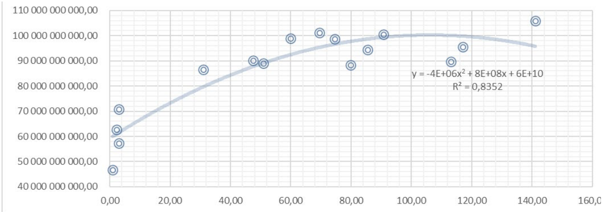

Fig. 12. Dependence of imports of parts for the automotive industry on the GDP of the Slovak Republic (source: Author according to oec.com)

To verify the dependence, it is necessary to compile a table where the individual variables on the basis of which the dependence will be verified, resp. independence of the factors examined. This verification is in Table 5.

Table 5. Factor dependence verification table

R^2	0,8352
k	2
n	16
n – (k + 1)	13
F	32,94174757
F_{TAB}	3,806

From the table 5 we can see that the calculated value of the F-test is larger than the table value. Based on this fact, it can be concluded that it is possible to accept hypothesis H0 and reject Hypothesis H1.

The import of car parts from China started only after 2007, when the car manufacturer KIA was founded in Slovakia. The logistics sub-supplies of this carmaker also extend to the territory of the PRC, which means that this connection seems to be justified.

4.2 South Korea hypotheses testing

We selected the survey of imported commodities from South Korea according to their impact on our national economy. We know that the dependence of imports is linked to the national economy, but the strength of this dependence may be increased when examining articles that are somehow directly linked to key enterprises, e.g. KIA, SAMSUNG (Trembošova 2019).

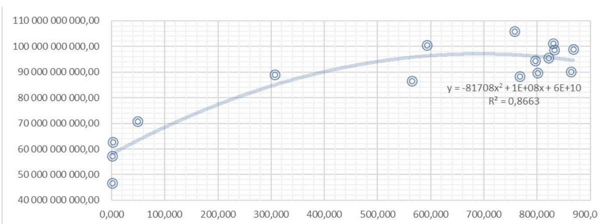

Fig. 13. Dependence of imports of automotive parts from South Korea on the GDP of the Slovak Republic (source: Author according to oec.com)

To verify the dependence, it is necessary to compile a table where the individual variables on the basis of which the dependence will be verified, resp. independence of the factors examined. This verification is in Table 6.

Table 6. Factor dependence verification table

R^2	0,8663
k	2
n	16
n – (k + 1)	13
F	42,11630516
F_{TAB}	3,806

From the table 6 we can see that the calculated value of the F-test is larger than the table value. Based on this fact, it can be concluded that it is possible to accept hypothesis H0 and reject Hypothesis H1.

Imports of car parts from South Korea, on the other hand, operate in a stable supply mode. Its value is stable, which follows from Figure no. 7. The confidence level is 0,8663.

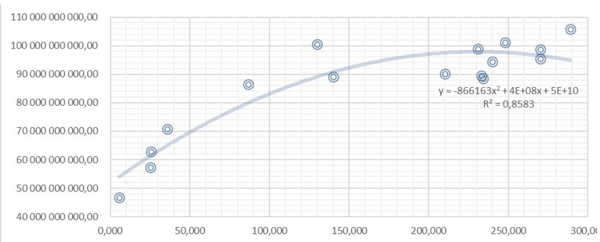

Fig. 14. Dependence of imports of metallurgical industry products from South Korea on the GDP of the Slovak Republic (source: Author according to oec.com)

To verify the dependence, it is necessary to compile a table where the individual variables on the basis of which the dependence will be verified, resp. independence of the factors examined. This verification is in Table 7.

Table 7. Factor dependence verification table

R^2	0,8583
k	2
n	16
n – (k + 1)	13
F	39,37155963
F_{TAB}	3,806

From the table 7 we can see that the calculated value of the F-test is larger than the table value. Based on this fact, it can be concluded that it is possible to accept hypothesis H0 and reject Hypothesis H1.

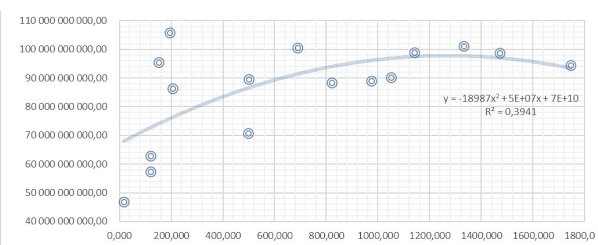

Fig. 15. Dependence of imports of LCD screens from South Korea on the GDP of the Slovak Republic (source: Author according to oec.com)

To verify the dependence, it is necessary to compile a table where the individual variables on the basis of which the dependence will be verified, resp. independence of the factors examined. This verification is in Table 8.

Table 8. Factor dependence verification table

R^2	0,3764
k	2
n	16
n – (k + 1)	13
F	3,9233483
F_{TAB}	3,806

From the table 8 we can see that the calculated value of the F-test is larger than the table value. Based on this fact, it can be concluded that it is possible to accept hypothesis H0 and reject Hypothesis H1.

Screen imports from South Korea represent the weakest dependency at only 0,3764. The reason is sharp fluctuations in the volume of imports, which behave too jumpy, which does not correspond too much with stable economic growth.

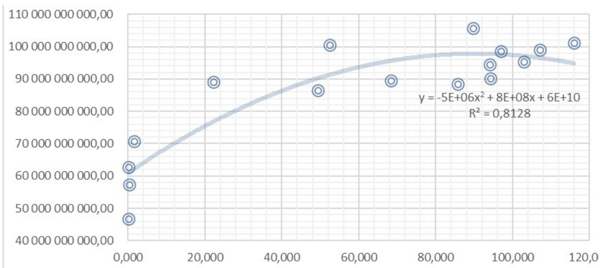

Fig .13. Dependence of automotive imports from South Korea on the GDP of the Slovak Republic (source: Author according to oec.com)

To verify the dependence, it is necessary to compile a table where the individual variables on the basis of which the dependence will be verified, resp. independence of the factors examined. This verification is in Table 9.

Table 9. Factor dependence verification table

9	0,8128
k	2
n	16
n – (k + 1)	13
F	28,22222222
F_{TAB}	3,806

From the table 9 we can see that the calculated value of the F-test is larger than the table value. Based on this fact, it can be concluded that it is possible to accept hypothesis H0 and reject Hypothesis H1.

Engine parts imported from South Korea have the same course as car parts but differ only in value. The level of significance is at the level of 0,8128, which means that the import of this article is strongly related to the development of our national economy.

Conclusion

International trade from the countries of East Asia is strongly preferred in the conditions of the Slovak Republic. Products, products and materials that are imported into the territory of the Slovak Republic are often many times cheaper, whether they are consumer products or material or raw materials as inputs to production processes.

By evaluating the regression models and their impact on the national economy, in particular GDP, we found that all the commodities we chose from both countries examined partly contribute to GDP growth. The reason is the strong orientation of the Slovak Republic towards industrial production. The import of material ensures a smooth production process, which in turn ensures sufficient jobs for the population and the associated cycle of the national economy.

At present, the trend of imports from East Asian countries is slightly declining, as we have declared in the market analysis, but this phenomenon is only a presumption of a cyclical economic crisis, after which the market mechanism is likely to reopen and import volumes return to their level.

However, the import of goods from abroad also brings with it risks, e.g. in the metallurgical industry, which employs a large number of economically active people in the Central EU region. In the event of a sharp increase in imports and a decrease in local production, such steps could mean a gradual reduction in production for the metallurgical industry. Similar cases may occur in other sectors, so it is important that it grows internationally and supports each other with the national economy through synergy effects.

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CONSTRUCTION LAYOUT OF STATIONS AND ITS IMPACT TO TRAIN DELAYS

Abstract. The paper focuses on construction layout of railway stations, mainly platforms for boarding passenger trains. Platform layout has significant impact to the operation of trains, because passengers cross some tracks horizontally, when the train boarding is necessary. Horizontal track crossings cause possible dangerous situations from passengers' point of view as well as operational problems from dispatcher point of view, because other trains have to slow or stop their ride. It may cause delays and it negatively influences timetable planning too. The problem is deeply analysed and described in a case study of Opatov railway station.
Keywords: railway transport, safety of passengers, station layout, train delay

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Introduction

Construction layout varies in each railway station, so scientific method of induction is the best way for the analysis and solution of the problem as well as way to prove the impact of the layout to train delays. Induction means that the general solution is found from particular examples therefore the case study of railway station Opatov is used in the paper.

In the railway station Opatov, there are three platforms for boarding passenger trains. It is necessary to cross some tracks horizontally, when passengers is going to get on or get off the train. Construction layout of the railway station Opatov is shown in the figure 1.

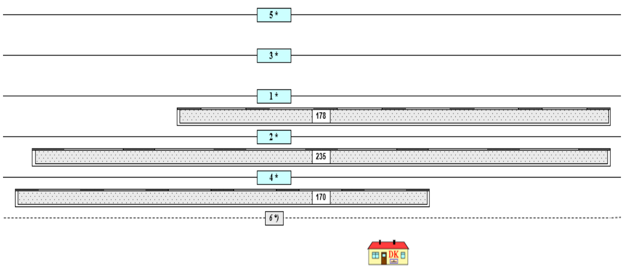

Fig. 1. Station tracks and platforms in railway station Opatov

In case when passenger trains stop there for boarding, it is necessary to decide the right point of stopping. If other train at the same time is arriving to the station or going through the station, it is also necessary to decide the right order of these trains. It may cause dangerous situation for passengers when they are crossing tracks horizontally, because the second train route could collide with passengers' movement. Simple solution is to indicate the train route of stopping train to those station tracks, which are closer to the station building as the track, which is used for other trains. From operation point of view, these problems may occur:

1. The stopping passenger train delays due to the ride of other train with higher priority.
2. Other train has to stop out of the railway station while the stopping passenger train is waiting for passengers' boarding.
3. First stopping train has to wait in the railway station until second stopping train is waiting for passengers' boarding.

1. Analysis of the railway operational problems

Operational problems can occur in case when other type of railway vehicle is used, because it determines the maximum speed of the train. Simple analysis is done on selected situation from the train timetable of regional passenger train no. 4765 and long-haul express train no. 273. Period for the analysis is one month (30 days) – November 2020. Analysis provides these outputs:

1. Regional passenger train was everyday operated by railway vehicle with maximum speed 80 kph instead of 120 kph as it had been planned for the timetable. It caused that average ride time from station Česká Třebová to station Opatov was 10 minutes instead of 7 minutes as it is done in timetable. Difference is 3 minutes. It led to situation that the long-haul express overtook regional passenger train 21 times (70%).
2. Average arrival delay was 3.57 minutes while average departure delay was 5.53 minutes. This means that the delay of regional passenger train was increased due to redundant waiting caused by operational situation described below.
3. Average ride time of the long-haul express from station Česká Třebová to station Opatov is 6.97 minutes but in timetable, 8 minutes of ride time for this type of train is there. Ride time could be

decreased to 6 minutes because current ride time involves also deceleration of this train in case when regional passenger train occupies the track.

Other situation that causes operational problems was analysed with one-month period (31 days) – October 2020. Dispatcher decided to prefer long-haul train from the direction Svitavy. Regional passenger trains had to wait. The analysis provides these outputs:

1. This situation occurred 10 times. Regional passenger train had to wait due to freight train four times and due to other passenger train.
2. Regional passenger train increased its delay about 3 minutes in average.

Due to the lower speed of some freight trains, it is not always advantageous to stop the regional passenger train so usually freight trains stop and regional passenger trains are prioritised. Stopped freight train waits until the regional passenger train depart from the platform. This situation will not delay the regional passenger train, but freight train has to wait. A similar type of situation can also occur in a combination of regional passenger train from the opposite direction Česká Třebová. Everything depends on dispatcher’s choice and preference as well as current operational situation. This situation was also monitored in the same period – October 2020 when seven such cases occurred:

1. Just five freight trains were affected; one long-haul passenger express train and one regional passenger train were affected too.
2. In all cases, there was an increase in the delay of the train going from the direction Svitavy by at least 2 minutes, on average by 3 minutes. Combination of two passenger trains led to 2 minutes increase of delay while the delay of freight trains was increased by 3-5 minutes. It is mainly due to the higher weight of trains and thus longer time needed to acceleration.

2. Alternative solutions for operational problems

Operational problems in railway station Opatov is mainly caused due to the necessity that passengers should horizontally cross some station tracks when they want to board the train. It means that entrance to each platform in the station is on the same level as all station tracks. These level crossings also have an impact on station technology and organization of train routes there. The most difficult situation is the case when regional passenger train in the direction from Česká Třebová to Svitavy is led to station track no. 1 and another train in Opatov railway station does not overtake this train. High risk comes from trains with opposite direction, because their ride would directly endanger the safety of passengers who get on or get off the regional passenger train. This situation can be solved in two ways:

1. Regional passenger train will wait at the entrance of the station until the train of opposite direction pass the station.
2. Regional passenger train standardly arrives to the station while the train of opposite direction is waiting at the entrance of the station until the regional passenger train departs.

Both ways cause the delay of the train, because some of trains has to wait at the entrance of the station. This reason will increase the delay by an average of 3 minutes. The occurrence of this delay is directly evidenced by the platform-operating interval. Next part of the paper is aimed to description of three possible alternatives, which can solve operational problems as well as increase safety for the traveling public.

First alternative means that a new platform between tracks no. 1 and no. 5 will be built. This platform will be accessible only by underpass or overpass, so passengers will not cross directly and horizontally any station track. It is necessary to have much space for this new platform and PRM needs must be taken into account. It means that station track no. 3 will be cancelled, because new platform must have minimum 6.1 meters wide. Distance between each station tracks is only 4.75 meters therefore one station track (no. 3 as it was mentioned below) must be cancelled. Less station tracks will decrease the capacity of the station as well as the whole railway line, what is significant negative aspect of this alternative, what may cause other operational problems. First alternative is shown in the figure 2.

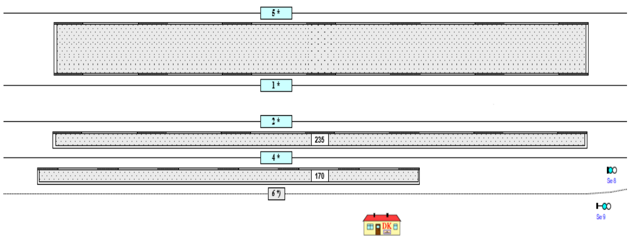

Fig. 2. First alternative – new platform between tracks 1 and 5

Second alternative means that a new platform behind the station track no. 5 will be built. This platform will be accessible only by underpass or overpass, so passengers will not cross directly and horizontally any station track. Advantage of this alternative is that platform-operating intervals will be eliminated. In the figure 3, there is proposed layout of the railway station Opatov according this alternative.

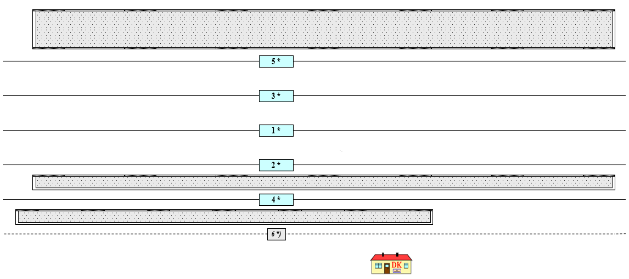

Fig. 3. Second alternative – new platform at track 5

In case that the same track layout is used for this alternative as well as all speed limits, it will negatively influence the ride time of regional passenger trains. Trains should follow junction speed limits, when their route is not on direct station track. Current junction speed limit is 40 kph therefore each train, which will use new platform, will be limited and the ride time will increase, but not significantly.

Third alternative means that two new platforms will be built according the figure 4. This alternative combines advantages and disadvantages of previous alternatives but it has not so negative impact to station tracks capacity as well as train ride will be influenced only partly in one direction, because it depends on junction speed limits.

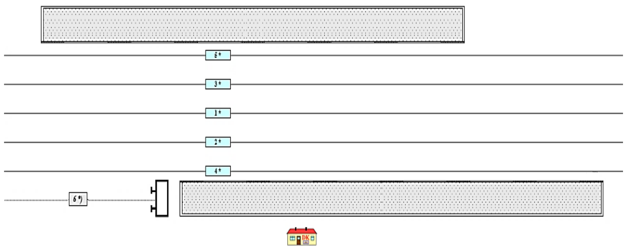

Fig. 4. Third alternative – new platforms at tracks 4 and 5

Description of each alternative points out that there are important issues with significant impact to overall evaluation – junction speed limits (JSL). Exact impacts to traveling times (TT) of regional passenger trains according the vehicle type is shown in the table 1.

Table 1. Comparison of riding times on different station tracks

TRAVELING TIME Svitavy-Lačnov → Semanín				
Vehicle (type)	**JSL** (kph)	**TT** (min)	**TT** (min)	**Δ TT** (min)
814	60	6.5	7	**+0.5**
841		5.5	6	**+0.5**
814	80	6.5	6.5	**0**
841		5.5	5.5	**0**
841	100	5.5	5.5	**0**

It seems that junction speed limit 100 kph is the best but this speed is not sufficient for both vehicles, because vehicle type 814 has the maximum speed just 80 kph. In case when the train is moving 100 kph (only vehicle type 841), it must brake therefore the potential will not be fulfilled. In case of acceleration, this type of vehicle cannot reach the speed 100 kph before junction therefore the potential will not be fulfilled too. This parameter is based on total length of station tracks, mainly those tracks, where are the platforms for boarding passenger trains. Station track length is limited so it must be also take into account. Optimal solution from traveling time point of view is junction speed limit 80 kph. It is necessary to prove that vehicles and traveling time will be influenced by this junction speed limit. It is proved in the figure 5.

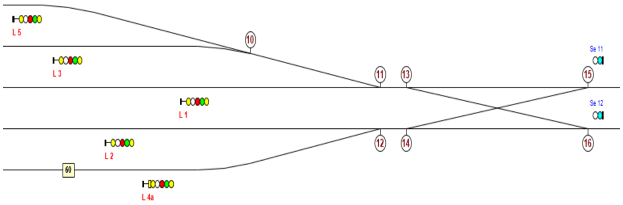

Fig. 5. Junction area in the station Opatov

Conclusions

Conclusions is done by multicriteria analysis and the comparison of presented alternatives. As it was described in previous chapters, operational problems result from platforms and track level horizontal crossings as well as number of station tracks, junction speed limits and vehicle type. These parameters and aspects directly influence traveling time of each train. Due to some unexpected situations, possible dangerous situations for the traveling public may occur. Alternatives offer solution for these problems as well as their impact to train delays and reasons of those delays. Table 2 shows criteria and current situation. Table 3 compares each alternative according the criteria. Problematic values are marked red while right values are marked green.

Table 2. Criteria and current situation

CRITERIA	**NOW**
Level crossings for direction Č. Třebová	**Yes**
Level crossings for direction Svitavy	**Yes**
Train route cross the passenger path	**Yes**
Interval – pass and arrive (min.)	**+3**
Interval – depart and pass (min.)	**+2.5**
Ride on track no. 5 speed above 40 kph	**No**
Ride on track no. 4 speed above 40 kph	**No**
Number of station tracks	**5**

Table 3. Comparison of alternatives according criteria

Alternative 1	**Alternative 2**	**Alternative 3**
Yes	**Yes**	**No**
No	**No**	**No**
No	**No**	**No**
0	**0**	**0**
0	**0**	**0**
No	**Yes**	**Yes**
No	**No**	**Yes**
4	**5**	**5**

Third alternative has only positive values in the comparison therefore this alternative seems to be the best. Complex solution is based on elimination of level crossings by building of new platforms with overpass or underpass. Number of station tracks in third alternative is the same as currently so track capacity is enough.

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PROPOSAL FOR THE EVALUATION OF THE STABILITY LEVEL OF PERIODIC TIMETABLE IN TERMS OF OPERATION AND INFRASTRUCTURE

Abstract. The introduction of tact timetable in rail passenger transport is currently a new evolving trend that increases the efficiency of rail transport. This article seeks to contribute in this area of the issue and thus to raise and improve this system of organizing transport in railway transport. The aim is to propose a methodology that assesses the level of stability of tact timetable based on operational and infrastructural factors. The methodology identifies operational-infrastructural factors that affect the stability and reliability of tact timetable. Using scientific methods, it presents the method of their quantification and determination of the weights of these factors, which evaluate the line sections and transport points of the examined transport path. From a practical point of view, the methodology is generally tact applicable to other European railway networks. In the final part of the work, this methodological procedure is applied in the form of model examples for various transport path.
Keywords: Railway transport, Capacity, Periodic timetable, Stability

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Introduction

Today's modern trend in compiling timetables is the introduction of tact or tact timetable. This mode of operation has been researched and tested for several years in other developed countries such as Switzerland and Germany. Scheduling a tact timetable with regular connections to other lines of connecting railway has proven to be one of the successful tools for providing quality transport services and thus to attract and retain public transport users more closely. Such a timetable also has its disadvantages and poses its risks. As it requires high reliability of running times, it is necessary to ensure its stability to maintain its quality.

The daily timetable is a stochastic process, and the occurrence of any unforeseen event can cause delays and their subsequent spread, which can have a negative impact not only on the carrier but also on passengers. This article describes a proposal for a methodological procedure for assessing the stability of tact timetable in terms of operational and infrastructural factors. By researching and finding an effective way in the field of reliability of tact timetables, the authors sought to contribute to the optimization of railway capacity and to broaden the perception of the element of stability from another point of view.

1. Stability of periodic timetable

The capacity of the railway network is limited by its bottle necks - elements (track sections and railway junctions), i. e. places whose capacity is used to the maximum and their higher use would endanger the stability of the timetable. The capacity of these constraints cannot be used any more, but professionals need to look for new ways to use existing infrastructure more efficiently.

It follows that it is necessary to thoroughly assess the infrastructure and operational level of the transport path. It is therefore the implementation of the train service plan and the basis of the level of stability which is directly related to the safety of the railway system. The main core of the operational level is the train timetable. It is therefore important to design a high-quality timetable.

According to the studies of V. Cacchiani and P. Toth, we can divide the problems of stability of timetables into four areas:

1. synetrical (periodic) or asynmetrical timetables;
2. railway network or single track;
3. freight orpassenger transport;
4. various other objective functions.

We can say that stability is a broad concept. We can also define it as the ability to survive or as a model of balance. It is a caching-capable ability to restore the status of a timetable that acts as a cache. It is important to note that stability is inversely proportional to the capacity of rail transport. Under normal circumstances, the higher the utility capacity ratio, the less time left to compensate for time delays. This "balancing" backup time is therefore in the two components of the timetable.

The first component is the journey time on the track sections and the second component is the residence time at the railway stations. Optimizing the stability of the timetable is the ability to absorb timetable disruption and adjust the departure and arrival time of trains in the railway station described by Xuelei M.E.

Andersson et al. presented a way to quantitatively measure timetable robustness to identify emerging timetable shortcomings and thus provide a proposal for improvement. The constantly growing demand for railway capacity sometimes leads to high-capacity consumption, resulting in a network sensitive to delays with insufficient robustness. According to this theory, it is important to identify the so-called critical points where trains can increase delays in the delay that has already occurred. Based on this, it is necessary to set the time reserves correctly before and after the critical point. Sufficiently available time spans (accumulated amount of reserve) before the critical point increase the train's ability to arrive on time. On the contrary, the margin of time of the incoming train after the critical point to the next stopping point increases the possibility to delay this train in favor of other trains.

Caimi et al. in the process of tact transport they developed the idea of dividing the railway network into condensation zones (areas with a bottle neck where the smallest possible time reserves and high accuracy are needed due to better capacity utilization) and into compensation zones (places where higher time reserves are needed to compensate for small delays from condensation zones) to solve the problem of timetables. Condensation zones are located near major railway junctions where available capacity is limited and therefore maximum speed is required from trains. On the other hand, train network is less dense in the compensation zones that connect the condensation zones. In this way, time reserves can be introduced for train running in compensation zones in order to increase the stability of the timetable. each zone is then treated according to its specific property.

2. Proposal of a methodology for evaluating the stability of periodic timetable from an operational-infrastructural point of view

The proposed methodology is to be used to evaluate the stability of the constructed tact timetable in terms of operational and infrastructure. In other words, it is a more complex indicator of infrastructure-operational conditions, which in a relative relationship expresses the percentage risk of instability of the timetable or its ability to reduce the transmission of delays. The larger the stability indicator, the more stable tact timetable is, which leads to its reliability. Stability assessment is based on the principle of comparing operational and infrastructural factors that affect the stability of tact timetable. An important part of this proposal was the correct setting of the quantification of these assessed factors that assess the stability. The first step is to divide the transport route into interstation sections, which will be separated by transport points where delays can be compensated. These transport points include railway stations and passing point. Another important part of the methodological procedure is the determination of condensation and compensation zones based on the evaluated factors. It is this ratio that helps us determine the level of tact timetable stability.

Condensation zones are very sensitive to time and reliability. These are therefore mainly sections or transport points with a low ability to reduce the transmission of delays. These areas are characterized by short stopping time of a train, slow travel time, operating control point with a small number of running tracks or a low number of block sections, etc.

Compensation zones serve to compensate for the time when the delay is created, i.e., the times of the initial delay. They can also be used to overtaking and train crossing when organizing transport so as to reduce the risk of reduced travel times in condensation zones and thus ensure the reliability of tacts. Thus, these are zones that are the opposite of condensation zones. We can say that these zones serve as areas that provide a "backup time well". Based on this characteristic, this methodology does not pass points as transport points and, due to operational and technological functions, passing points defines it as a compensation zone.

The higher the number of compensation zones, the greater the stability of tact timetable. Due to the difference in operational-infrastructural factors, it is necessary to evaluate interstation sections and transport points separately for even and odd directions due to different stopping time of a train or directional and slope conditions, which affects the travel times of passenger trains. After determining the indicator of stability of interstation sections and transport points, the average value of these two indicators is determined, which expresses the resulting overall stability of tact timetable of the given transport route. For easier understanding, this proposed methodological procedure was processed into individual steps.

Summary of the methodological procedure in partial steps:

Step 1: Dividing the transport route into interstation section and transport points.
Step 2: Identification of operational-infrastructure factors using the documents of the infrastructure manager.
Step 3: Quantification of factors (allocation of weights).
Step 4: The sum of all assigned weights of the interstation section and transport point factors.
Step 5: Determination of condensation and compensation zones.
Step 6: Determine the stability of interstation sections and transport points.
Step 7: Determine the overall tact timetable stability of the examined transport route.

The complex heuristic procedure for determining the level of stability according to the mentioned partial steps is graphically processed in Figure 1.

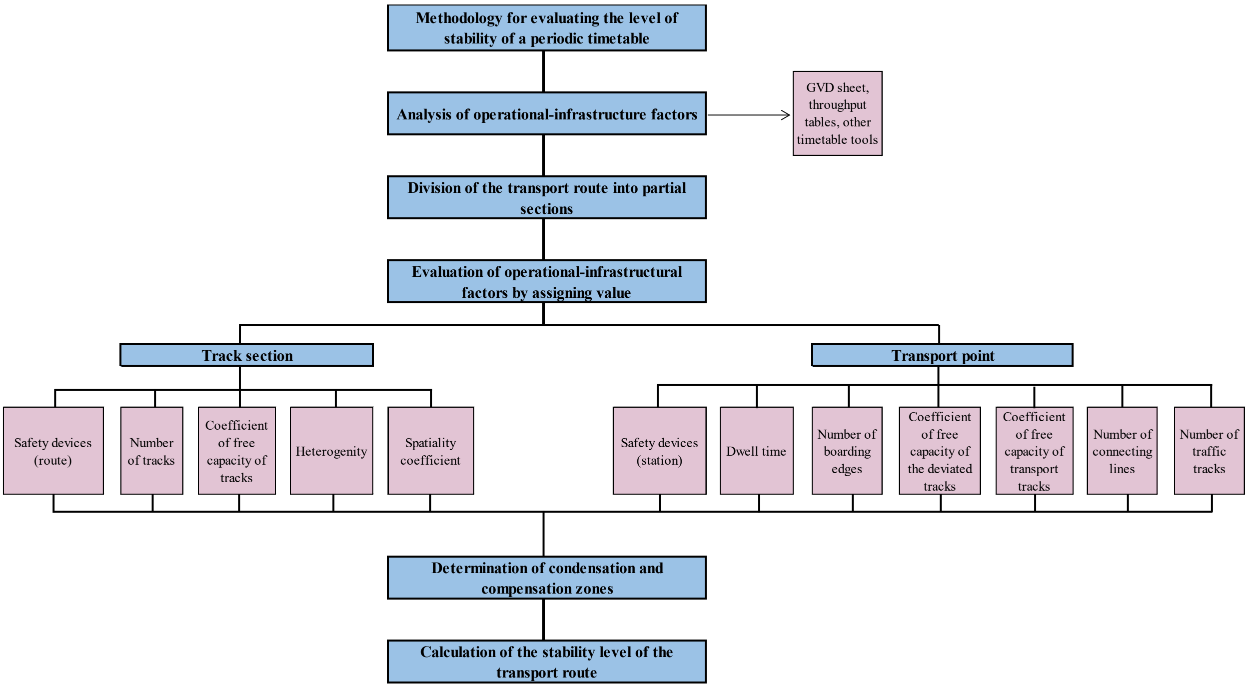

Fig. 1. Graphical representation of the methodical procedure

3. Characteristic of identified factors

Stopping time of a train - when quantifying the stopping time of a train for a given transport point, the average value of the stopping time of passenger trains is used:

$$stopping\ time\ of\ a\ train = \frac{\sum t_p^{OS}}{N_{vl}} \tag{1}$$

where:
t_p^{OS} - stopping time of a passenger trains
Nvl - the number of passenger trains stopping at a given transport point

Spatiality coefficient - this factor in the proposed methodological procedure considers the average travel time in each section of track and the number of open lines. The more open lines there are on the interstation section, the more this interstation section can reduce the delays. We calculate the value of the coefficient as:

$$k_{pr} = \frac{n^{PO}}{t_j^{TÚ}} \tag{2}$$

where:
k_{pr} – apatiality coefficient
n^{PO} – number of open lines on interstation section
$t_j^{TÚ}$ – average travel time of passenger trains on the interstation section considered

Number of main tracks - this infrastructure factor expresses the number of main tracks on a given interstation section. With a larger number of main tracks, the risk of transmission of delays in the event of unexpected situations by the carrier or the infrastructure manager, such as e.g., exclusions, accidents, technical failure of rail vehicle, etc.

Coefficient of free capacity of main tracks - expresses free or usable capacity of the interstation section. It takes into account the practical utilization factor given by the infrastructure manager. From the regulatory point of view, 100% means maximum capacity utilization, if we subtract the value of practical utilization from this number, we get the value of free capacity:

$$k_{vk}^{TK} = 1 - k_p \tag{3}$$

where:
k_{vk} – coefficient of free capacity
k_p – coefficient of practical use

Heterogeneity - this train traffic diagram factor has a significant effect on tact timetable stability. The use of several types of trains in tact timetable results in different occupation times of the interstation section or travel times or even stopping time of a train which creates inconsistent technological and operational conditions. To methodically quantify this factor, it was necessary to assign weights to the individual degrees of heterogeneity, which are shown in Table 1.

Table 1. Determination of the heterogeneity factor using the weight of the criterion.

Evaluation of the heterogeneity factor	
Number of types of trains of the examined transport route	Weight
1 species	6
2 species	5
3 species	4
4 species	3
5 species	2
6 species	1

Number of edge of platforms - expresses the number of edges of platform at the transport point. The more edge of platforms there are or the more platforms, the more passenger trains we can put on the boarding and getting out of passengers at a given transport point. This way, the missed train does not have to wait for the running track with the edge of platforms to be released.

Coefficient of free capacity of station gridiron and running tracks - is determined in the same way as the coefficient of free capacity of main tracks.

$$k_{vk}^{zh} = 1 - k_p \quad (4)$$

$$k_{vk}^{dk} = 1 - k_p \quad (5)$$

where:
k_{vk}^{zh} – coefficient of free capacity of station gridiron
k_{vk}^{dk} – coefficient of free capacity of main tracks

Number of connecting railway - this factor expresses the number of lines leading to the transport point. The more lines connected to a transport point, the more complex the transport management and the number of endangered places increases. This factor is expressed by a negative value of the number of connected lines.

Number of running tracks - is a factor considering the number of running tracks at the transport point. With a larger number of running tracks, transport management is easier, even in the case of overtaking of a train or crossing delayed trains.

Safety installation - expresses the value of safety installation in terms of speed of delay reduction according to individual types of block system and interlocking. This factor was difficult to quantify and for this reason the Saaty multicriteria decision method was used to determine the weight of the criterion, which compared the safety installation according to three variants:

1. delay reduction rate
2. security level
3. station and track operating intervals

The resulting values for determining the weights of safety installation are processed in Table 2.

Table 2. Values for quantification of block system and interlocking

Block systems	
Type	**Weight**
Automatic block	0,78
Automatic signal box with signal point	0,76
Automatic signal box without signal point/semi-automatic block system	0,67
telephone communication	0,49
Interlocking	
Type	**Weight**
Electromechanics signal box	0,63
All-relay interlocking box	0,60
Type electric interlocking devices	0,56
Electromechanics signal box/electrodynamic signal box	0,51
mechanical interlocking cabin	0,50

4. Method for determining the stability of constructed tact timetable

The next step after assigning weights to the individual criteria, the method of determining, which is described in the previous chapter, is to determine the stability of interstation sections and transport points. The allocation of these transport route weights is based on the infrastructure manager's documents such as train traffic diagram equipment, routing diagram, railway guide, carrying capacity tables, etc. After assigning weights to all factors on each interstation section and at the transport point, all factor weights in the lines must be added, separately for the interstation section and separately for each transport point and subsequently divide these points and sections into condensation and compensation zones. To determine the stability of tact timetable based on operational-infrastructural factors, it is necessary to divide the transport route into condensation and compensation zones. Evaluation of the originating points and terminating points of the transport route where the lines originate, or they disappear is not relevant, because we do not consider these points as places where we can reduce delays but as places where it is necessary for trains to run on time.

These zones can be determined as condensation zones, although we will not include them in the calculations of the evaluation of the stability of the transport route. Also, another exception in this methodological procedure is the turnouts. These specific transport points are mainly used for train crossing and overtaking of a train, thus acting as compensation zones. For this reason, turnouts are fixed as compensation zones as transport points. It is not necessary to assign weights to switches, but in relation (6) we calculate them for the calculation of tact timetable stability.

$$Stability\ level = \frac{number\ of\ compensation\ zones}{total\ number\ of\ zones} \qquad (6)$$

In order to be able to determine these zones on the basis of individual weight sums, it is necessary to know the break value of the weight sums, ie the value from which larger values including the upward break value will determine the compensation zones and the sum values below this number will determine the condensation zones. We determine this value according to the relation:

$$Break\ value\ when\ determining\ zones = \frac{the\ total\ sum\ of\ the\ weights\ of\ the\ critrria\ of\ the\ evaluated\ factors}{total\ number\ of\ rated\ zones} \qquad (7)$$

The last step is to determine the overall stability of the tact timetable transport route based on the evaluation of operational-infrastructure factors. This stability is expressed by the resulting average value of the stability of interstation sections and transport points.

$$The\ level\ of\ stability\ of\ the\ train\ path = \frac{stability\ of\ interstation\ section + stability\ transport\ points}{2} \qquad (8)$$

The optimal value of the stability level of the transport session recommends accepting the values defined in the UIC 406 regulation concerning the consumption of railway infrastructure capacity. Determining the optimal consumption of railway infrastructure capacity is problematic due to several factors that affect it. The standard values depend on the investigated line, the composition of the bag routes and the specific infrastructure conditions. Nevertheless, UIC 406 stipulates the optimal use of railway infrastructure capacity according to the values defined in Table 3. We propose that the indicator “level of stability of the transport route” should consider the values determined by UIC 406. We can assume that if, 6 for lines with greater heterogeneity of traffic, we can say that the level of stability of the transport route (8) should also have a value of at least 0.6.

Table 3. Recommended values of the occupancy time coefficient according to UIC

Type of track	Traffic peak	All day long
reserved for suburban service	0,85	0,70
high speed tracks	0,75	0,60
Track with mixed type of trains	0,75	0,60

5. Application of the proposed methodology

This chapter deals with the practical results of the applied methodology for a specific transport route Humenné - Košice on the ŽSR network in the even direction.

Table 4. Calculation of spatiality coefficient for even direction Humenné - Košice

Interstation section	Average driving time on the interstation section	Number of open lines	Spatiality coefficeint
Humenné - Strážske	31	1	0,032
Strážske - Petrovce n. Laborcom	24	1	0,042
Petrovce n. Laborcom - Michalovce	14	1	0,071
Michalovce - Bánovce n. Ondavou	26	1	0,038
Bánovce n. Ondavou - Hrinište	15	1	0,067
Hrinište - Trebišov	15	1	0,067
Trebišov - Čeľovce	17	1	0,059
Čeľovce - Výh. Slivník	16	1	0,063
Výh. Slivník - Slanec	31	6	0,194
Slanec - Ruskov	22	5	0,227
Ruskov - Nižná Mšľa	21	5	0,238
Nižná Myšľa - Krásna n. Hornádom	22	5	0,227
Krásna n. Hornádom - Košice	30	5	0,167

Table 5. Allocation of weights by factors of line sections of the Humenné – Košice transport route

Name of operating control point/open line	Interstation section				
	Interlocking system	Number of main track	Coefficient of free capacity of main track	Heterogeneity	Spatiality coefficeint
ŽST Humenné					
Humenné - Strážske	0,49	1	0,27	2	0,03
ŽST Strážske					
Strážske - Petrovce n. Laborcom	0,67	1	0,57	2	0,04
Výh. Petrovce n. Laborcom					
Petrovce n. Laborcom - Michalovce	0,67	1	0,57	2	0,07
ŽST Michalovce					
Michalovce - Bánovce n. Ondavou	0,67	1	0,57	2	0,04
ŽST Bánovce n. Ondavou					
Bánovce n. Ondavou - Hrinište	0,67	1	0,57	2	0,07
Výh. Hrinište					
Hrinište - Trebišov	0,67	1	0,57	2	0,07
ŽST Trebišov					
Trebišov - Čeľovce	0,67	1	0,67	2	0,06
Výh. Čeľovce					
Čeľovce - Výh. Slivník	0,67	1	0,67	2	0,06
Výh. Slivník					
Výh. Slivník - Slanec	0,78	2	0,58	2	0,19
ŽST Slanec					
Slanec - Ruskov	0,78	2	0,58	2	0,23
ŽST Ruskov					
Ruskov - Nižná Mšľa	0,78	2	0,58	2	0,23
ŽST Nižná Myšľa					
Nižná Myšľa - Krásna n. Hornádom	0,78	2	0,58	2	0,23
ŽST Krásna n. Hornádom					
Krásna n. Hornádom - Košice	0,78	2	0,58	2	0,17
ŽST Košice					

Table 6. Allocation of weights by factors of transport point of the Humenné – Košice transport route

Name of operating control point/open line	Transport point						
	Interlocking system	Stoppi ng time of a train	Number of edges of platform	Coefficient of free capacity of the station gridiron[1]	Coefficient of free capacity of running track	Number of connecting railway	Numb er of runnin g track
ŽST Humenné	ORIGINATING STATION						
Humenné - Strážske							
ŽST Strážske	0,51	0,95	3	0,30	0,51	-1	8
Strážske - Petrovce n. Laborcom							
Výh. Petrovce n. Laborcom	0,51	0	0	0,30	0,51	0	2
Petrovce n. Laborcom - Michalovce							
ŽST Michalovce	0,56	0,92	2	0,30	0,51	0	5
Michalovce - Bánovce n. Ondavou							

[1] In the column of free capacity of the station gridiron and main tracks, the blue numbers represent only the model value of the capacity, as the infrastructure manager does not have the exact data of these transport points at all.

Table 6. continued

ŽST Bánovce n. Ondavou	0,60	1,58	3	**0,30**	**0,51**	0	5
Bánovce n. Ondavou - Hrinište							
Výh. Hrinište	0,60	0	0	**0,30**	**0,51**	0	2
Hrinište - Trebišov							
ŽST Trebišov	0,56	1,50	5	**0,30**	**0,51**	-1	6
Trebišov - Čeľovce							
Výh. Čeľovce	0,60	0,50	2	**0,30**	**0,51**	0	2
Čeľovce - Výh. Slivník							
Výh. Slivník	0,60	0	0	**0,30**	**0,51**	-1	3
Výh. Slivník - Slanec							
ŽST Slanec	0,60	1,00	3	0,75	0,91	0	5
Slanec - Ruskov							
ŽST Ruskov	0,60	1,50	4	**0,75**	**0,91**	0	5
Ruskov - Nižná Mšľa							
ŽST Nižná Myšľa	0,60	1,00	3	**0,75**	**0,91**	0	4
Nižná Myšľa - Krásna n. Hornádom							
ŽST Krásna n. Hornádom	0,60	1,00	3	**0,75**	**0,91**	-1	6
Krásna n. Hornádom - Košice							
ŽST Košice	TERMINAL STATION						

Table 7. The sum of the assigned weights of the line section factors in the even direction

Name of operating control point/open line	**Interstation section**				
	Interlocking system	**Number of main track**	**Coefficient of free capacity of main track**	**Heterogeneity**	**Spatiality coefficient**
ŽST Humenné					
Humenné - Strážske	3,79				
ŽST Strážske					
Strážske - Petrovce n. Laborcom	4,28				
Výh. Petrovce n. Laborcom					
Petrovce n. Laborcom - Michalovce	4,31				
ŽST Michalovce					
Michalovce - Bánovce n. Ondavou	4,28				
ŽST Bánovce n. Ondavou					
Bánovce n. Ondavou - Hrinište	4,31				
Výh. Hrinište					
Hrinište - Trebišov	4,31				
ŽST Trebišov					
Trebišov - Čeľovce	4,40				
Výh. Čeľovce					
Čeľovce - Výh. Slivník	4,40				
Výh. Slivník					
Výh. Slivník - Slanec	5,55				
ŽST Slanec					
Slanec - Ruskov	5,59				
ŽST Ruskov					
Ruskov - Nižná Mšľa	5,59				
ŽST Nižná Myšľa					
Nižná Myšľa - Krásna n. Hornádom	5,59				
ŽST Krásna n. Hornádom					
Krásna n. Hornádom - Košice	5,53				
ŽST Košice					

Table 8. The sum of the assigned weights of the transport point factors in the even direction

Name of operating control point/open line	Transport point						
	Interlocking system	Stopping time of a train	Number of edges of platform	Coefficient of free capacity of the station gridiron	Coefficient of free capacity of running track	Number of connecting railway	Number of running track
ŽST Humenné	ORIGINATING STATION						
Humenné - Strážske							
ŽST Strážske	12,27						
Strážske - Petrovce n. Laborcom							
Výh. Petrovce n. Laborcom	TURN-OUT						
Petrovce n. Laborcom - Michalovce							
ŽST Michalovce	9,29						
Michalovce - Bánovce n. Ondavou							
ŽST Bánovce n. Ondavou	10,99						
Bánovce n. Ondavou - Hrinište							
Výh. Hrinište	TURN-OUT						
Hrinište - Trebišov							
ŽST Trebišov	12,87						
Trebišov - Čeľovce							
Výh. Čeľovce	5,91						
Čeľovce - Výh. Slivník							
Výh. Slivník	TURN-OUT						
Výh. Slivník - Slanec							
ŽST Slanec	11,26						
Slanec - Ruskov							
ŽST Ruskov	12,76						
Ruskov - Nižná Mšľa							
ŽST Nižná Myšľa	10,26						
Nižná Myšľa - Krásna n. Hornádom							
ŽST Krásna n. Hornádom	11,26						
Krásna n. Hornádom - Košice							
ŽST Košice	TERMINAL STATION						

Table 9. Calculation table of the level of stability of the transport route in the even direction.

Interstation section	
The total sum of the weights of the criteria	61,92
Total number of zones	13
Breakthrough value of zone determination	**4,76**
Condensation zones	8
Compensation zones	5
Stability level	**0,38**
Transport point	
The total sum of the weights of the criteria	96,87
Total number of zones	12
Breakthrough value of zone determination	**10,76**
Condensation zones	3

Table 9. continued

Compensation zones	9
Stability level	**0,75**
Stability level transport route	**0,57**

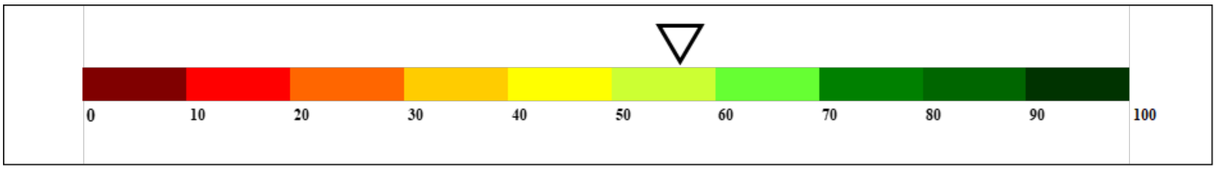

Fig. 2. Graphic expression of the stability of the Humenné - Košice transport route for an even direction

Conclusion

The proposed methodology examines the ability to reduce delays, which it considers as one of the main components of tact timetables stability and looks at the issues addressed in terms of operational and infrastructure factors. In this way, it seeks to contribute to the optimization and improvement of railway transport in the tasks of public passenger transport. The methodology consists of partial steps of a heuristic procedure, which consistently identify and characterize the factors influencing the stability of tact timetables. It will gain importance in the field of tact timetable as well as integrated transport system, where it helps to compile such complex timetables more efficiently and thus can serve as an aid or guide for the infrastructure manager in the creation of various technological or construction and reconstruction measures.

Further research in this area may lead to the quantification of other elements of infrastructure or elements of operation, which need to be determined for a more detailed perception of this methodology and thus reveal a broader view showing the entanglement of interconnections in connection with determining the level of stability or reliability of timetables. However, it is important to set these relevant criteria correctly and subsequently to effectively apply the proposals, which can lead to a more rational design of train traffic diagram and thus lead to reliable railway operation to attract and retain customers and thus increase demand and quality of rail transport.

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IMPACT OF SIGNALLING DEVICE FAILURES IN CONTEXT OF THE RAILWAY TIMETABLE

Abstract. The quality of the transport process in railway transport depends on the compliance of the timetable. Delays in rail transport are due to various reasons. One of the common factors is also failures in the stations or track interlocking systems. In the article is published the results of the performed simulation of failures of interlocking systems in the conditions of the transport laboratory at the Department of Railway Transport. The research was part of a student project solved at the University of Zilina.
Keywords: Signalling devices, Train delays, Railway infrastructure

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Introduction

One of the factors influencing the quality of the transport process is the carrier's ability to provide its services reliably - in a guaranteed, pre-announced, or agreed time. In case of deviations from the timetable, resp. agreed transport times in freight transport, the customer's sense of confidence in the carrier's seriousness decreases. Deviations (usually delays) can be classified according to who is responsible for their occurrence (Dedík, 2019).
A significant group of delays in rail transport are those caused by the infrastructure manager. These include delays caused by the impact of closures (planned and unplanned), emergencies and accidents, or incorrect transport organisation, but also, for example, individual infrastructure equipment failures (failures regarding switches, traction lines, interlocking devices, etc.). Station and line disruptions, as well as level crossing interlocking devices (ID), are some of the frequent causes of train delays, which adversely affects the train schedule (timetable) fulfilment and, as a result, customer satisfaction with the provided transport services. By analysing the impact of ID failures on the timetable performance and its concretisation, it is possible to obtain new knowledge on the issue of railway transport irregularities, which could be used in the future, for example in operational traffic management. However, this effect cannot be clearly defined or quantified in the stochastic conditions of real railway operation (Lupták, 2017 and Meško, 2017).

Therefore, to assess the impact we simulated railway operation in the transport laboratory of the Department of Railway Transport, Faculty of PEDAS at the University of Žilina in Žilina, and addressed issues with its equipment (various types of station and line signalling systems used in practice) and functions. The experimental measurement was performed in December 2019 and had two phases, each lasting 2 hours, whereby transport on the track was carried out according to a pre-prepared train traffic schedule. Only passenger transport trains were included in the chart, i.e., trains in the express (Ex), fast (R), passenger train (Os) and trains categories. A total of 6 fast trains, 5 express trains, 9 passenger trains and 2 set trains ran during the timetable. Two sets were used for passenger train transport, one set for IC train transport and one set for express train transport, so a total of four sets were used in the chart. The transport was managed according to the usual service regulations and procedures of the Railways of the Slovak Republic (ŽSR).

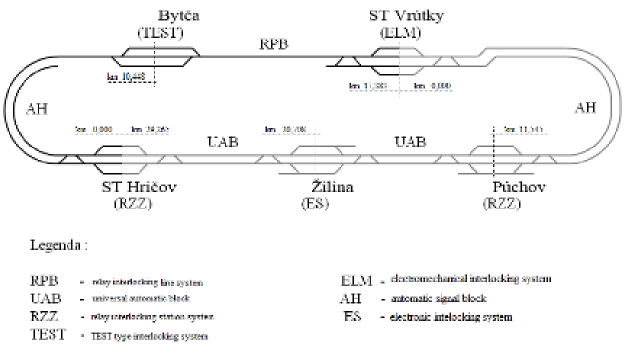

Fig. 1 Track diagram in the KŽD transport laboratory (Gašparík, 2013)

1. Solving specific issues

In the first phase, the railway operation was simulated without any emergencies or operational failures. This schedule was met 100%, all trains went on all sections of routes on time. In the second phase of the measurement, we simulated a large-scale station security equipment failure, where it was necessary to completely stop the traffic in the adjacent inter-station sections during the removal. For example, a similar situation occurred in February 2016 at the Bohumín railway station, when due to a fire in several electrical parts of the security equipment, traffic through this important transport station was completely stopped for several hours.

In the transport laboratory, we simulated this situation at the Púchov railway station, which is equipped with a relay station interlocking device (SID) with digital dialling. Alternative bus transport (ABT) was introduced in the sections Púchov - Vrútky and Púchov - Žilina. ABT was fictitiously provided by two groups of buses, while one group replaced trains of categories IC and R in the affected section Žilina - Púchov - Vrútky, the other group formed a replacement for Os trains. The number of buses in both groups were different, commensurate with the capacity of the trains. The ABT driving time surcharge was set at 2 minutes for each section. As at the same time with the ABT introduction, the so-called rotation of train sets in Žilina and Vrútky stations, there were also changes in their order - express and express sets were interchanged for trains in these categories in the mentioned stations, because of this both set trains were also abandoned.

Of course, with the introduction of a large alternative bus transport the chart could no longer be met 100%. Due to train delays, operational changes were taken in traffic management, these mainly concerned the train sequence. Ex operational trains had the highest priority in operational management, followed by express trains. The running of regional passenger trains had the lowest priority. Evaluation of train running according to the electronic traffic log data is the subject of Table 1.

Table 1. Summary of all trains dispatched in the examined timetable together with an overview of their delays at the point of departure and destination

Train number	Cate gory	Time of departure from starting station	Initial train delay [min]	Time of arrival at the destination station	Total train delay [min]
501	**Ex**	17:15	**4**	17:26	**10**
503	**Ex**	17:28	**0**	17:45	**12**
505	**Ex**	17:46	**5**	18:02	**15**
507	**Ex**	18:06	**6**	18:20	**16**
509	**Ex**	18:44	**28**	18:52	**32**
511	**Ex**	18:54	**26**	19:03	**30**
600	**R**	17:28	**10**	17:37	**14**
602	**R**	17:46	**12**	17:56	**18**
604	**R**	17:59	**12**	18:23	**21**
606	**R**	18:15	**5**	18:30	**15**
608	**R**	18:32	**0**	18:47	**10**
1831	**Os**	18:38	**0**	18:40	**0**
2800	**Os**	17:12	**0**	17:32	**0**
2801	**Os**	17:11	**0**	17:32	**5**
2802	**Os**	17:42	**2**	17:55	**3**
2803	**Os**	17:38	**0**	17:56	**7**
2804	**Os**	17:59	**2**	18:18	**6**
2805	**Os**	18:00	**0**	18:10	**0**
2806	**Os**	18:22	**0**	18:33	**0**
2807	**Os**	18:15	**0**	18:29	**2**

Table 1 shows that the average delay of express trains at the destination station was 19.17 min, at speeds of 15.60 min, but in the case of passenger trains only 2.56 min. The total average train delay in the destination RST was 10.80 min. We also evaluated the average arrival delays of arrivals and departures at individual stations. These statistics can be found in Table 2.

Table 2. Average train delays on arrival and departure from individual transport

ŽST	Average delay at arrival [min]	Average delay at departure [min]	Average reduction of delays at the railway station [min]
Púchov	11.00	8.38	**2.62**
Žilina	9.29	8.60	**0.69**
Vrútky	8.50	10.27	**-1.77**
Hričov	7.33	5.93	**1.40**
Bytča	8.27	8.40	**-0.13**

Source: Authors

The absolute fulfilment of the train traffic schedule in the second measurement phase reached only 52.5% when calculated by the ŽSR methodology. The ŽSR methodology for calculating the absolute performance of the timetable correlates the number of trains going on time (according to the ŽSR methodology, trains going on time are considered to be trains with a delay of no more than 5 minutes) and the total number of departing and ending trains taken over from another regional directorate or network of another infrastructure manager and to another circuit or network of the transferred trains. Therefore, each train is counted twice in this calculation.

Table 3. Calculation of absolute timetable fulfilment using ŽSR methodology

Number of trains according to timetable	20 starting trains
	20 destination trains
Total number of trains for ŽSR calculation method	**40 trains**
Number of trains	14 starting trains
	7 destination trains
Total number of trains on time for ŽSR calculation method	**21 trains**
Absolute performance of timetable according to the ŽSR methodology	**21 / 40 = 52.5 %**

Source: Authors

When calculating the timetable's relative performance, each train is considered only once - only the terminating trains and trains handed over to the district of another regional directorate or to the railway network of the neighbouring infrastructure manager are used. In this way, only the delay of trains at the end of the journey in the monitored circuit is monitored. The timetable's relative fulfilment in the second phase of the simulation reached 35% - relatively on time (with a delay of no more than 5 minutes) only seven of the twenty trains arrived at the destination station. It was always a regional train of category Os.

The implemented timetable's analysis provided us with a detailed overview of the course of railway transport during the measurement and pointed out several facts that would occur in a similar operating situation or could occur in real conditions of railway operation. Passenger trains ran mostly on time during the timetable, most delays in this category of trains did not exceed 5 minutes. However, long-distance trains (categories Ex and R) had very high delays. Regional (9 train axes in total) and long-distance trains (11 Ex and R trains in total) had the same conditions - two train sets and one group of ABT buses were deployed on both groups of trains in the section excluded due to a signalling equipment failure. The length of turnovers at the destination train stations was slightly different for regional and long-distance trains in the implemented timetable - for express trains it was 9.80 min on average, for express trains 13.50 min and for passenger trains 8.71 min, in total 10.25 min. It turned out that the significant difference between regional and long-distance train delays was caused by the very short running times of long-distance trains. No time reserve in the event of emergencies was considered when constructing their routes. Due to the very short stays at the waypoints, it was not possible to achieve a reduction in train delays during stays; in addition, long-distance trains did not stop at all stations according to the timetable. The deployment of only one group of buses for Ex and R trains also proved to be insufficient, because during the measurement there were moments when ABT buses as a substitute for a long-distance train were still fictitious in one station or on the road but in another station, which bounded section with ABT, a long-distance train in the opposite direction has already arrived. This train was unnecessarily late.

Statistics regarding average train delays on arrival and departure from individual stations also brought interesting results, whereby the influence of individual types of SID on the overall course of timetable was demonstrated. In the stations Hričov (relay SID with road selection) and Žilina (electronic SID) the reduction of delays was achieved, and to which the double-track operation between these stations also contributed. This section is equipped with an automatic line ID, the so-called autoblock. Reduced delays were also recorded at the Púchov station, which, however, was served only by ABT buses. As it is an operationally important station, where, according to the simulated timetable, trains of all categories stopped and several trains ended and started here, there was room for a more significant reduction of delays even during the ABT introduction. At the Bytča station, equipped with an electric SID of the TEST type, the average train delays on arrival and departure were approximately the same. The reason is probably the nature of the traffic - it is an intermediate station on a single-track line. Therefore, crossings often took place here, during which delays were also passed on to oncoming trains. The Vrútky station is equipped with an electromechanical SID. At present, it is already a morally and technically obsolete type of SID, and at the same time the oldest type of SID represented in the transport laboratory. A shift in stations with electromechanical SID is unsecured - the position of switches and freedom of travel are not controlled by SID. Therefore, the entire course of the shift depends on the station staff, which prolongs its total time. This may be one of the reasons why there was a significant increase in the average train delay at the Vrútky station, where train sets ended and switched to trains in the opposite direction.

The analysis of train traffic during the simulated timetable also revealed the incorrect organisation of the dispatcher's work at the Vrútky railway station at train 509. For this departure train to Púchov via Hričov, a set from train 606 was available here, which arrived in Vrútok at 18:21. After considering the necessary shift and technological tasks at the initial passenger transport train, train 509 was able to leave the station at approximately 18:35 after the arrival of train 2806 from Bytča. However, the dispatcher forgot the Ex 509 train and sent it out of the station after the next train sequence at 18:44. It was a human factor failure, which is one of the most difficult to eliminate, but by its nature significant risks of traffic management in the event of unforeseen events in railway operation.

Conclusion

Based on identifying the weak points in the eliminating the consequences of irregularities in railway traffic, concrete measures can be taken to better address them in the future. One of the basic means for train delay elimination has proven to be the construction of train paths with targeted time reserve inclusion as a tool for reducing delays and covering other irregularities in operation. In order to significantly eliminate delays and limit their transmission to subsequent trains, it is also possible to consider longer turnovers at destination stations. However, when applied in practice, this measure is likely to increase the turnover of vehicles and staff, and therefore a significant increase in operating costs. Therefore, from the carrier's point of view it is more effective to focus on the operational solution of complex operational situations, such as security device failures. For the operative solution of extraordinary events in operation, it is necessary to have enough contractually secured bus carriers and buses themselves, which could be used in the event of extraordinary or accidental events to provide alternative bus transport in the affected section to a reasonable extent and quality. The performed simulation showed that if a third group of buses were available for ABT in the section Žilina - Púchov - Vrútky, would the ABT be better organised (if the capacity of both groups of ABT buses allowed them to be deployed on any long-distance or regional train), the overall train delays could be significantly lower.

Further train delay elimination can be achieved by modernising (especially) station signalling equipment. Modern types of electronic signalling devices significantly shorten the operating intervals (crossing interval, the interval of gradual entrances) in transport stations. The shift in stations equipped with electronic SID is ensured, i.e., is under the control of the station signalling device.

Reducing the impact of emergencies on timetable compliance can also be achieved at the level of human resources. With quality training in the transport emergencies field for employees involved in traffic management, it is possible to increase their ability to deal with emergencies and eliminate their impact on traffic decisively and correctly. For example, training on traffic management simulators is suitable, such as the so-called training halls in the centres of remote-control tracks, whereby employees have the opportunity to practice solving various emergencies. Another possibility is to increase the psychological resilience of transport staff, for example, to stress or fatigue through special psychological courses.

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