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PARKING REQUIREMENT OF SHOPPING CENTERS

Abstract. The parking problem is a severe challenge in city planning because of its impact on road congestion and accidents, delay time, and cities' economy. therefore, many cities conducted different studies, reports, and projects to find the number of parking generation as it related to land use, in form equations, rates, and even data plots by using different independent variables. Iraq, till now, does not have a comprehensive study of parking requirements, or in specific how many parking spaces the different land uses are generated or needed. The general situation in Baghdad city at present is inadequate public transportation, few transportation alternatives, large private car use. besides the high illegal parking on the roads which means higher traffic density and congestion roads. this research studies three different shopping centers in Baghdad and analysis their parking generation as related to three different independent variables. these variables are GFA, GLA, and entertainment percentage where each variable is analyzed separately. the analysis was done based on parking accumulation in these sites. as it was counted manually for three days for Parking counting time that selected according to the peak of visitors for Retail is from 4 pm – 11 pm. in a result several parking generation rates and models with different forms are developed by using simple linear regression and only the best of them that has high R2 value and low RMSE is recommended. from the conclusion, the GFA and GLA have the most significant effect on parking generation as they developed strong models and rates. as these rates are 4.1 and 4.57 parking spaces for each 100 m2 of GFA and GLA respectively.
Keywords: Trip generation; Parking generation rate; shopping centers; parking requirement.

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Introduction

The trips generation and parking demand rates or models one of the most important keys of cities urban planning, and states around the world always worked hard on produced the most suitable rates and models relied on their local conditions, regulations, and people habits, in a way that the produced rates and models fruition the highest benefits to the state. The rates and models assist the decision-makers like municipalities and ministries, in their planning decisions. By giving expected effects for the proposed project. For example, accepting, rejecting, or even modifying the parking demand as related to creating or changing the (development or land use), in a particular place.

Ignore provision parking generation rates for different land uses types, would-led to setting the number of parking spaces arbitrarily. So parking spaces will be either lower than required in this case there will be many negative effects as mentioned before. Or the parking spaces be more than needed, and this case is not desirable also. As it will cause land loss which can be used in other efficient ways. Besides, the economic losses. For example in 2017 san Francisco city made a comparative report of the parking area, the report concluded that approximately 28 % of available parking spaces are not used as an average, which means which construction cost is 198,034,400 $ are losses. (Chayan, 2018).

The general situation in Baghdad city in the present time is increasing construction shopping centers, poor public transportation, few transportation alternatives, a large private car using and high illegal parking on the roads, which means high traffic density and congestion roads. Since 2003, Baghdad city has seen many changes and developments; one of crucial change is the high inflation of car number, which caused the high pressure on the transportation network and parking areas besides many other problems like traffic congestion, increasing accidents, and air pollution (Asmael and Alkawaaz, 2019). Also, the other changes which have been in Baghdad city, are the high increase in construction of new shopping centers (malls) which also increase the number of employees, workers, and increase attraction activity which leads to congestion in the area around malls. These constructions are usually done randomly without sufficient study for urban and transportation planning or a study of required parking spaces for these malls. This insufficient planning and studies made the shopping centers and area around them from the first day are suffering from many problems like failure in providing sufficient parking spaces, pressure on the transportation network, and others. As Iraqi local parking studies are few. especially in the present, there is no specific study conducted to develop a parking generation model (equation or rates) for the new development as related to single land use where the existing studies have a different objective with a limited range.

2. Background

The literature studies produced parking demand generation rates for many land-use types. Parking demand is affected by the land use characteristics of that area (Parmar, Das, and Dave, 2020). The parking demand of individual retail stores varies with the size and type of store as well as its location, in a planned shopping center, or at an isolated point. A shopping mall can impact an area of over 50 km in radius, which its effect higher on the surrounding area (Regidor, 2007). The peak-hour parking generation average of small retail stores is 2.1 space per 1000 Sq. Ft. with range 0.9 to 3.8. (Academy of Science, 1971). The independent variables used in the ITE manuals are related to land use type and its characteristics, where several variables are used with the single land use, each variable produces a separate parking generation model. For example, in the 5th ITE manual, the used independent variables for the office and shopping center are.

- Office: employees, 1000 sq. ft. of GFA, occupied GFA, acre.
- Shopping center: 1000 sq. ft. GFA, employees, % restaurant space, % entertainment space.

(Douglass and Abley, 2011) reported several parking generation rates for the retail sites relied on the site's GFA and the type of the retail site supermarket, shopping centers, or large retail centers. For example, the suburban shopping center parking demand is 5 spaces per 100m2 GFA for 10,000 m2 site areas. For the larger shopping center around 15,000 m2 GFA, the parking demand variation is 2 to 4 spaces per 100 m2 GFA, as for the large retail centers, the parking demand rate is 3 parking spaces per 100 m2 of GFA. The report stated that the range of these averages is diverse depending on several factors like the catchment population, the promotion of the center, and the exposure to passing vehicle traffic. Also, the research stated that the parking demand shows reducing relationships with increasing the floor area. The following table shows different trip attractions across four countries

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Table 1. Parking generation rates for the four countries New Zealand, Australia, the UK, and the USA. (Douglass and Abley, 2011)

Land use	New Zealand		Australia	UK		USA	
	Average	85%	85%	Average	85%	Average	85%
Commercial premises/offices	2.7/100m² GFA	3.2/100m² GFA	2.5/100m² GFA	3.05/100m² GFA	5.02/100m² GFA	3.06/100 m²	3.7/100 m²
Shopping center (4000–10,000 m²) GFA	3.3/100m² GFA	4.9/100m² GFA	5.5/100m² GLFA	5.64/100m² GFA	6.25/100m² GFA	3.25/100 m² GLA	4.69/100 m² GLA

Al-Masaeid et al., 1999 (AL-MASAEID, AL-OMARI, and AL-HARAHSHEH, 1999) recommended that parking space requirements must base on local conditions rather than using figures developed in other countries. This issue is very crucial to minimize the economic consequences of providing more or less than the optimal level of parking demand, particularly in cities where the cost of land or construction is relatively expensive. Al Ghanimy and Asmael 2020 (Al-Ghanimy and Asmael, 2020) stated that GFA is a primary factor that affects parking requirements for an educational building. Stein H. 1991 (STEIN, 1991) found that a base parking rate of 4.0 spaces per 1,000 ft2 of GLA will enough for adequate parking during the year at almost all neighborhood and community shopping centers, regardless of most of the factors studied. The Mayoralty of Baghdad, the Design department, published several laws and regulations about the building of local Iraqi units, one of these regulations is the parking regulation that circulated to the municipalities in 2012. The regulation provides the number of parking spaces required for different land uses types. For example, from the regulation, the required parking spaces for supermarkets and malls are 5 spaces for every 100 m2.

The procedure of most studies depends on ITE manuals, with some changes that may use commensurate to their countries, conditions, experience in addition to other factors(Pi, Currans, and Muhs, 2012). Some studies have taken into account the seasonal variation, the transit impact, parking fees, the surrounding area type, and others. The institute of transportation engineer (ITE)(institute of transportation engineer, 2019) is considered one of the major organizations that published several parking generation manuals, which are used widely across the world as a point of reference to estimate the number of parking spaces to be supplied by the development. (McCourt, ITE 3rd Ed.) (McCourt, 2004).

3. Sites Selection

Baghdad city is the study area; several sites in different parts of Baghdad were selected for data collection, analysis, and model production. this research is focused on urban sites out of CBD area and some criteria were used for site selection like the site should be mature at least two years old, occupied at least by (85%), the site should be clear and no abnormal condition besides it, and most importantly the site should have an obvious and specific parking lot.

The sample size concept should be appropriate and reasonable to give the best representation to the study area. The 4th ITE manual stated that a minimum of four sites for an individual land-use type should be provided for the best analysis and outputs. However, the total number of shopping centers in Iraq is six. According to the above criteria, only three of them are achieved it. So, they were adopted and used for data collection and model generation. The selected study sites and their location are presented in Table 2.

Table 2. Selected Shopping Centers and Their Location

Site Name	Location
Zayoona mall. (ZY.)	Al-Rusafaa side. Zayonaa district. Palestine street.

Al-Nakheel mall. (NKH.)	Al-Rusafaa side. Palestine street. Port said street.
Baghdad mall. (BGH.)	Al-karkh side. Harthiya district. Al-kindi street.

The following section is a brief description of the selected sites:

A. Zayoona mall (ZY)

It is the largest mall located on the Al-Rusfaa side, as shown in Fig 1. It is sited in a residential area, and its gate opens on a service street that separates from the major street. It is located near many shops and restaurants. This mall is more famous for young customers most of the weekdays than in other malls. The mall has several problems with its parking and its garage in a way that has an adverse effect on the adjacent street.

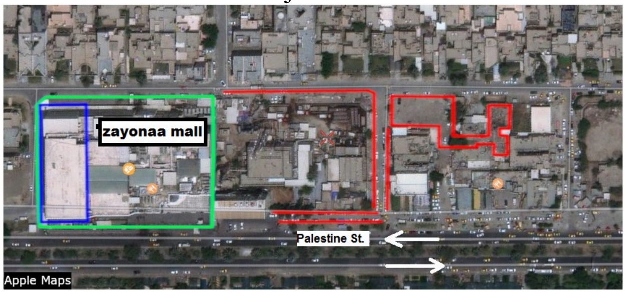

Fig 1. Zayonaa Mall location site and its surveyed parking areas

Color lines keys:
Green: Site Boundaries
Red: Outside Parking
Blue: Inside Parking

B. Al-Nakheel mall (NKH)

This mall is located at the Al-russafa side, at Palestine Street, where two sides of it align Palestine street as shown in Fig 2. Also, there is a four legs intersection in front of it at a small distance and Palestine Street Bridge. Nearby it, there are many ministries whose employees represent the morning customers of the mall, but they are usually not gone by private cars. The public transportation can reach directly to it. The mall contains many shops, some of them are international brands, restaurants, cafes, in addition to four places dedicated to kids' games. This mall does not have a parking area. However, there are adjoins to it, a private 5-floor garage. Where this garage has its gate open in the mall.

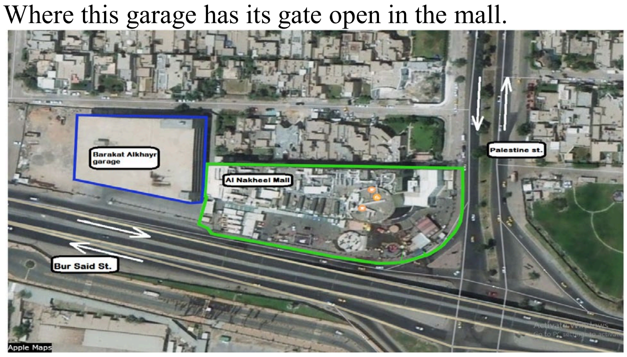

Fig 2. Al Nakheel Mall location site and its surveyed parking area

C. Baghdad mall (BGH)

This mall is located on the Al-karkh side, at the beginning of AL-Kindi Street, as shown in Fig 3. Nearby from it, many shops, restaurants, and doctor clinics. The mall design is divided into two parts, the larger mall building and the restaurants street, which includes more than 25 restaurants, besides, there are many shops located in the outer courtyard of the mall on the side of the mall building. The mall building, although it with a large area, but the number of the total shops inside it is not large. That due to the shops of international brands occupy large areas inside the building. The public transportation can reach directly to it.

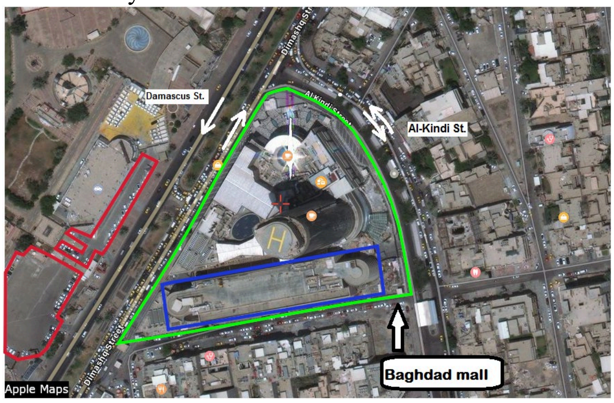

Fig 3. Baghdad Mall location site

Color lines keys:
Green: Site Boundaries
Blue: Outside Parking

4. Data collection

The data collection was done in two steps as follows:

1. Independent variables selection: The parking generation models and rates are used to predict the parking demand for a site, according to its land-use type. These models and rates are consists of independent variables, which vary with the land use type. The research selected independent variables used to generate the model and rates are:

Gross Floor Area (GFA): is the area within the external walls of a building, excluding any area dedicated to the parking of vehicles. including all common areas shared by customers when considers the joint retail areas

Gross Leasable Area (GLA): this area represents the leasable floor area in the developments designed for tenant occupancy and exclusive use. It is mostly used with supermarkets and various occupations stores, malls, and others. It is frequently used and commonly forms 80% of the GFA.

Entertainment Percentage (E%): it represents the percentage of entertainment space (including that, restaurants, cafes, cinemas, kids, and adult games) to the total mall size. this variable is adopted from the ITE manual.

2. Field Surveys: this step was done to collect two types of data:

First type: site's properties data: it is the data about the selected independent variables Gross Floor Area

(GFA), Gross Leasable Area (GLA), and Entertainment Percentage (E%).

Second type: parking counts and inventories, the parking counts were done to calculate the parking demand at each site. According to Garber and Hoel, the parking demand is the accumulation of vehicles parked at a given site at any associated point in time. Therefore this survey is done in two steps:

A. Determination Counting periods and duration; This step is the major step in the counting of the parked vehicles accumulation for a particular site. Whereas every site has different times for parking demand, According to site land-use type, site activities, site work hours, etc. therefore, the ITE manual mentioned that the parking counts time must be connected with the study purpose. This study objective is to determine peak periods of parking demand (max accumulation), for each site on particular days. Parking counting time for Retail land use in this research is from 4 pm – 11 pm. Besides, this study counts the parking demand for three days for each site

B. Counting the parking demand. This step is to count the parked vehicle accumulation at the sites, on a particular day. The ITE manual stated that the counting must cover the total site parking demand. This means all the parked vehicles related to the site, whether in the site, or parked vehicles out the site, in the public or private parking or on streets. The Hourly surveys were conducted at each site during the period 4 pm – 11 pm.

Determine the Maximum Average Parking Demand.

This average is the average of three days of the maximum parked vehicle accumulation at each site, it represents the parking demand in this research, which then it used in analyzing to develop parking generation models and rates.

5. Collected data

As mention before, in this research two types of data, were collected, the first about site properties, and the second about the parking surveys. As shown in tables 3 and 4 below

Table 3. Shopping Center Properties

Shopping Center. Name	No. of Parking Area	GFA. Per 100 m^2	GLA. Per 100 m^2	E %
Zayonaa	1	99.5	88.91	33 %
Nakheel	1	110.84	92.25	28 %
Baghdad	1	164.82	152.67	42 %

GFA = total area – parking area. GLA; gross leasable area. From table 3 the gross floor area for shopping centers is not including the parking areas, the gross leasable area is the mall’s area that can be rented (shops, restaurants, etc.). Approximately all the malls have close entertainment percentage because the malls somewhat have a similar design, and Baghdad mall has the largest entertainment percentage because the mall contains (Al-Nahr Street) which is a restaurants street that contains 15 restaurants approximately, besides the other restaurants and cafes in the mall building. These percentages, GFA, and GLA were taken from the malls' engineers.

The second type of the collected data is the parking demand and supply for each shopping center. As explained before the parking demand that used in this research is represents (the average of three days of max parking accumulation, that calculated in period 4 pm – 11 pm). as for parking supply represents the legal parking supply spaces, within the sites only, These parking spaces usually be marked and striped, and they were counted manually. however, the parking supply information does not directly participate in parking model generation. But it gives more clarification about parking demand phenomena to a specified site in general. As well, it can be used for comparison purposes. also, the ITE guide and some references recommended providing such information. The parking demand and supply for each shopping centers are present in table 4.

Table 4. Number of parking supply spaces and parking demands for each shopping center

Shopping center	Supply	Time	Off-street Parking	On-street parking	Parking Demand	D/S
Zayonaa	172	Pm	212	186	398	2.29
Nakheel	600	Pm	430	0	430	0.7
Baghdad	482	Pm	512	186	698	1.45

D/S: Demand/ supply ratio. Parking demand: ave. of three days max parking demand.

In general, many reasons are playing a role in determining the actual parking demand for malls. Like the visitor's transportation modes, malls' location in commercial or residential areas, the type of mall’s stores and merchandise and prices, the population of areas near malls and their level of income, and also the ability of public transportation to reach them. for example, Zayona mall has a lot of visitors more than al-Nakheel mall but its visitors were coming by many modes of transportation like the public bus, taxis, and private cars or even walking unlike al-Nakheel and Baghdad mall as their visitors are more used to private cars than other modes of transportation.

The distribution of parking demand is the variation of the parking demand ratio for the various hour of the day divided by the peak parking demand ratio, expressed as a percentage. (100 percent represents the hour(s) of peak parking demand. (ITE 5th, manual, 2019). (Parking demand in an hour/ peak parking demand). table 5 display the parking demand distribution by each hour for each shopping center.

Table 5. Time of day parking distribution of shopping Ccenters

Time range	Zayonaa	Nakheel	Baghdad
4 – 5 PM	25 %	12 %	20 %
5 – 6 PM	51 %	38 %	45 %
6 – 7 PM	95 %	72 %	78 %
7 – 8 PM	100 %	91 %	100 %
8 – 9 PM	95 %	100 %	98 %
9 – 10 PM	92 %	86 %	94 %
10 – 11 PM	75 %	58 %	82 %

From Table 5, the parking demand variation of the three malls is somewhat close, the rush hours of the malls are from 6.30 p.m. to 9 p.m. where all the malls during this time see a very high number of visitors. After 9 p.m., the number of visitors continues, but some cars start to leave the mall and make space for other cars; therefore, the parking demand became lower. This variation of parking demand has been counted in the malls on the weekends of the summer season. For Baghdad and Zayonaa malls, their parking demand was causing greatly interrupted for adjacent main street traffic. The matter reached to occupy a two-lane that adjoining the main street.

Data analysis and models generation

The descriptive statistics such as mean, standard deviation, coefficient of variation, maximum and minimum values, and range were calculated for each variable, as shown in Table 6 below.

Table 6. Descriptive statistics for collected data for retail land use

Variable	Mean	std. dev.*	CV %*	Maximum	Minimum	Range
Entertainment (%)	34.33	7.1	20.6	42%	28%	14%
GFA per 100 m^2.	125.1	35	27.8	164.82	99.50	65.32
GLA per 100 m^2.	111.27	36	32.24	152.67	88.91	63.76
Parking demand pm.	509	164.75	32.37	698	398	300

* std. dev. Standard deviation. CV%; coefficient of variation.

From Table 6, the variation values (Std. dev. And CV.) For all variables that are close and moderate, the CV values are ranging (20.6 to 33.4 %). This closeness in dispersion values is related to the type of studied shopping centers, as they are convergent by their sizes, design, and features.

Besides the general design of shopping centers is very similar, depends on creating many entertainment places and using most of GFA for leasable purpose, thus the CV value of entertainment % is 20.6, and the mean of GFA is close to the mean of GLA.

As for parking demand, the CV value is 32 percent, means low dispersion about the mean, and this related to the fact that all the shopping center are seeing a high and close number of visitors.

6. Models Development

This research explores the relationship between parking demand and different independent variables. the simple linear regression was used to produce parking generation models by using three independent variables that related to the retail land use. All forms of models were investigated, but only the most appropriate of models, with the best fit of the regression line, are presented which are linear, exponential, power, and logarithm models.

The best models with the high correlation (R2 values) and best statistical significance are then chosen, these models are used to calculate the parking demand for shopping centers. in this research, for retail land use the parking demand was counted only for the evening period because, in Iraqi shopping centers, the max parking accumulation occurs in the evening period. Therefore, the parking generation models were developed only for the evening periods by using the three selected independent variables, as shown in the subsections below.

6.1. The entertainment percentage (E %)

The amount of entertainment (restaurants, cinemas, playgrounds, and others) in the shopping center is considered as one of the most trips attraction in the mall, particularly in Iraq, where the entertainment places are trending low. Therefore, the entertainment percentage is used to develop parking generation models for retail land use. Table 7 presents the developed models and their properties as shown below.

Table 7. Parking Generation Models (PM) and Their Properties for Variable Entertainment's Percentage (%)

No	Model Type.	Model	R^2	Adj. R^2	F- test	P-Value.	T-test	P-Value.	RMSE
1	Linear	$P = 21X – 220.3$	0.82	0.64	4.605	0.2	2.146 -0.465	0.2 0.6	98.4
2	Logarithm	$P = 713\ln X – 2007$	0.78	0.56	3.506	0.3	1.872 -1.496	0.3 0.3	109.75
3	Power	$P = X^{1.313} * 4.772$	0.75	0.52	3.129	0.3	1.769 0.382	0.3 0.7	0.214
4	Exponential	$P = e^{0.039X} * 128$	0.8	0.61	4.073	0.29	2.018 1.492	0.29 0.37	0.193

From table 7 all the developed models show good R2 values ranging from 0.73 to 0.81, but at the same time, they differ from the adj. R2 values by a large amount approximately 20%. So, adj. R2 values are considered instead. The (adj. R2) values show acceptable R2 values (> 0.5) for all models except the power model. According to the ITE manual (R2 > 0.5) is acceptable. The good R2 values mean there is a good relationship between the parking demand and entertainment percentage for the shopping center. Furthermore, the RMSE values for linear and logarithm models are 102.88 and 114.12 respectively, where these high error values so weaken the predictive power of the models and affect their accuracy, so they are not recommended to be used. On the other hand, from the same Table, all the developed models are not significant at a 95% confidence interval, where all the models have (p-value > 0.05). The small sample size also affects the model's significance, therefore, a lower confidence interval here may be appropriate.

However, all the developed models for the entertainment percentage variable are not recommended to be used, alternatively, rates can be used instead of them. Figure 4 displays the regression model plot of parking demand in the evening period vs. entertainment percentage for shopping centers. From the figure, the points have a large deviation distance from the regression line, the line worse fit.

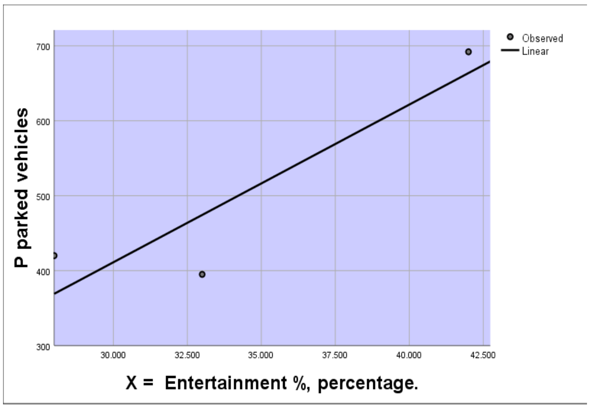

Fig 4. Model plot of parking demand (PM) vs. entertainment percentage for retail land use.

6.2. Gross Floor Area (GFA)

The shopping center's gross floor area is the second variable used to develop the models for retail land use. As shown in Table 8, the developed models and their properties.

From table 8, all the developed models have high $R^2 > 0.95$, indicates to the strong models and strong relationship between the shopping center GFA and parking demand. Also, the RMSE values for all models are acceptable, especially for the power and exponential models; their error is 0.029 and 0.01, respectively. As for models significant show up that at a 0.95% confidence interval, all the models are significant except the logathrim model. The p-value of the logarithm model is 0.06 and that affects the model significantly, so the logarithm model is not recommended to be used. Figure 5 displays the regression model plot of parking demand of the evening period vs. the shopping center GFA, for retail land use. From the figure, the points are distributed very well around the regression line, low deviations from the line indicate a strong relationship.

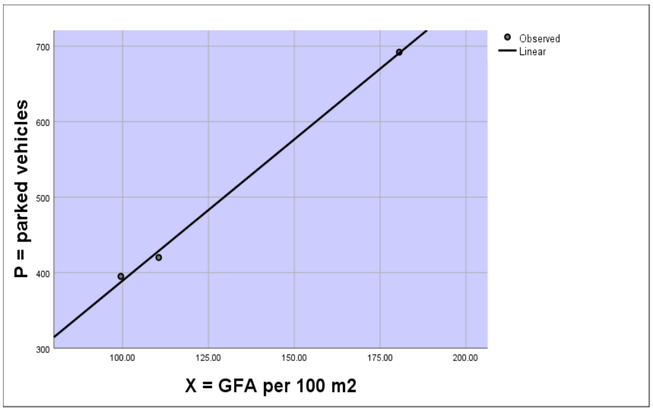

Fig 5. Model plot of parking demand (PM) vs. site GFA for retail land use.

Table 8. Parking generation models (PM) and their properties for variable site's GFA

No	Model Type.	Model	R^2	Adj. R^2	F- test	P-Value	T-test	P-Value	RMSE
1	Linear	$P = 4.7\,X - 80$	0.99	0.99	229.578	0.04	15.152 -2.012	0.04 0.3	15.34
2	Logarithm	$P = 616\ln X - 2452$	0.99	0.98	86.346	0.06	9.292 -7.688	0.06 0.08	24.93
3	Power	$P = X^{1.14} * 2$	0.99	0.97	167.388	0.049	12.938 2.355	0.049 0.3	0.033
4	Exponential	$P = e^{0.009X} * 165.5$	0.99	0.99	777.923	0.023	27.89 24.94	0.023 0.026	0.015

6.3. Gross Leasable Area (GLA)

The shopping centers' gross leasable area is the third variable used to develop parking generation models for retail land use, as shown in Table 9 that presented the developed models and their properties.

From table 9, all the developed models have a high R^2 equal to 0.99, which indicated the very high relationship between the shopping center's parking demand and its gross leasable area. Also, the RMSE values for all developed models are low and acceptable. Further from the same table, all the models are significant at a 95% confidence interval. So, the developed models for GLA are strong models for prediction, and all of them are recommended to be used.

Figure 6 displays the regression model plot of the parking demand for the evening period and shopping centers' gross leasable area. From the figure, the regression line has fitted the points very well.

Table 9. Parking Generation Models (PM) and Their Properties for Variables Sites' GLA

No	Model Type.	Model	R^2	Adj. R^2	F- test	P-Value	T-test	P-Value	RMSE
1	Linear	P = 4.58 X – 1.52	0.99	0.99	388.057	0.032	19.699 - 0.057	0.03 0.9	11.81
2	Logarithm	P = 545ln X – 2042	0.99	0.99	762.786	0.023	27.619 -22.081	0.023 0.024	8.43
3	Power	P = X * 4.45	0.99	0.99	227.128	0.04	15.071 3.197	0.04 0.1	0.029
4	Exponential	$P = e^{0.008X} * 199$	0.99	0.99	152.563	0.05	12.352 12.693	0.05 0.05	0.035

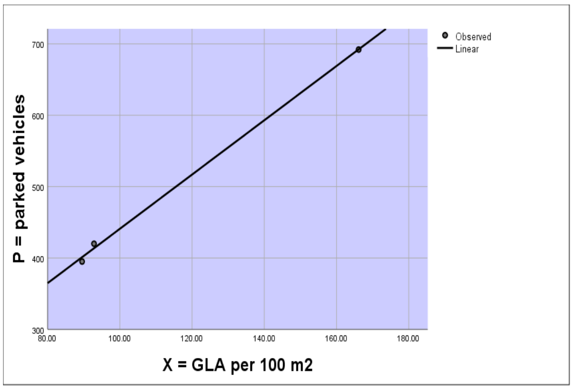

Fig 6. Model Plot of Parking Demand (PM) vs. Site GLA for Retail Land Use.

7. Parking generation rates

These rates are represented by the weighted mean, they are most predominately used across the world like the USA, UK, and other countries. The rates are used when the model is not efficient predictive of parking generation.

The parking generation rates in table 10 are produced by using the same variables that were used to develop the models earlier. The statistical dispersion measurements for the weighted mean were also calculated and presented, these measurements illustrated the variation of the data and the differences between the data value and the mean. As the smaller dispersion the better rates. For example the parking generation rate for gross floor area is = (total gross floor areas/ total parking demand), which equal (99.5 + 110.84 + 164.82) / (398 + 430 + 698) = 4.1 vehicle (space) per 100 m2 of GFA. As for the rate, the range represents the parking generation rate for each shopping center, the highest and lowest rates between them.

Table 10. Parking Generation Rates

Retail land use.						
No.	Period	Rates	Range	Std. dev.	CV%	Rates Range
1	PM	14.82 spaces per entertainment's %	4.558	2.354	15.9	12.1 – 16.6
2		4.1 spaces per 100 m^2 of GFA.	0.355	0.181	4.4	3.88 – 4.2
3		4.57 spaces per 100 m^2 of GLA.	0.185	0.092	2	4.5 – 4.7

Statistically: the produced models and rates are must verified by using new data but For retail land use there is no valid data to verify them, for several reasons. The overall number of shopping centers in Baghdad city is six; three of them are studied and used to develop parking generation rates and models in this research. The remain is three shopping centers, one of the is AL- Waha mall which is a small shopping center with GFA 1750 m2, this mall is dependent mostly on morning demand from the employees and students because of its location surrounded by several ministries and universities. so, For the evening period, there is low demand, so it is not similar to the state of studied shopping centers. As for the two other shopping centers are Babylon mall and al Mansour mall, they have no specific parking lot or garage; their customers are using the public parking lots distributed in the region. Further, they are located on Commercial Street with many shops and restaurants, and there is no way to know the actual parking demand for them.

8. Recommended models and rates

The best models and rates are selected and recommended for each variable. The best model selection is made based on R2 values (the highest value), confidence level (significant at 95%), the model's error of estimate (the lowest error), residuals plot and test (normal distribution), and models and rates verification (differences < 30%). Relying on all the above, the recommended models and rates for retail land use are presented in Table 11.

Table 11. Recommended Parking Generation Models and Rates

Time	No.	Parameter.	Models	R^2	Rates
Pm	2	Entertainment %.	-	-	14.82
	3	GFA per 100 M^2	$P = e^{0.009X} * 165.5$	0.99	4.1
	4	GLA per 100 M^2	$P = e^{0.008X} * 199$	0.99	4.57

From the above table, no models are recommended for the variable entertainment percentage because all of its models were insignificant,
rates can be used instead of them. As for the other variables, the models and rates are recommended, use any of them are applicable, but the models statistically are more favorable.

9. Parking supply rates

It is the parking supply ratio according to the ITE manual is the number of spaces per independent variable. (Spaces per employee, spaces per 100 sq. m. of GFA, or any other variable). This ratio is based on the total supply spaces for the site, rather than the occupied spaces. For example for (ZYM.) shopping center the parking supply rate per GFA is (172/99.4= 1.73 space per person), per is (269/2432= 0.111 space per employ), and per 100 m2 of GFA is (269/1878.64 = 0.14 space per 100 m2), and so on for other sites. The parking supply ratio for each site and independent variable is presented in Table 12 below.

Table 12. Parking supply rates for shopping centers.

Shopping center Name	Supply	Entertainment %	GFA	GLA
ZYM.	172	6.18	1.73	1.93
NKHM.	600	21.4	5.41	6.5
BGHM.	482	11.5	2.92	3.16

10. Comparison and discussion

The developed parking generation rates in this research are produced relied on Iraqi field survey data for each site, as these rates simulate the actual situation for parking demand in Iraqi malls. These rates are compared with the rates suggested by the majority of Baghdad (local regulation), and the rates of the ITE 5th manual, and Palestine to show up how much the differences between them if existed. Tables 13 and 14 below are present these comparisons.

Table 13. Comparing Obtained Parking Generation Rates Vs. Iraqi Regulation Rates

Developed parking rates	Local regulation
4.1 spaces per 100 m^2	5 spaces per 100 m^2

Table 14. Comparing Obtained Parking Generation Rates vs. Palestine and (ITE 5th) Rates

Developed parking rates	ITE 5th Rates	Palestine Rates
4.57 spaces per 100 m^2 of GLA.	3 spaces per 100m^2 Of GLA.	2.25 spaces per m^2 Of GLA.

The displayed comparison in Table 14 shows the retail parking generation rate is 4.57 space for each 100 m, which is higher than the ITE and Palestine's rates. This is natural because the number of visitors to the shopping centers in Iraq is usually very high, because of the high attraction of these shopping centers. That is related to several reasons like, there are a few numbers of shopping centers in Baghdad and Iraq in general, the shopping center design that contains the cinemas' halls, playground halls for kids, several numbers of restaurants as well as the number of shops. Also, the number of entertainment places in Iraq is few, for example, there are no independent cinemas halls or several playgrounds for kids, and that's what made the shopping centers in Iraq are highly attractive for the visitors. Besides, Iraqi shopping centers are usually contained particular supermarkets that offer special goods and provide certain offers for their customers, besides mall special offers and others.

Moreover, another comparison of the developed parking generation rates with parking supply rates presented in Table 12. shows that the two malls' zayonaa and Baghdad parking supply ratios very lower than the recommended parking generation rates in this research, for example, in relied on GLA the parking supply ratios for Zayonaa and Baghdad malls are (1.93 and 3.16 space / 100 m) respectively from Table 12, as compared with the recommended parking rates is 4.57 space / 100 m. This means the two malls have inadequate parking spaces and that also what has been noticed during the field survey where the parked vehicles fill up the garage and float to the adjacent roads. Al-Nakheel mall has a high supply ratio more than recommended in this research, and that was also noticed in the field survey as there were many empty parking spaces.

Conclusion

The following points concluded from the study

1. The parking modeling is essential, because of its impact on the planning, development, and management of the cities and their transportation network. The developed rates are simulating the Iraqi reality travel pattern.
2. The entertainment percentage produced insignificant parking generation models.
3. The GFA and GLA are the most predominant independent variable that has a strong power to predict parking generation rate for shopping centers.
4. Exponential and power models were the best forms that express the relationship between the parking demand and different variables. As they produced lower error and high R2 values.

5. Higher parking generation rates for retail land use (14.82 space per Entertainment (%), 4.1 space per 100 m2 of GFA, and 4.6 space per 100 m2 of GLA). That indicates the high proportion of trips for entertainment purposes. Accordingly, careful planning is required when constructing malls because they generate a high number of trips compared to other land uses.
6. The obtained parking generation rates are a high difference from local regulation and intentional or regional parking generation rates. Besides, to their differences by large amount with the provided parking supply rates at each site. As only Al-Nakheel mall had a sufficient parking supply rate.

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PROPOSAL FOR A NEW CONCEPT OF NIGHT TRANSPORT IN URBAN TRANSPORT ŽILINA

Abstract. Night urban transport in Slovakia is realized by public transport only in selected regional cities. In the long run, due to the increasingly available taxi services and the lack of connection between rail transport and night public transport, it has a declining share in passenger transport. A new operation proposal is necessary for the regional city of Žilina, which considers not only the factor of continuity, but also other factors, such as economical operation and travel expenses. The main task of the article is therefore to propose a more usable concept that will attract as many satisfied passengers as possible to this segment of public transport.
Keywords: night urban transport, transfer time, Žilina town

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Introduction

Night urban public transport is characterized as a public passenger transport service operated at night. This type of public transport is operated mainly by buses, but in some cities trams and trolleybuses are also used. The labeling of night routes may be different from the labeling of daytime routes. The letter N is usually used before the line number to indicate night routes. Some towns also have separate day and night tariffs (night fares are usually more expensive). Night lines are much more geographically limited, so they serve only selected important urban areas with a high population density. They are also characterized by a smaller number of connections (usually 30- or 60-minute intervals) and different or longer routes than daily lines (Plyushteva & Boussauw, 2020).

The main goal of this article is to design the transport service of the town of Žilina by night bus lines so that it primarily meets the criterion of connection to railway transport. This requirement stems from the preferences of rail transport, which is widely used mainly by pupils and students under the age of 26 and seniors over the age of 60 regarding free transport. Furthermore, the operational-economic criterion represented by vehicle kilometers will be considered. The aim of both selected criteria is to compare with the current situation. The subsequent proposal already takes these criteria into account as much as possible.

1. Urban public transport in Slovakia

The history of the first operation of public transport dates to the 19th century, when the first horse-drawn trams appeared in Bratislava. The current state of urban public transport operations is described in Figure 1, where the individual operations are divided into day and night. it is common ground that every night operation also has day operation.

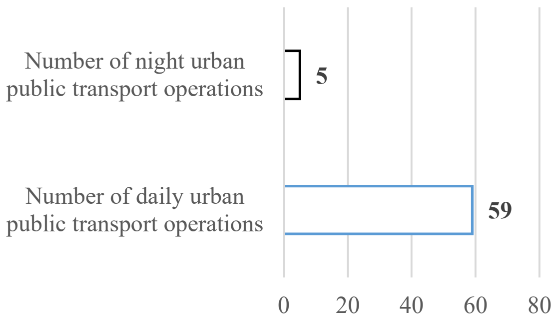

Fig. 1. Number of public transport operations in Slovakia (iMHD.sk, 2017)

Night urban public transport is operated in a total of five regional cities. The operating principles, the means of transport used as well as the number of lines are given in Table 1.

Table 1. The structure of urban public transport in Slovakia (iMHD.sk, 2017)

Town	Number of lines	Type of vehicle
Bratislava	20	buses and trolleybuses
Košice	7	buses
Prešov	2	buses and trolleybuses
Trenčín	1	bus
Žilina	1	

It is clear from the table that most night city transport lines run in the capital. They are followed by Košice, as the second largest town. Night lines usually run from 23:00 to 04:30. In some towns, their operation starts earlier (around 22:30) and ends later (around 5:00).

It is important for the efficient functioning of night public transport that the setting of the timetable. This setting must be based on the bindings that each night line must have. They are shown in Figure 2.

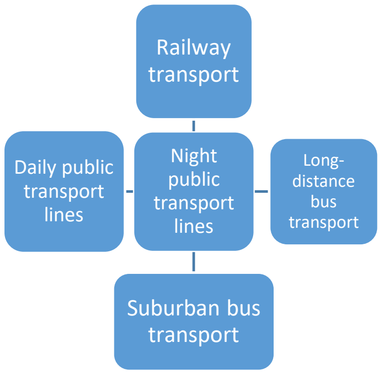

Fig. 2. Bindings between night transport and other modes of transport

If these bindings are secured in the timetable, the use of night lines by passengers is greater. If some bindings do not correspond to the smooth transfer of passengers between modes, their use is smaller and economically unsustainable in the long run.

2. Current state of night public transport in Žilina

The history of night public transport in Žilina dates to 1970, when the night line 50 was established. Its route began at the railway station and ended at university dormitories, because at that time students were the most numerous groups of passengers (Mihalik, 2021).

Line 50 has been running on the current route since 1 April 2009. In principle, only the departure times of the individual stops and the vehicles used changed. In the last 12 years, Žilina has not undergone such massive housing construction that it is necessary to adapt public transport lines (Mihalik, 2021). Currently, the line serves all important points in the city. The railway station, the hospital (only in the return direction), the university halls of residence Hliny and Veľký Diel and the housing estates Vlčince, Solinky and Hájik. The current timetable in direction Železničná stanica - Hájik is in Table 2.

Table 2. Timetable for night line 50 in the direction of Železničná stanica - Hájik valid from 1 April 2021 (Dopravný podnik mesta Žiliny, s. r. o., 2021)

Stops				
Železničná stanica	**22:55**	**0:05**	**1:20**	**3:00**
Predmestská	22:57	0:07	1:22	3:02
Košická, TESCO hypermarket	22:58	0:08	1:23	3:03
Svätých Cyrila a Metoda	23:00	0:10	1:25	3:05
Obchodná	23:01	0:11	1:26	3:06
Matice slovenskej	23:02	0:12	1:27	3:07
Fatranská	23:03	0:13	1:28	3:08
Pod hájom	23:06	0:16	1:31	3:11
Jaseňová	23:07	0:17	1:32	3:12
Limbová	23:08	0:18	1:33	3:13
Smreková	23:09	0:19	1:34	3:14
Poľná	23:11	0:21	1:36	3:16
Hlinská	23:12	0:22	1:37	3:17
Mostná	23:13	0:23	1:38	3:18
Polícia	23:15	0:25	1:40	3:20
Hálkova	23:16	0:26	1:41	3:21
Závodského	23:18	0:28	1:43	3:23
Žitná	23:19	0:29	1:44	3:24
Mateja Bela	23:21	0:31	1:46	3:26
Slnečné námestie	23:22	0:32	1:47	3:27
Stodolova	**23:23**	**0:33**	**1:48**	**3:28**

We can see from the table that the distribution of individual connections during the night is even. Each of the four connections has a travel time of 28 minutes. The omission of a hospital stop in this regard can be considered a shortcoming.

For the return direction Hájik - Železničná stanica, the current timetable is given in Table 3.

Table 3. Timetable for night line 50 in the direction of Hájik – Železničná stanica valid from 1 April 2021 (Dopravný podnik mesta Žiliny, s. r. o., 2021)

Stops					Ω
Stodolova	**23:28**	**0:43**	**1:58**	**3:43**	
Slnečné námestie	23:29	0:44	1:59	3:44	
Mateja Bela	23:30	0:45	2:00	3:45	
Hôrecká	23:32	0:47	2:02	3:47	
Žitná	23:33	0:48	2:03	3:48	
Závodského	23:34	0:49	2:04	3:49	
Mostná	23:37	0:52	2:07	3:52	**4:22**
Hlinská	23:38	0:53	2:08	3:53	4:23
Poľná	23:39	0:54	2:09	3:54	4:24
Smreková	23:41	0:56	2:11	3:56	4:26
Limbová	23:42	0:57	2:12	3:57	4:27
Jaseňová	23:43	0:58	2:13	3:58	4:28
Pod hájom	23:44	0:59	2:14	3:59	4:29
Fatranská	23:47	1:02	2:17	4:02	4:32
Matice slovenskej	23:49	1:04	2:19	4:04	4:34
Obchodná	23:50	1:05	2:20	4:05	4:35
Svätých Cyrila a Metoda	23:51	1:06	2:21	4:06	4:36
Poštová	23:52	1:07	2:22	4:07	4:37
Spanyolova, nemocnica	23:54	1:09	2:24	4:09	4:39
Železničná stanica	**23:57**	**1:12**	**2:27**	**4:12**	**4:42**

From the table we can see that the bus in the direction from the Hájik housing estate to the railway station will also serve the hospital. The journey in this direction takes a total of 29 minutes, which is a minute longer than in the opposite direction. On weekdays, the morning transport of workers is also strengthened by means of a connection with departure at 4:22 from the Mostná stop. According to the timetable, only one vehicle is deployed on the route throughout the night. All stops on the route are at the sign. The connection to the night public transport line from / to the train is an important indicator, especially in terms of passenger potential. To define the connection, it is necessary to characterize the temporal and spatial continuity of connections.

The time sequence of connections is such a sequence of arrivals and departures of various means of public passenger transport, which allows, about the time needed to make the transfer, to comfortably use the subsequent departing connection of the same or another type of transport to continue the journey (Pečený, 2000).

The spatial sequence of connections expresses the distance to be traveled from one means of transport to another by which the passenger intends to continue the journey, considering the level of barrier-free access (Pečený, 2000).

Table 4 shows the links between passenger trains and night line 50.

Table 4. Bonds night public transport and rail transport (Dopravný podnik mesta Žiliny, s. r. o., 2021) (Železnice Slovenskej republiky, 2020)

From the direction	**Train number and type**	**Train arrival**	**Departure of the night line**	**Time to transfer**
Bratislava	RR 717	22:37	22:55	18 min.
Púchov	Os 3357	23:25	0:05	40 min
Košice	RR 766	23:55		10 min.
Košice	RJ 1020	0:32	1:20	48 min.
Praha	LE 1259	1:07		13 min.
Humenné	EN 442	1:26	3:00	94 min.
Bratislava	R 615	1:27		93 min.
Košice	LE 1248	2:34		26 min.
Praha	RJ 1021	2:49		11 min.
Humenné	R 614	2:58		2 min.
Praha	EN 443	4:17	-	-

The distance of spatial accessibility between railway transport and public transport ranges from 50 m to 200 m, depending on the platform at which the train ends/starts. The problem is with barrier-free accessibility, as line 50 starts and ends at the Železničná stanica stop on the other side of the street in the direction of Štefánikovo námestie. The underpass under the train station is not barrier-free. However, due to the upcoming reconstruction of the Žilina junction, which also includes the pre-station area of the Žilina station, this problem will be eliminated.

With time availability, let's assume that the passenger wants to wait a maximum of 15 minutes during the transfer and needs a minimum of 5 minutes to transfer. The primary reason for such thinking is the fact that the passenger ends the journey in the city, so he is not tolerant of a longer wait. If he must wait longer, he will call a taxi service or, in good weather conditions, he can use a shared bicycle. Out of the total number of eleven transfer connections for incoming trains and the departing night line bus, only three transfer connections meet the condition set by us.

Table 5 shows the opposite bonds, i. e. transfer night line - train.

Table 5. Bonds rail transport and night public transport (Dopravný podnik mesta Žiliny, s. r. o., 2021) (Železnice Slovenskej republiky, 2020)

To direction	**Train number and type**	**Train departure**	**Arrival of the night line**	**Time to transfer**
Praha	RJ 1020	0:44	23:57	47 min.
Košice	LE 1259	1:08		61 min.
Humenné	R 615	1:31	1:12	19 min.
Praha	EN 442	1:41		29 min.
	LE 1248	2:38	2:27	11 min.
Košice	RJ 1021	2:50		23 min.
Bratislava	R 614	3:07		40 min.
Košice	RR 765	4:12	4:12	0 min.
Bratislava	RR 702	4:23		11 min.
Humenné	EN 443	4:36		24 min.

For these connections, the transfer time is set at 20 minutes from the arrival of the train and 5 minutes required to switch between getting off the bus and getting on the train. The first significance of such a step is that the passenger starts his journey at the railway station, ie tolerates more time to change. The second significance is that some night trains stay in Žilina for several tens of minutes. However, immediately after the arrival of the train, the passenger can board.

This applies to the following trains (Železnice Slovenskej republiky, 2020):

- RJ 1020 – arrival from the station Košice at 0:32
- EN 442 – arrival from the station Košice at 1:26,
- R 614 – arrival from the station Humenné at 2:58,
- EN 443 – arrival from the station Praha at 4:17.

From the above, we can see that long-distance rail transport was primarily investigated in providing transfers between trains and night buses.

However, regional passenger trains also leave the Žilina station during night bus, but they do not have such great potential primarily for the following shortcomings:

- Os 3500 (Žilina – Rajec) - after adjustment of the night line timetable, a pedestrian transfer between the Smreková and Žilina-Solinky stops is possible,
- Os 3302 (Žilina – Trenčín) - low potential due to non-adaptation of the timetable for staff rotation at the Continental plant in Púchov,
- Os 3902 (Žilina – Čadca) - low potential due to non-adaptation of the timetable for staff rotation at the INA Kysuce plant in Kysucké Nové Mesto.

In the case of the mentioned operational shortcomings, in the following section we will look at the indicator of an economic nature, vehicle kilometers.

Vehicle kilometer is a unit of measurement representing the movement of a vehicle over one kilometer. The distance to be considered is the distance run. It includes movements of empty vehicles. Units made up of a tractor and a semi-trailer or a lorry and a trailer are counted as one vehicle (European Environment Aency, 1997). In our case, it will be a burden on the infrastructure of the town of Žilina by a night public transport line. This indicator is calculated according to the relationship 1 per year.

$$Vehicle\ kilometer = (number\ of\ connection * distance) * 365 \qquad (1)$$

In Table 6, the calculations according to relation 1 are performed for all connections in both directions, including the inserted connection in the section Mostná - Železničná stanica.

Table 6. Calculation of vehicle kilometers of line 50

Route	Distance	Number of connections	The result
Železničná stanica – Hájik	15.1 km	4	22 046 vehicle kilometers/per year
Hájik – Železničná stanica	14.4 km		21 024 vehicle kilometers/per year
Mostná – Železničná stanica	10.6 km	1	2 660.6 vehicle kilometers/per year
Σ	**45 730.6 vehicle kilometers/per year**		

For connections from the Železničná stanica to Hájik and back, the number of days for the whole year was calculated. With the inserted connection from Mostná to the Železničná stanica, only working days were expected, which is a total of 251 working days for 2021. When driving back from the Hájik housing estate, the number of vehicle kilometers per year is lower by 1,022 km. This is due to the different shorter route.

3. Proposal of a new night public transport line

The proposal of a new line is based on two basic factors. First, it is necessary to streamline the route so that the travel time of passengers from individual housing estates is not artificially extended and other stops are included in the public transport system, which are not served by night transport today. Another equally important factor is the connection between night line connections and passenger trains. Therefore, in the new concept, two lines are proposed to eliminate these problems. Both lines pass through the city center and are proposal to form a complete circuit without the need to turn the bus in front of the train station (Mihalik, 2021).

Night line 50 is proposal to speed up the service of the Vlčince and Solinky housing estates, running in both directions through Vysokoškolákov and Vojtecha Spanyola streets, stopping at all stops on the route. According to the proposal, the night line in the center is traced clockwise. The route of line 50 is proposed as a roundabout with a final / initial stop at the Railway Station. Line 50 would leave from the Železničná stanica stop (trolleybus platform) in the direction of Vlčince (Mihalik, 2021). Table 7 shows the proposed timetable for line 50.

Table 7. Proposed night bus timetable 50 (Mihalik, 2021).

Stops							K
Železničná stanica	**22:50**	**23:40**	**0:40**	**1:35**	**2:20**	**3:25**	**4:30**
Štefánikovo námestie	22:51	23:41	0:41	1:36	2:21	3:26	4:31
Spanyolova, nemocnica	22:52	23:42	0:42	1:37	2:22	3:27	4:32
Vysokoškolákov, plaváreň	22:54	23:44	0:44	1:39	2:24	3:29	4:34
Poštová	22:55	23:45	0:45	1:40	2:25	3:30	4:35
Svätých Cyrila a Metoda	22:57	23:47	0:47	1:42	2:27	3:32	4:37
Obchodná	22:58	23:48	0:48	1:43	2:28	3:33	4:38
Matice slovenskej	22:59	23:49	0:49	1:44	2:29	3:34	4:39
Fatranská	23:01	23:51	0:51	1:46	2:31	3:36	4:41
Žilinská univerzita	23:03	23:53	0:53	1:48	2:33	3:38	4:43
Pod hájom	23:04	23:54	0:54	1:49	2:34	3:39	4:44
Jaseňová	23:05	23:55	0:55	1:50	2:35	3:40	4:45
Limobvá	23:06	23:56	0:56	1:51	2:36	3:41	4:46
Smreková	23:07	23:57	0:57	1:52	2:37	3:42	4:47
Centrálna	23:09	23:59	0:59	1:54	2:39	3:44	4:49
Pod hájom	23:10	0:00	1:00	1:55	2:40	3:45	4:50
Žilinská univerzita	23:11	0:01	1:01	1:56	2:41	3:46	4:51
Fatranská	23:13	0:03	1:03	1:58	2:43	3:48	4:53
Matice slovenskej	23:14	0:04	1:04	1:59	2:44	3:49	4:54
Obchodná	23:16	0:06	1:06	2:01	2:46	3:51	4:56
Svätých Cyrila a Metoda	23:17	0:07	1:07	2:02	2:47	3:52	4:57
Košická, TESCO hypermarket	⇑	⇑	⇑	⇑	⇑	⇑	***5:00***
Poštová	23:18	0:08	1:08	2:03	2:48	3:53	
Vysokoškolákov, plaváreň	23:20	0:10	1:10	2:05	2:50	3:55	
Spanyolova, nemocnica	23:21	0:11	1:11	2:06	2:51	3:56	
Veľká Okružná, AUPARK	23:22	0:12	1:12	2:07	2:52	3:57	
Polícia	23:24	0:14	1:14	2:09	2:54	3:59	
Hurbanova	23:26	0:16	1:16	2:11	2:56	4:01	
Železničná stanica	**23:28**	**0:18**	**1:18**	**2:13**	**2:58**	**4:03**	

The proposal includes a total of 6 connections on the entire circular route and the seventh connection is a commuter connection to the Košická garage, as the carriage of the night line falls under this garage. At the same time, this connection is also advantageous for the employees of the TESCO department store. The whole circuit takes a total of 38 minutes by bus. The advantage is also the connection at the Fatranská stop to the trolleybus line 4 from the last commuter connection, so that the connection to the trains at the railway station will be ensured by means of one transfer.

The concept of night line 51 is designed with an emphasis on the service of smaller town districts (Hliny, Bánová, Závodie and Hájik housing estates). This night line would also stop at all stops on its route. Opposite to line 50, it would be routed counterclockwise in the center. Line 51 would leave the platform in front of the station building in the direction of Hurbanova. Table 8 proposes a timetable for night line 51.

Table 8. Proposed night bus timetable 51 (Mihalik, 2021).

Stops							K
Železničná stanica	**22:50**	**23:40**	**0:40**	**1:35**	**2:20**	**3:25**	**4:30**
Hurbanova	22:52	23:42	0:42	1:37	2:22	3:27	4:32
Polícia	22:54	23:44	0:44	1:39	2:24	3:29	4:34
Komenského	22:55	23:45	0:45	1:40	2:25	3:30	4:35
Mostní	22:56	23:46	0:46	1:41	2:26	3:31	4:36
Hlinská	22:57	23:47	0:47	1:42	2:27	3:32	4:37
Poľná	22:58	23:48	0:48	1:43	2:28	3:33	4:38
Kamenná, obchodné centrum	23:01	23:51	0:51	1:46	2:31	3:36	4:41
Kamenná, domáce potreby	23:02	23:52	0:52	1:47	2:32	3:37	4:42
Námestie Svätého Jána Bosca	23:04	23:54	0:54	1:49	2:34	3:39	4:44
Oslobodenia	23:05	23:55	0:55	1:50	2:35	3:40	4:45
Jedľová	23:06	23:56	0:56	1:51	2:36	3:41	4:46
Žitná	23:07	23:57	0:57	1:52	2:37	3:42	4:47
Závodského	23:08	23:58	0:58	1:53	2:38	3:43	4:48
Križna	23:09	23:59	0:59	1:54	2:39	3:44	4:49
Pod vinicou	23:10	0:00	1:00	1:55	2:40	3:45	4:50
Stodolova	23:13	0:03	1:03	1:58	2:43	3:48	4:53
Slnečné námestie	23:14	0:04	1:04	1:59	2:44	3:49	4:54

Mateja Bela	23:15	0:05	1:05	2:00	2:45	3:50	4:55
Hôrecká	23:18	0:08	1:08	2:03	2:48	3:53	4:58
Bánovecká cesta	23:19	0:09	1:09	2:04	2:49	3:54	4:59
Poľná	23:21	0:11	1:11	2:06	2:51	3:56	5:01
Hlinská	23:22	0:12	1:12	2:07	2:52	3:57	5:02
Bernolákova	⇑	⇑	⇑	⇑	⇑	⇑	*5:03*
Nemocničná	⇑	⇑	⇑	⇑	⇑	⇑	*5:05*
Košická, TESCO hypermarket	⇑	⇑	⇑	⇑	⇑	⇑	***5:07***
Mostná	23:23	0:13	1:13	2:08	2:53	3:58	
Veľká Okružná, AUPARK	23:25	0:15	1:15	2:10	2:55	4:00	
Štefánikovo námestie	23:27	0:17	1:17	2:12	2:57	4:02	
Železničná stanica	**23:29**	**0:19**	**1:19**	**2:14**	**2:59**	**4:04**	

Also in this proposal, there are a total of 6 connections running the entire route and the seventh connection ends at the Košická, Tesco hypermarket stop. The ride takes a total of 39 minutes, and one bus is planned on the line. At the Hlinská stop, it is possible to change from the last seventh connection to trolleybus line 4.

Table 9 shows the newly created transfer times between the proposed night lines and passenger trains according to the current timetable.

Table 9. Transfer times between passenger trains according to the current timetable and the proposed night lines 50 and 51

From the direction	Train number and type	Train arrival	Departure of the night line	Time to transfer
Bratislava	RR 717	22:37	22:55	13 min.
Púchov	Os 3357	23:25	23:40	15 min.
Košice	RR 766	23:55	0:40	45 min.
Košice	RJ 1020	0:32		8 min.
Praha	LE 1259	1:07	1:35	28 min.
Humenné	EN 442	1:26		9 min.
Bratislava	R 615	1:27		8 min.
Košice	LE 1248	2:34		51 min.
Praha	RJ 1021	2:49		36 min.
Humenné	R 614	2:58		27 min.
Praha	EN 443	4:17	4:30	13 min.

Transfer times have improved compared to the current situation and while maintaining the conditions set by us. The advantage is also that the lines leave the Železničná stanica stop at the same time. The formation of a transfer time between EN 443 and a night bus can also be assessed positively, as it has been missing so far.

Table 10 sets out the transfer times in reverse, ie night bus arrivals and train departures. Line 51 arrives at the Železničná stanica stop a minute later, so there will be two-time data in the arrival column in the table. First the arrival time of line 50 and then the arrival time of line 51. The same will apply to the transfer time.

Table 10. Transfer times between the proposed night lines 50 and 51 and passenger trains according to the current timetable

From the direction	Train number and type	Train arrival	Departure of the night line	Time to transfer
Praha	RJ 1020	0:44	0:18/0:19	26 min./25 min.
Košice	LE 1259	1:08		50 min./49 min.
Humenné	R 615	1:31	1:18/1:19	13 min./12 min.
Praha	EN 442	1:41		23 min./22 min.
Praha	LE 1248	2:38	2:13/2:14	25 min./24 min.
Košice	RJ 1021	2:50		37 min./36 min.
Bratislava	R 614	3:07	2:58/2:59	9 min./8 min.
Košice	RR 765	4:12	4:03/4:04	
Bratislava	RR 702	4:23		20 min./19 min.

Again, an improvement in transfer times can be stated based on the proposed operation of night public transport. It is clear from the table that the authors focused primarily on the preference for transfer times for national long-distance trains. This is mainly due to the good transfer times between these domestic trains and international connections in the capital town Bratislava and in Košice. It will be possible to change to the 3500 passenger train from Žilina to Rajec at the Smreková stop from line 50. The distance between the bus and the railway stop is 150 m.

In Table 11, the calculations according to Equation 1 are performed for all connections in both directions, including the last commute connection to the Košická garages.

Table 11. Calculation of vehicle kilometers of the proposed night line service

Number of night line	Distance	Number of connections	The result
50	19.4 km – the whole circuit	6	42 486 vehicle kilometers/per year
	16.7 km – commute night bus	1	6 095.5 vehicle kilometers/per year
51	17.1 km – the whole circuit	6	37 449 vehicle kilometers/per year
	16.9 km – commute night bus	1	6 168.5 vehicle kilometers/per year
Σ	**92 199 vehicle kilometers/per year**		

Due to the increase in the number of connections and the length of individual routes, the difference in this indicator compared to the current state is considerable. After percentage conversion, the proposed outputs are increased by 101.61%.

Conclusion

Public transport at night has experienced decline or stagnation in most places in recent years, resulting in the reduction or disruption of such passenger routes. Such is the case in the city of Žilina, where the stagnant operation of line 50 is caused by various unfavorable factors, including insufficient links between trains and the night line.

Based on a better interconnection of these two modes of transport, the article was to streamline operations by proposing a new concept of night transport. Figure 3 shows a comparison of the state of vehicle kilometers before and after the proposed variant of night traffic.

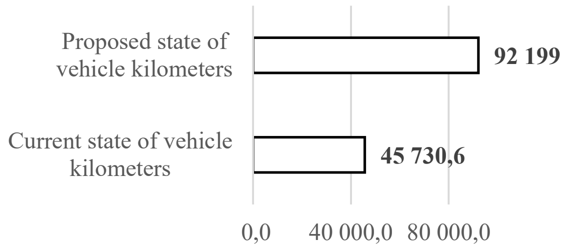

Fig. 3. Comparison of vehicle kilometers

At the same time, it was pointed out the possibility of introducing a new line that would serve those parts of the city that are not currently connected to the night public transport network. All this was evaluated by means of the vehicle kilometer indicator, which has not only operational but also economic significance.

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POSSIBILITIES OF BUILDING CONNECTION OF M.R. ŠTEFÁNIK AIRPORT TO THE ŽSR NETWORK

Abstract. The current conditions of the railway infrastructure near the M. R. Štefánik Airport is analysed as unsatisfactory. The current form of the railway infrastructure of the monitored area is not adapted to the creation of a suitable place for boarding and alighting of passengers. The point determined for boarding and alighting of passengers must be at a reasonable distance from the M. R. Štefánik Airport terminal. This distance must be able to be overcome by walking so that it is not necessary to use another mode of transport to move between these places. The article deals with the possibilities of connecting of M. R. Štefánik Airport to the ŽSR network. The basis for the proposal to connect M. R. Štefánik Airport with a suitable infrastructure ŽSR network within the framework of railway passenger transport is the determination of a suitable transfer point. One of the logical priorities is to place the transfer point as close as possible to the air transport terminal of the M. R. Štefánik Airport within the space possibilities and technical conditions.
Keywords: ŽSR network, transfer point, M. R. Štefánik Airport, terminal of integrated passenger transport, track section

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Introduction

Rail transport which is located in the vicinity of the M. R. Štefánik Airport works only for the purpose of freight transport. It is primarily in the form of fuel imports, to which the given infrastructure is also adapted. The potential of the M. R. Štefánik Airport is not spent. The possibilities of access to this airport are considerably limited by the degree of development of individual types of infrastructure. The railway infrastructure that currently serves the needs of the M. R. Štefánik Airport exists in the form of a railway siding. It opens into the railway network by turning the airport onto a non-electrified single-track line, which leads to the Podunajské Biskupice railway station. At present, not much is expected to be used for passenger transport purposes. This is mainly the distance from the airport terminal, while the advantage is not even the mouth of the railway network. A justified step is the analysis of the possibilities of connecting the M. R. Štefánik Airport to the ŽSR railway network and to prepare a proposal for the routing of the relevant infrastructure. The proposed infrastructure will be suitable for the purposes of passenger transport with an adequate level of comfort, quality and safety. This step must be in particular in accordance with the Railways Act 513/2009 Coll. and Decree 350/2010 Coll. on the construction regulations of railways. For the purpose of the proposal, it is necessary to pay attention to the conditions specified in the Aviation Act 143/1998 Coll., which will meet the conditions for the completion of the proposal itself. (Čechovič, et. al., 2020). In their research, transport service around the airport and to the airport was solved by Čechovič, L. et. al. (2020), who examined the transport service of Ostrava Airport in the Czech Republic. A similar issue was dealt with by Černá, L. et. al (2018), Zitrický, V. et. al. (2020) who dealt with Comparative analysis in terms of environmental impact assessment between railway and air passenger transport operation. The sustainability of transport in the Danube region, where the M. R. Štefánik Airport is located, was addressed in his research Mako, P. et. al. (2021).

1. Characteristics of the railway network of Slovakia and M. R. Štefánik Airport

The current railway infrastructure in the territory of the capital of the Slovak Republic is conceived as an important transport hub. This hub consists of several interconnected European important lines also included in the TEN, AGC and AGTC networks. (Zitrický, et. al., 2020). Transregional main railway lines marked according to sections in the Slovak territory from the tables of line conditions of ŽSR pass through the area radially in the following directions (BSK, 2012):

- 126 A: Bratislava - Brno - Prague - Dresden - Berlin - Hannover,
- 125 A: Bratislava - Žilina - Čadca - Zwardoň - Warsaw - Gdańsk,
- 120 A: Bratislava – Štúrovo – Budapest - Belgrade - Istanbul - (Thessaloniki).

The Bratislava railway junction has a standard track gauge of 1435 millimetres. It consists of individual sections with a total length of 100.7 kilometres, of which 49.5 kilometres are double-track and the other length consists of single-track sections. Of the total length of track sections, 86.6 kilometres are electrified by a single-phase AC supply system of 25 kV and 50 Hz. (Černá, et. al., 2018). The railway infrastructure currently serving the needs of M.R. Štefánik Airport, exists in the form of a railway siding, which is connected to the railway network by a branch airport, according to Figure 1, on a non-electrified single-track line leading to the Podunajské Biskupice railway station. This siding is used to supply loaded wagons with oil products. These are mainly aviation fuels and the subsequent removal of empty wagons. (Mako, et. al., 2021)

At present, not much is expected to be used for passenger transport purposes. This is mainly the distance from the airport terminal, while the advantage is not even the mouth of the railway network. Figure 1 shows the current connection of the airport siding to the ŽSR network. M. R. Štefánik Civil Airport - Airport Bratislava has a 24hours operation. This airport was established in 1951 and is situated near the city of Bratislava with a distance of 9 kilometres northeast of the city centre.

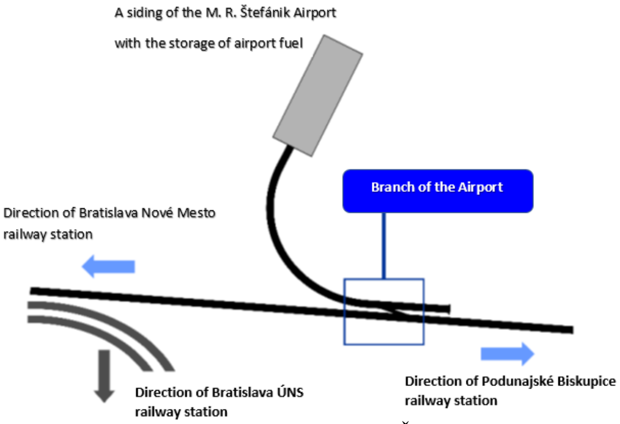

Fig 1. Connection of the siding of M. R. Štefánik Airport to the railway network (Source: Remeň, 2019)

There are currently two runways with a concrete surface in operation (Figure 2). The main track is 2950 metres long and 45 metres wide. It is marked with data 13/31, which determine the direction of travel according to the magnetic azimuth. The side runway 04/22 is 2900 metres long and 60 metres wide. The intersection point is 904 metres from runway 13 and 1428 metres from runway 04. The airport's check-in area, with an area of 143,000 m^2, has 33 marked aircraft stands. (BTS, 2018)

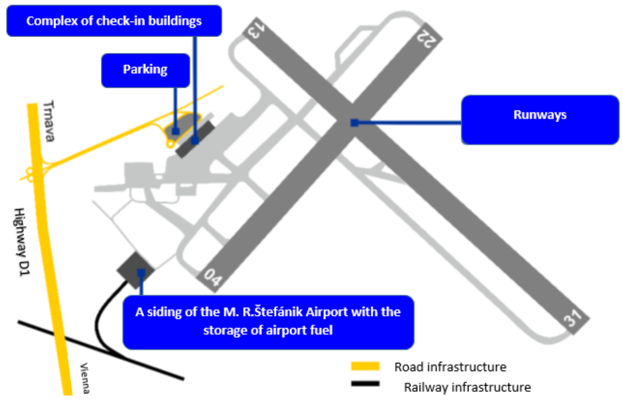

Fig 2. Schematic representation of the layout of the M. R. Štefánik Airport (Source: Remeň, 2019)

The location of the complex of three consecutive terminal check-in halls is schematically shown in Figure 2. Its total area is 48,545 m^2 with an estimated capacity of 5 million passengers handled per year. Figure 2 also shows the existing infrastructure around the airport. We can also see that the different distance between the location of the railway infrastructure and also the road infrastructure to the terminal is demonstrated. Between the terminal and car parks P1 and P2, there are parking slots for taxi services and bus transport. (BTS, 2018)

2. Position of the transfer point between M. R. Štefánik Airport and the railway infrastructure

The basis for the proposal to connect M. R. Štefánik Airport with a suitable infrastructure to the ŽSR network within the framework of railway passenger transport is the determination of a suitable transfer point. One of the logical priorities is to place the transfer point as close as possible to the air transport terminal of the M. R. Štefánik Airport within the space possibilities and technical conditions.

The basic dispositional possibilities of the location of the railway infrastructure are shown in Figure 3 together with a map of the area around the complex of check-in buildings of the M. R. Štefánik Airport processed at a scale of 1: 5,000. Here is shown the spatial radius, which is centred in the plane of the entrances of the airport terminal. This radius consists of two distance zones 250 and 500 metres. The plane shown divides the radius and semicircle that arose naturally beyond this plane and cannot be classified as an area in which the railway infrastructure can be located. The first zone of 250 metres limits the maximum distance when planning the terminal of integrated passenger transport, which is overcome by walking between the platform and the place of transfer to another mode of transport. The standard is a distance of about 50 metres. The zone up to 500 metres was chosen within the current spatial situation around the M. R. Štefánik Airport with an impact on open and undeveloped areas. In this case, the location of the railway platform should not be considered as part of the terminal of integrated transport, but only as a railway station or a railway station close to the airport. However, the aim of designing attractive connections and promoting public rail transport would not have to be achieved to the extent expected. The reason is the immediate distance before entering the complex of check-in buildings, where bus stops, taxi ranks and car parks for individual car transport have already been set up.

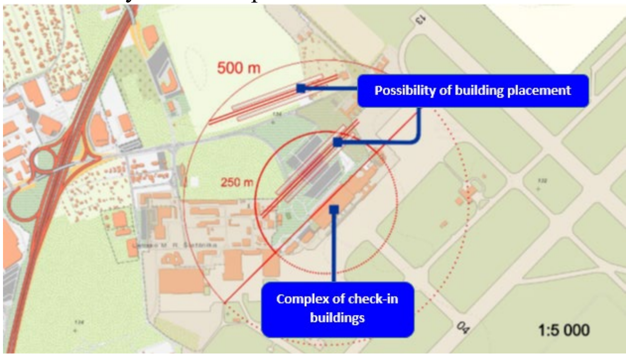

Fig 3. Spatial radius of the possibility of position the transfer point from railway transport (Source: Remeň, 2019)

The final location of the railway station, which as a part of the transport of integrated passenger transport of the M. R. Štefánik Airport includes the above-mentioned conditions of attractiveness. Due to the spatial possibilities, this is a sub-level variant of routing the railway infrastructure of the planned station.

The advantages of the proposed solution include

- out of level crossing with roads around the airport,
- minimum distance to the airport terminal,
- straight 400 metres long and 550 millimetres above the top of the track high standardized platforms,
- the possibility of excavating the area with excavation work for placement above the undeveloped area (except for the temporary abolition of the car park),
- better possibilities of connection with the ŽSR network by sections with higher track speed,
- terrain and subsoil in the construction area,
- less impact on the character of the landscape and the city after completion.

At the same time, these solutions also bring disadvantages in the form of:

- higher construction costs,
- technological complexity of construction in comparison with the location on the surface,
- operating costs.

3. Possibilities of connecting the terminal of the integrated passenger transport of the M. R. Štefánik Airport to the ŽSR network

There are a total of three possibilities for connecting the terminal of the integrated passenger transport of the M. R. Štefánik Airport to the existing railway infrastructure of ŽSR. It is justified to compare and consider their advantages alone or in combination with each other. According to ŽSR track condition tables, suitable interstation sections are 120A track section between the Bernolákovo railway station and the Močiar branch in both directions, 127C track section between the Bratislava - Nové Mesto and Bratislava - ÚNS railway stations also in both directions, and 124A track section towards the Podunajské Biskupice railway station, current siding to the airport.

3.1 Connection to the ŽSR 120A track section

The planned single-track line section is 3.3 kilometres away from the integrated passenger transport terminal of the M. R. Štefánik Airport, which is directed from the Močiar branch and is electrified along its entire length by a 25 kV and 50 Hz supply voltage system.

It is connected to the main track ŽSR 120A at kilometres 62,797 in front of the railway station Bratislava - Vajnory. This section is called BTS A in this article (Figure 4). It leads through an almost undeveloped area and crosses the level of the D1 highway section (E75), the motorway road I / 61 and the local road Overpass of Vajnory below ground level. Routing is different from the Traffic-urban study of the original TEN - T 17 project of the airport connection from 2009. According to this study, the route was to be connected to the ŽSR 120A track section behind the Bratislava - Vajnory railway station.

Fig 4. Proposal for the connection of the terminal of integrated passenger transport of the M. R. Štefánik Airport to the ŽSR 120A track section (Source: Remeň, 2019)

A visual illustration of routing BTS A track sections shown at a 1: 25,000 scale map in Figure 4. Here we can see the overall spatial possibilities of routing this section. The problem is the space in the gardening area at the Overpass Vajnory and at the Zlaté Piesky rest area. The route is led from the ground level from the place of connection, where possible, and also in the cuts to the airport from where it continues through the tunnel to the terminal of the integrated passenger transport of the M. R. Štefánik Airport.

An overall assessment of the benefits as well as the negative effects of the construction of the BTS A section is given in Table 1. A disadvantages arise especially in the construction phase. In principle, they have a negative impact on the construction of all alternatives. The permanent negative effect is the occupation of arable land in the area and further spatial division of the area by a line led mostly in notches. (ŽSR, 2019)

Table 1. Assessment of the effects of the construction of the BTS A track section; (Source: Remeň, 2019)

Advantages of the BTS A track section
Connection to the main double-track electrified line (track speed currently up to 120 kph).
Ongoing modernization and electrification of the track on the Austrian side with a line speed of 200 kph.
Electrification of the railway station Devínska Nová Ves - state border in the phase of project preparations.
In this alternative, the direct connection route leads through the busy transfer node of the Bratislava main station.
Possibility of direct connection of the airport with the lowest construction costs.
Tracing is in a minimally built-up area and this is associated with the technological complexity of construction.
Line speed of this section at least 100 kph.
Disadvantages of the BTS A track section
Local drops of maximum line speed on the current infrastructure up to 30 kph.
Current use of infrastructure capacity between the Bratislava main station and the Devínska Nová Ves railway station.
Occupancy of agricultural land.
Restrictions on traffic during construction on important roads and main roads.
Increased noise and dust levels during construction.

At present, the importance of this route will increase significantly due to the planned electrification of the adjoining track section or the addition of a second line track and also a comprehensive modernization along the Devínska Nová Ves railway station. This can be included in the advantages of building the BTS A track section. The strategic development of the Bratislava transport hub, which is based mainly on the ŽSR Feasibility Study from 2019, would also contribute to minimizing these disadvantages. The advantage of building this section may increase in combination with the alternative of connecting the BTS C track section. This will create the possibility of using the infrastructure "loop" in the Bratislava transport hub for trains leading to the Bratislava - Nové Mesto railway station from the direction of Trnava and Malacky.

Figure 4 shows the connection of the terminal of integrated passenger transport of the M. R. Štefánik Airport to the marked BTS B track section. This track section leads from the Bernolákovo railway station and is connected to the line called ŽSR 120A at kilometres 67,500. This track section is intended as double track and electrified. The track section is run at ground level, while the crossing with the D4 and I / 61 roads is solved off-level.

The BTS B track section is connected to the BTS A track section at the level of the Zlaté Piesky rest area. From there, together with BTS A, it will be led through a tunnel as a double-track section to the terminal of integrated passenger transport of M. R Štefánik Airport. The planned BTS B track section is justified within the framework of passenger transport to the airport. Therefore, it will be considered as a development variant within the subsequent stages of the construction of the railway infrastructure to connect the planned terminal of integrated passenger transport of the M. R. Štefánik Airport.

Table 2. Assessment of the effects of the construction of the BTS B track section; (Source: Remeň, 2019)

Advantages of the BTS B track section
It will create a parallel route to the ŽSR 120A track section in combination with the BTS C track section.
It will be possible to connect the terminal of integrated passenger transport of the M-R. Štefánik Airport, the Bratislava - Nové Mesto railway station, and the Bratislava main station in combination with the BTS C track section. This makes it possible to increase their attractiveness and use in international and regional passenger transport.
An infrastructure "loop" suitable for trains leading to the Bratislava - Nové Mesto railway station from the direction of Senec will be created with the BTS C track section.
Disadvantages of the BTS B track section
Occupancy of agricultural land.
Restrictions during construction, as for BTS A track section.

The proposed BTS B track section is 4.2 kilometres long. It is also justified when transporting people not only to the airport. The elaborated table 2 shows the influences caused by the construction of this section. Nevertheless, it is a development variant within the purpose of building infrastructure. This section shows the greatest benefits in combination with the BTS C track section. With the appropriate routing of international trains, a connection will be established between Budapest, M. R. Štefánik Airport by means of the terminal of integrated passenger transport, as well as the cities of Bratislava and Prague. The potential of the Bratislava - Nové Mesto railway station will increase, which will also be a connecting hub in regional transport or urban public transport. The condition for this positive impact of these sections is to increase the capacity of the track section referred to as ŽSR 127G between the Bratislava - Nové Mesto railway station and the Bratislava main station by adding a second track. This recommendation is also supported by the feasibility study of the Bratislava transport hub from 2019 based on an analysis of the current situation.

3.2 Connection to the ŽSR 127C track section

Another suitable point of connection of the terminal of integrated passenger transport of M. R. Štefánik Airport to the existing railway infrastructure is 127C track section. Several studies have been devoted to the construction of railway infrastructure for the purposes of the airport. The traffic-urban study of the TEN-T 17 project from 2009 assumed the construction of railway infrastructure, which is connected to the ŽSR 127C track section in both mentioned directions. The connection from the direction of the railway station Bratislava - ÚNS was to be realized by a bridge structure at the place where the track in front of the airport descends. It continues in the tunnel together with the branch from the direction of the Bratislava - Nové Mesto railway station to the underground station, which is located at the airport. The connection ideas from this study remain. These two connection alternatives not only from the Bratislava - Nové Mesto railway station, but also from the direction of the Bratislava - ÚNS railway station have a justification with demonstrable potential. These alternatives are referred to as BTS C and BTS D sections for clarity. This designation and routing of the sections is shown on a 1: 25,000 map in Figure 5.

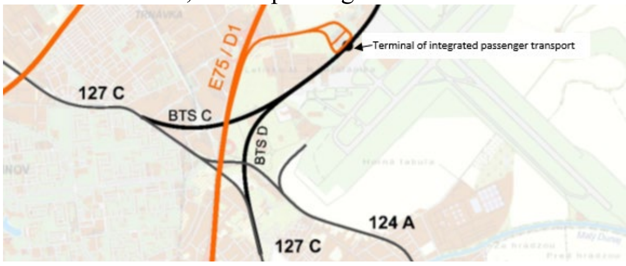

Fig 5. Spatial radius of the possibility of position the transfer point from railway transport (Source: Remeň, 2019)

Due to the extensive urban construction in the planned route, the BTS C track section is 2.3 kilometres long and is routed below ground level. In the current construction with the BTS B track section, it is suitable to build these sections with two tracks. This creates a high-quality and parallel section with the original track section called ŽSR 120A with the advantages described above. In the case of independent construction, it is possible to consider this section as a single track, without considering a change in the route of some passenger trains from 120A track section. With these two options, the point where called 127C track section connects should reflect the planned development of not only this section. It should also take into account the part of the city routed in parallel on the track section referred to as 124A track section to the Podunajské Biskupice railway station.

The feasibility study of the Bratislava transport hub from 2019 recommends an increase in capacity and the addition of a second track as part of the development of these existing track sections and, in particular, the section designated as 124A. Among other things, the construction of the terminal of integrated passenger transport called Ružinov is planned in the area of Vrakuňa road. The construction of platforms and adjustment of the geometric position of the tracks is planned here. As part of increasing the capacity of the track designated as 124A in the inter-station section in question, the construction of a new transport station in the form of the Ružinov branch is proposed, which is recommended in each alternative. (ŽSR, 2019)

These proposals are therefore followed by the planned section of BTS C. This section should be connected to the current railway infrastructure in the planned branch of Ružinov. The routing does not necessarily have to include the Ružinov terminal of integrated passenger transport due to the nature of the passenger transport to the airport. Table 3 shows the advantages and disadvantages of the construction of BTS C track section.

Table 3. Assessment of the effects of the construction of the BTS C track section; (Source: Remeň, 2019)

Advantages of the BTS C track section
The advantages are identical in combination with the BTS B track section.
Possibility of direct connection with other airports.
When building independently, the route of the planned connection will also include the Bratislava - Nové Mesto railway station.
Disadvantages of the BTS C track section
Capacity of the inter-station section between Bratislava main station and Bratislava - Nové Mesto railway station.
Higher cost and construction difficulty compared to BTS A track section.

The difference between the benefits of the BTS C track section and the BTS A track section lies in the method of routing the planned connection through the Bratislava - Nové Mesto railway station. These alternatives have other advantages in common. The disadvantage of the section is that the entire length of the section routing is below ground level and below the built-up urban area. This significantly increases construction costs and the overall complexity of construction. Most of the existing disadvantages of routing a planned connection through Marchegg are common to these two BTS A and BTS C alternatives. The second possibility is disadvantaged by the restrictive section of Bratislava main station and Bratislava - Nové Mesto railway station. This inter-station section is currently the busiest section of the Bratislava railway junction. (ŽSR, 2019)

The condition for balancing the effects of sections BST A and BTS C is the construction of a second track in this restrictive section. The method of connection of the terminal of integrated passenger transport of the M. R. Štefánik Airport from the track section marked as ŽSR 127C, which leads to the railway station Bratislava - ÚNS, is shown in Figure 5. This BTS D track section is shown here. It is routed below the ground level from the terminal of integrated passenger transport. It continues to the track section designated 127C. Here it is fed in the area of Na piesku street at 9,200 kilometres. Below track 124A and Vrakuňa road, the routing was chosen below ground level due to the slope conditions. The single- BTS D track section is planned in the same way as the previous sections as electrified by the standard 25 kV 50Hz power supply system. The illustration of the effects of the construction of the BTS D track section in the length of 2.15 kilometres is shown in Table 4.

Table 4. Assessment of the effects of the construction of the BTS D track section; (Source: Remeň, 2019)

Advantages of the BTS D track section
Possibility of direct connection of M. R. Štefánik Airport with Vienna Airport.
The existing connection infrastructure is fully electrified.
Disadvantages of the BTS D track section
Technologically and economically demanding section for construction.
Technical condition of the connected infrastructure to the Bratislava – Petržalka railway station.

The disadvantages of building a separate BTS D track section are mainly high investment costs in the construction of this section and the modernization of the adjoining infrastructure to the Bratislava - Petržalka railway station. By eliminating them, this planned section would significantly increase its importance. This would also be dramatically increased by the planned construction of a railway line between Wien Flughafen and Bruck a. d. Leith in order to increase the capacity of the current Ostbahn between Vienna and Budapest. With the construction of this track section, the Wien Flughafen station would be connected to the TEN - T network by a high - performance line. This will make it possible to adjust the routing of passenger trains through this important transfer point. (ÖBB, 2017)

These include, for example, trains from the track between Wien hbf and the Bratislava - Petržalka railway station, which could thus be extended to the terminal of integrated passenger transport of M. R. Štefánik Airport. It would be possible to create a connection between the main station in Vienna, Vienna Airport and M. R. Štefánik Airport. During the simultaneous construction of BTS D and BTS A track sections, it will be possible to extend such a connection to the Bratislava main station. The maximum possibility of designing a railway connection, which is conditioned by the existence of infrastructure formed by BTS A and BTS D track sections, is the Bratislava - Vienna ring road.

Conclusion

The investigated alternatives are not mutually exclusive and each of these planned sections represents its own special contribution with regard to the purpose of connecting the terminal of integrated passenger transport of the M. R. Štefánik Airport. The synergistic effect of combining these track sections significantly increases the value of their separate benefits. Therefore, it is appropriate to consider these planned sections as individual stages of the development of railway infrastructure at M. R. Štefánik Airport, rather than separate alternatives. They need to be classified according to a set priority level. The level of priority construction of these sections is shown in Table 5, where the level is based on a modified analysis of the management of the company's internal environment. This is supplemented by the scale of individual factors.

Due to the difference in the effects of these factors on these track sections, a significance scale in the range of 1 - 10 was chosen in the assessment. The evaluation of a section for a specific factor on a scale of 1 - 5 is multiplied by the weight so that its significance is taken into account. Number 5 in the rating means the best rating and number 1 means the worst rating. The resulting sum of points will determine the significance of the assessed track sections to the terminal of integrated passenger transport of M. R. Štefánik Airport. Emphasis was placed on the complexity of construction when choosing the scale in comparison with the immediate benefit and the lowest conditional requirements for the modification of the current infrastructure.

The analysed influences and effects of the construction of these track sections from the terminal of integrated passenger transport of M. R. Štefánik Airport, which are connected to the ŽSR network, show, according to Table 5, a different level of significance, due to the current form of infrastructure. This ratio will change significantly when considering the planned development of existing infrastructure. Due to the complexity of the construction and the immediate benefits after the construction of a separate section, the BTS A track section becomes a priority.

This is the basic stage of the construction of the railway infrastructure to the M. R. Štefánik Airport. The BTS D track section will receive significant justification after the construction of the line on the Austrian side between Wien Flughafen and Bruck a.d. Leith. At present, the BTS A section does not outperform its benefits, mainly due to construction technology and the need to introduce new passenger trains.

At present, the Wien hbf and Wien Flughafen railway stations cannot be operated directly, as is the case with the BTS A, with dead ends causing time losses. Therefore, section BTS D is considered to be the first development stage of the basic scheme of railway infrastructure in the vicinity of M. R. Štefánik Airport. Along with this section, a BTS C track section is also planned below ground level, which should be built at the same time as BTS D track section. Especially under the condition of building the second track of the inter-station section called ŽSR 127G. The considered section BTS B is semantically connected with the section BTS B. It is justified within the stages of development only in the final phase. The final phase will complete a total of 11.7 kilometres of new lines connected to the ŽSR network within the Bratislava transport hub.

Based on the analysis of the possibilities of connecting the M.R. Štefánik Airport to the ŽSR railway network, it is necessary to build an underground railway station in the parking area below ground level in the initial phase of construction. It will become part of the terminal of integrated passenger transport. It will be connected in the first stage to the ŽSR network and will be the construction of a single-track section. This section will have a total length of 3,342 kilometres and will be electrified by an alternating supply voltage system of 25 kV, 50 Hz, including the said railway station. This section will have a track speed of up to 160 kph and will be routed from the terminal of integrated passenger transport of the M. R. Štefánik Airport via the left bend. The left bend will have a radius of 1200 metres and an elevation of 126 millimetres of rails into a straight section with a length of 715 metres. This straight section is followed by a second, again left, bend with a maximum track speed reduced to 100 kph, a radius of 810 metres and an elevation of 88 millimetres. It opens into the track section called ŽSR 120A at kilometres 62,797 and in the perimeter of the Bratislava - Vajnory railway station.

Table 5. Critical factors of prioritizing the planned sections of the connection of the terminal of integrated passenger transport of the M. R. Štefánik Airport (Source: authors)

Evaluation of a section for a specific factor	1	2	3	4	5	Scale	BTS A	BTS B	BTS C	BTS D
1. Attractiveness of the track section of the connection of the terminal of integrated passenger transport of the M. R. Štefánik Airport within the passenger transport							**352**	**250**	**329**	**331**
The current overall potential for the use of the track section	B			A C D		10	40	10	40	40
Prospective total potential for the use of the track section			A C	B D		8	24	32	24	32
The potential for connecting M. R. Štefánik Airport and other airports	B				A C D	8	40	8	40	40
Potential use of the track section separately	B			C	A D	7	35	7	28	35
Potential use ofthe track sections in combination				A D	B C	5	20	25	25	20
2. Technical condition of the connected infrastructure during the design of the airport connection route										
Current overall condition (electrification, etc.)			A	B C D		5	15	20	20	20
Impact of ongoing projects	B D				A C	2	10	2	10	2
Planned overall condition (electrification, etc.)		B	C D	A		5	20	10	15	15
Current capacity of the track sections	C	A B D				8	16	16	8	16
Planned capacity of the track sections			D	A B C		5	20	20	20	15
Current technical speed			C D	A B		7	28	28	21	21
Planned technical speed				C	A B D	4	20	20	16	20
3. Construction of the track sections connecting the terminal of the integrated passenger transport of the M. R. Štefánik Airport										
Technological complexity of construction	C D			B	A	7	35	28	7	7
Occupancy of agricultural land		A B		D	C	7	14	14	35	28
Permanent impact of the section on the surroundings		B	A	D C		5	15	10	20	20

Acknowledgment

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DESIGN OF THE POWER OF AN ELECTRIC LIFTING MOTOR FOR A SINGLE GIRDER BRIDGE CRANE WITH A 500 KG LOAD CAPACITY

Abstract. An electric hoist could be considered as the most important component of an electric overhead crane. Electric hoists are material handling equipment used for lifting, lowering, and transporting materials and products. They are powered by an electric motor and have a controller to adjust the lifting parameters. Three-phase induction motors are most often used as electric lifting motors for bridge cranes. This paper concerns the design of the power of the electric lifting motor for an electric hoist of the single girder bridge crane with the 500 kg load capacity. It represents the design of the electric lifting motor according to a commonly used scheme for the design of electric motors, from the power at a uniform load to the relative load of the motor. Based on the input data, the necessary motor parameters are calculated using Microsoft Excel. The main parameter is the static power of the motor, the calculated value of which is 0.823 kW. Based on the value of this power, a three-phase induction motor 1.1 kW, MS90-4 is selected. This electric lifting motor is suitable for the above-mentioned bridge crane, as it meets the condition of torque overload.
Keywords: Induction motor, electric hoist, motor power, bridge crane, lift, torque

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Introduction

The hoist can be considered as one of the most essential components of the bridge crane system, because it ensures the lifting and lowering of the load. The lifting mechanism (Fig.1) of the crane lifts and lowers the load by means of a drum or a lifting wheel in which a chain or a wire rope is wound. Electric hoists can be designed to use chain or wire rope and use an electric motor to turn gears located inside the hoist that lift or lower the load. Electric hoists are controlled by pushbutton pendant or radio controls. Electric hoists are typically hard-wired into the crane's electrification system (Close, 2017).

The motor in the lifting process is constantly in different states, such as a power-up, outage, start, brake and reverse state in order to meet the operating characteristics of the crane. The motor is variously exposed to the load at all stages. In view of these facts, an overload capacity of the lifting motor must be strong and sufficient to withstand greater overload and mechanical shock (Dongqui, 2017). Most electric hoists are designed to withstand hazardous and high-temperature environments. Electric hoists have faster operation than other types of hoists. Electric wire rope hoists, like electric chain hoists, are equipped with a hoist motor with an integrated braking system. They also utilize a series of gears inside a gearbox that amplify the transmitted torque from the motor. The concentrated force from the gearbox is transmitted to a spline shaft. The spline shaft then rotates the winding drum. As the wire rope is pulled to vertically displace the load, it is wound around the winding drum (Industrial, 2021).

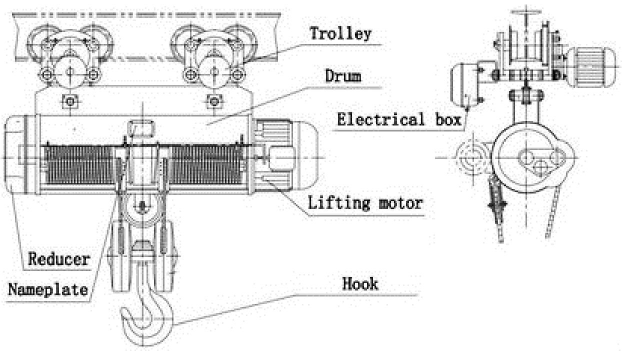

Fig. 1. Components of an electric hoisting mechanism (Nucleon, 2021)

The hoist drive on a crane is hard to implement because it must operate smoothly over a wide range of speeds to lift up or lower the hook at controlled speeds regardless of the load. The motoring torque with a relatively flat speed/torque characteristic must be provided by the drive during the lifting process to prevent excessive speed change from heavy-load to light-hook conditions. In practice, induction motors are most often used to drive electric hoists. The lifting (induction) motor is equipped with an electromagnetic brake, which plays an important role in lowering the load (Crowders, 1980).

1. Induction motor

The induction or asynchronous motor is a type of AC motor, which have two basic parts stator and rotor. The stator is a stationary part whereas the rotor is the rotating part. The winding placed on the stator acts as the primary winding and rotor as the secondary winding (Wat Electrical, 2019). The supply of energy to the rotor is ensured by electromagnetic induction from the rotating magnetic field of the stator winding (Diyoke, 2016). The advantages of asynchronous motors are good operating characteristics, a wide power range of feasibility and a simple design that increases their operational reliability (Voženílek, 2011). The rotor of the induction motor can be in the form of a squirrel cage rotor or wound type rotor. Almost 90 % of induction motors are equipped with squirrel cage rotor. The construction of these motors is robust and simple. The squirrel cage rotor comprises of cylindrical laminated core with evenly spaced bars along the periphery, whereby these bars are placed into semi-closed circular slots. Bars are made of aluminium and copper. These bars are connected at ends mechanically and electrically by the use of end rings. The rotor is mounted on the shaft using bearings on both ends (Fig.2). Skewed slots ensure smooth and ample torque, increase resistance of rotor since the length of the rotor bar conductors is increased (Alkhadim, 2020, Mansour, 2020).

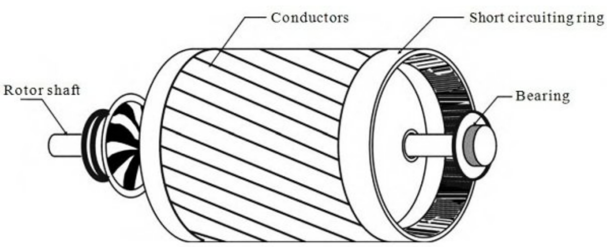

Fig. 2. Squirrel cage rotor components (Theengineeringprojects, 2021)

Squirrel cage type is more common compared to the wound rotor type due to:

- Robust, as no brushes, no contacts on the rotor shaft.
- Simple in construction and easy to manufacture.
- Almost maintenance-free, except for bearing and other mechanical parts.
- High efficiency as rotor has very low resistance and thus low copper loss (Alkhadim, 2020).

The wound rotor (Fig.3) has a set of windings on the rotor slots which are not short circuited, but they are terminated to a set of slip rings. These are helpful in adding external resistors and contactors. The rotor is also skewed as in squirrel cage rotor. The number of poles on which the rotor is wound is the same as in the case of the stator. There are several semi-closed slots on the outer periphery of rotor. The winding of rotor is connected in a star form (Alkhadim, 2020, Mansour, 2020).

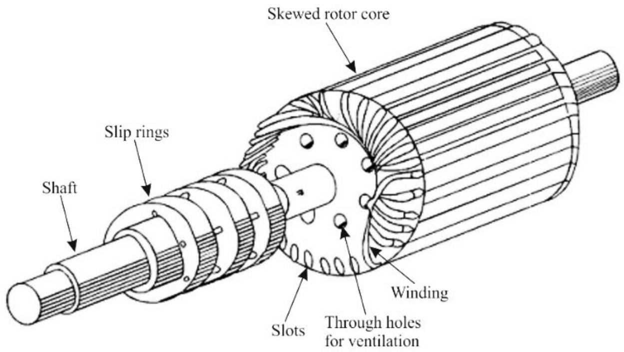

Fig. 3. Wound rotor components (EEEGUIDE, 2021)

Induction motors are produced in two versions, like as single-phase or three-phase. The single-phase induction motors are usually constructed in small sizes (Mansour, 2020). The three-phase induction motor with electromagnetic brake is commonly used for electric hoist.

The working principle of three-phase induction motor is based on electromagnetic induction. The stator of the motor consists of overlapping winding offset by an electrical angle of 120°. When the primary winding or the stator is connected to a three phase AC source, the rotating magnetic field which rotates at the synchronous speed is created. The mutual force action between the rotating field and the rotor currents creates a moment which, according to Lenz's law, acts against the cause of its origin, i.e. against the mutual movement of the stator field and the conductors in the rotor. As the speed of the rotor increases, its relative speed with respect to the rotating field decreases and thus the frequency of the rotor current also decreases. As a result of the generated torque, the rotor starts to accelerate in the same direction as the stator field rotates. Thus, from the working principle of three phase induction motor, it may be observed that the rotor speed should not reach the synchronous speed produced by the stator (Electrical4you, 2020, Uhlíř 2002, Voželínek 2011).

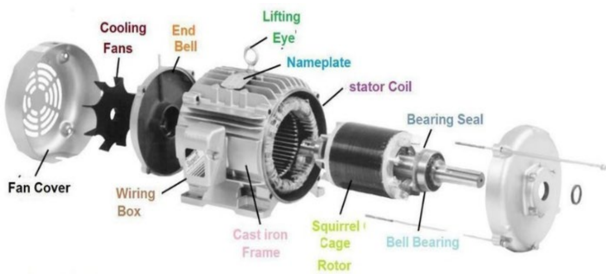

Fig. 4. Components of the Squirrel cage induction motor (Alkhadim, 2020)

2. Design of the lifting motor power

The lifting motor is an essential part of the electric overhead crane. The three-phase AC asynchronous motor (hereinafter referred as motor) is usually used as lifting motor. One of the fundamental parts of designing process of the lifting motor is to design a suitable motor power with regard to the maximum capacity of the overhead crane. Therefore, the design of the lifting motor power for a single-girder bridge crane with the load capacity of 500 kg will be performed. The design of the electric motor power generally proceeds according to the scheme in Fig. 4.

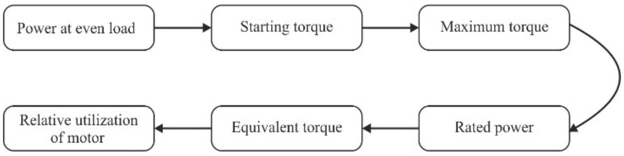

Fig. 5. A scheme of the design of the electric motors

The operation of the lifting motor is considered to be irregular, because the motor is forced to work with different loads, which vary depending on the weight of the load. The operation of the motor can be divided into phases, when the motor accelerates, when it lifts or lowers the load at a constant speed and when it decelerates or brakes. The required power of the electric motor at constant lifting can be determined according to (1):

$$P_s = \frac{v_l \cdot \sum m_i \cdot g}{\eta_t \cdot 1000} \tag{1}$$

where:
P_s – motor power [kW]
v_l – lifting speed [m·s^{-1}]
g – gravitational acceleration [m·s^{-2}]
η_t – total efficiency [-]

There is the sum of the weights of the lifted parts $\sum m_i$ in equation (1). This part of the equation represents the sum of the weights of the load and all the equipment that will be lifted together with the load. It is the sum of the weights of the rope, hook, spreader bars, grabber, and other means of fastening (2).

$$\sum_{i=1}^{n} m_i = Q + m_r + m_h + \ldots + m_n \tag{2}$$

The total mechanical efficiency η_t can be determined as the product of the efficiency of the pulley η_p and the efficiency of the gears η_i (3):

$$\eta_t = \eta_p \cdot \eta_i \tag{3}$$

The mechanical efficiency of the hoist η_h can be determined for n_p pulleys as (4):

$$\eta_h = \eta_1 \cdot \frac{\left(1-\eta_1^{n_p}\right)}{n_p \cdot \left(1-\eta_1\right)} \tag{4}$$

Efficiency of plain bearing is $\eta_p = 0.96$ and efficiency of rolling bearing is $\eta_r = 0.98$. The efficiency of transmissions of electric motor is determined as the product of the efficiencies of the individual transmission elements. The transmission elements include gears that correct the rpm of the electric motor to the rpm required to achieve the specified lifting speed. The lifting speed v_l is one of the variable parameters, the choice of which directly affects the required power of the lifting motor. Also, the lifting speed can be selected according to the lifting height (Kuľka, 2017). The torque of motor is usually specified by the manufacturer but can also be determined from equation (5).

$$M_{\eta} = \frac{P_{\eta} \cdot 1000}{2 \cdot \pi \cdot n_l} \tag{5}$$

where:
M_{η} – rated motor torque [N·m]
P_{η} – rated motor power [kW]
n_l – rpm of the lifting motor [s^{-1}]

2.1. Starting torque of the lifting motor

The motor must be checked for torque overload at lifting speeds greater than 0.08 m.s^{-1}. The check is based on the moment required to start the motor at the lifting speed in time t_a. The starting torque M_{start_l} is determined from (6):

$$M_{start_l} = M_{st_l} + M_{at_l} + M_{ar_l} \tag{6}$$

The static moment of the load M_{st_l} is determined according to the equation (7):

$$M_{st_l} = \frac{D_d \cdot \sum m_i \cdot g}{2 \cdot i_h \cdot \eta_t \cdot i_l} \tag{7}$$

where:
D_d – diameter of the drum [m]
$\sum m_i$ – sum of the weights of the lifted parts [kg]
g – gravitational acceleration [m·s^{-2}]
i_h – gear ratio of the hoist [-]
η_t – total efficiency [-]
i_l – transmission ratio between the motor and the lift [-]

The gear ratio of the hoist i_h is determined according to the number of pulleys n_p and the arrangement of the hoist. The transmission ratio between the motor and the lift i_l is determined from the ratio of motor rpm n_l and drum rpm n_d (10):

$$i_l = \frac{n_l}{n_d} \tag{8}$$

$$n_d = \frac{v_l}{\pi \cdot D_d} \tag{9}$$

$$i_l = \frac{n_l \cdot \pi \cdot D_d}{v_l} \tag{10}$$

The moment of accelerating forces with the translating effect M_{at_l} is determined as (11):

$$M_{at_l} = M_{st_l} \cdot \frac{a_l}{g} \tag{11}$$

According to STN 27 0601, the acceleration of lift must be in the interval $a_l \in \langle 0.2 - 0.3 \rangle$ m·s^{-2}. The moment of accelerating forces with the rotating effect M_{ar_l} is determined by the equation (12):

$$M_{ar_l} = \alpha \cdot I_m \cdot \frac{2 \cdot \pi \cdot n_l}{t_{a_l}} \tag{12}$$

where:

α – coefficient from rotating parts [-]

I_m – moment of inertia [kg·m^2]

n_l – rpm of the lifting motor [s^{-1}]

t_{a_l} – starting-up time [s]

The motion of the hoist´s lift is considered to be uniformly accelerated or uniform motion. The starting-up time can therefore be determined as (13):

$$t_{a_l} = \frac{v_l}{a_l} \tag{13}$$

The coefficient α_l takes into account the influence of the rotating parts of the motor except the rotor and is considered:

- α_l = 1.2 [-] for devices with one brake disc,
- α_l = 1.4 [-] for devices with two brake disc.

The moment of inertia I_m is given in the motor tables. Sometimes it is stated in the form of the so-called GD - quadrate, according to which the moment of inertia can be determined (14).

$$I_m = \frac{G \cdot D_l^2}{4} \tag{14}$$

The resulting starting torque can then be expressed in summary by substituting the individual moments into equation (6) and thus equation (15) is obtained (Kuľka, 2017):

$$M_{start_l} = \frac{D_d \cdot \sum m_i \cdot g}{2 \cdot i_h \cdot \eta_t \cdot i_l} \cdot \left(1 + \frac{v_l}{g \cdot t_{a_l}}\right) + \\ + \frac{\alpha_1 \cdot G \cdot D_l^2 \cdot \pi \cdot n_l}{2 \cdot t_{a_l}} \tag{15}$$

2.2. Torque overload capacity

The asynchronous motor can be overloaded, and it can produce 1.8 - 3.2 times more torque in the short term than the torque resulting from the nominal power of the motor. Thanks to this feature, the motor with less rated power than the maximum required power can be selected. The manufacturer states in the tables the coefficient of torque overload, which indicates how many times the motor can be overloaded. The torque overload is given by the ratio (16):

$$\xi = \frac{M_{\max}}{M_n} \tag{16}$$

The torque M_{max} is considered as the maximum possible torque that a motor with rated overload ξ can generate. Each torque required in operation must therefore be less than M_{max}. The coefficient ξ is determined according to the load factor ε:

- ε = 25 % then ξ = 2.1 [-]
- ε = 40 % then ξ = 2.5 [-]
- ε = 60 % then ξ = 2.9 [-]

The rated motor torque M_n must satisfy condition (17).

$$M_n \geq \frac{2 \cdot M_{start}}{\xi + 1.1} \tag{17}$$

If the selected motor does not meet the condition (17), a more powerful motor according to the manufacturer's catalogue must be selected (Kuľka, 2017).

2.3 Determination of the equivalent torque

The load on the motor causes it to warm up depending on the amount of torque required. Thus, the equivalent torque represents such torque whose constant action on the motor during one working cycle produces the same thermal effects as the real moments acting during one working cycle. If the crane operates in an irregular operating mode, the calculation of the equivalent torque is based on one operating cycle at full load. In general, the equivalent torque M_e is determined by the equation (18):

$$M_e = \sqrt{\left(\frac{\sum_{i=1}^{n} M_i^2 \cdot t_i}{T}\right)} \tag{18}$$

where:

M_i – torque of an individual phase [N·m]

t_i – duration of the phase [s]

T – period of duty cycle [s]

The duty cycle of the bridge crane lift can be divided into 3 phases. The first is the start of the lift, when the starting torque acts for the time t_{a_l}. The second phase is uniform lifting, where the load is lifted at a constant speed and the motor exerts a constant torque. The last phase is braking (Kuľka, 2017). The duty cycle is shown in Fig. 6.

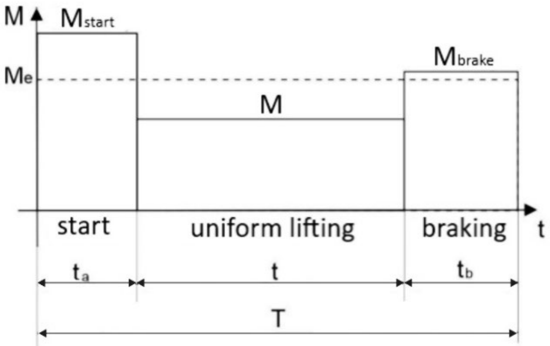

Fig. 6. A duty cycle of crane

Based on the equation (18), the equivalent torque for such a duty cycle is determined by equation (19):

$$M_{e_l} = \sqrt{\frac{M_{start_l}^2 \cdot t_{a_l} + M_{st_l} \cdot t_{st_l} + M_{brake_l}^2 \cdot t_{b_l}}{t_{a_l} + t_{st_l} + t_{b_l}}} \tag{19}$$

2.4. Relative utilization of the lifting motor

In operation, cranes usually lift loads of various weights. This means that the lifting motor is forced to work with a variable load. Therefore, it is necessary to determine the relative motor utilization μ_l. This indicates the ratio between the required motor torque at full load M_{full} when lifting a load with the maximum permissible weight and the torque at part load $M_{partial}$ (20).

$$\mu_l = \frac{M_{full} + M_{partial}}{2 \cdot M_{partial}} \tag{20}$$

For bridge crane lifting motors μ_z = 0.40 - 0.75 (-) is applied. Coefficient ν is determined according to coefficient μ using Tab. 1.

Table 1. Values of relative utilization depending on type of a mechanism

Mechanism		μ [-]
Lifting	Cranes with hook	0.40-0.70
Travel	Crane cats (hoists)	0.65-0.75
	Travel of crane bridge	0.75-0.90

Relative utilization μ [-]	0.55	0.6	0.7	0.8	0.9	1.0
Coefficient ν [-]	0.74	0.74	0.76	0.83	0.91	1.0

2.5. Braking of the motor lift

When designing the lifting device, it is also necessary to design the amount of torque that the brake (usually electromagnetic) will overcome. The brake overcomes during braking the same torques as the motor during lifting process, according to equation (15). However, the real braking torque M_{brake_l} must be increased by the braking coefficient k_b (21).

$$M_{brake_l} = k_b \cdot \frac{D_d \cdot \sum m_i \cdot g}{2 \cdot i_h \cdot \eta_t \cdot i_l} \cdot \left(1 + \frac{v_l}{g \cdot t_{a_l}}\right) + \frac{\alpha_1 \cdot G \cdot D_l^2 \cdot \pi \cdot n_l}{2 \cdot t_{a_l}} \tag{21}$$

The coefficient k_b is chosen according to the lifting class of the crane according to Tab. 2 (Kuľka, 2017).

Table 2. Value of the braking coefficient for individual lifting classes

Lifting class	Braking coefficient [-]
A	k_b = 1.5
B	k_b = 1.75
C	k_b = 2.0

3. Calculation of a bridge crane lifting motor

The calculation and subsequent selection of the lifting motor is performed for the single girder bridge crane with a load capacity of 500 kg. This calculation is processed in Microsoft Excel according to the above procedure using the above equations and conditions. The input data listed in Tab. 3. are important for the correct calculation of the lifting motor.

Table 3. Input parameters for calculation of the crane lifting motor

Input data	Notation	Value	Unit
Load capacity	Q	500	kg
Lifting speed	v_l	5	$m \cdot min^{-1}$
Lifting speed	v_l	0.083	$m \cdot s^{-1}$
Lifting acceleration	a_l	0.3	$m \cdot s^{-2}$
Acceleration time	t_{al}	0.278	s
Number of pulleys	n_p	1	[-]
Gear ratio of hoist	i_h	1	[-]
Efficiency of one pulley	η_l	0.96	[-]
Efficiency of gears	η_i	0.9	[-]
Gravitational acceleration	g	9.80665	$m \cdot s^{-2}$
Crane class	H_i	1	[-]
Diameter of rope drum	D_d	0.08	m

It is necessary to determine the values of individual coefficients for the calculation. These values are given in Tab 4.

Table 4. Used factors and coefficients in calculation

Factors and coefficients	Notation	Value	Unit
Coefficient of rotating parts	α_l	1.2	[-]
Load factor from the load weight	γ_{lo}	1.3	[-]
Load factor from the self-weight	γ_g	1.1	[-]
Dynamic lifting factor	δ_h	1.217	[-]

Based on the input data, the necessary parameters are calculated, and these are listed in Tab. 5.

Table 5. Calculated parameters

Parameter	Notation	Value	Unit
Lifting weight	m_i	870.155	kg
Efficiency of hoist	η_h	0.96	[-]
Total efficiency	η_t	0.864	[-]
Static motor power	P_s	0.823	kW

Based on the calculated parameters, a three-phase induction motor 1.1 kW, MS90-4 is selected as the suitable motor. The motor parameters are listed in Tab. 6.

Table 6. Parameters of the selected lifting motor

Three-phase induction motor 1.1 kW, MS90-4			
Parameter	Notation	Value	Unit
Static motor power	P_s	0.82	kW
Rated power	P_r	1.10	N.m
GD – quadrate	GD^2	0.0015	kg.m
Rpm of motor	n_l	1 390	min^{-1}
Moment of inertia	I_m	0.00037	$kg.m^2$
Rated torque	M_r	7.56	N.m
Coefficient of rated overload	ξ	2.10	[-]

Subsequently, it is necessary to check the motor for torque overload by determining the starting torque according to equation (15) and to check if the motor meets the condition of torque overload (17). The results are listed in Tab. 7.

Table 7. Calculated torques of motor

Parameter	Notation	Value	Unit
Static torque	M_{stl}	5.654	N·m
Moment of sliding parts	M_{atl}	0.173	N·m
Moment of rotating parts	M_{arl}	0.0581	N·m
Starting torque	M_{startl}	5.885	N·m

After substituting the values into condition (17), it can be stated that the three-phase induction motor 1.1 kW, MS90-4 (Fig. 7) meets the condition of torque overload for the specified parameters. Thus, it is suitable for use as the lifting motor for the single-girder bridge crane with the load capacity of 500 kg.

$$7.56 \geq \frac{2 \cdot 5.885}{2.1 + 1.1} \qquad (22)$$

$$7.56\ N \cdot m \geq 3.678\ N \cdot m$$

Fig. 7. A three-phase induction motor 1.1 kW, MS90-4 (Vyboelectric 2021)

Conclusion

One of the aims of this paper was to approach the use of induction motors to drive crane lifting mechanisms, such as bridge crane electric hoists. The three-phase asynchronous motor with electromagnetic brake is the most commonly used lifting motor for electric hoists. The main goal was to design the lifting motor, its power, for the single-girder bridge crane with the 500 kg load capacity. Based on the input data, the motor parameters were calculated using the Microsoft Excel program. The most important parameter for choosing the lifting motor was the static power of the motor. The value of the static motor power was 0.823 KW. Based on this power value, the three-phase induction motor 1.1 kW, MS90-4 was selected. Finally, it was necessary to check this lifting motor for torque overload. Since the rated motor torque of 7.56 N·m is greater than the calculated starting torque of 5.885 N·m i.e., the torque overload condition is met, it can be concluded that the selected three-phase induction motor is suitable for use as the lifting motor for the above-mentioned bridge crane.

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NEW RAILWAY TUNNELS AND THEIR CONSTRUCTION METHOD AS WELL AS THEIR IMPACT TO TRAIN OPERATION

Abstract. As the modernisation of the cities, railway road construction and modernisation of existing lines are demanded during the past decades more than before. Demand of short travel time is one the reasons that we redesign of existed railway roads and modernisation process. Tunnel construction is one the ways that we can shorten travel time in the existing railway roads. In this study, we introduced one of the commonly used tunnel construction methods, New Austrian Tunnelling Method (NATM), and some of important points of that method regarding tunnel excavation and bearing capacity of excavation support system. Furthermore, we gave some information about some tunnels which shortens the travel time and some tunnel project examples which are constructed with this method. The main purpose of construction of all these tunnels are to shorten the travel time of the existing railway line due to increasing on population and urbanization.
Keywords: railways, tunnels, NATM, operation

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Introduction

Number of railway road construction has been increasing during the past decades with the demand of short travel time as a result of increasing on population and urbanization. One of the ways for providing shorter travel time is changing route of the railway according to geographical and geotechnical conditions.

Due to some economical and technological reasons, routes of railways have been limited to construct before in easier geotechnical conditions such as implementing the route on the side of the mountains without any tunnel design, lack of proper tunneling machines etc.

In this study, we aimed to introduce one of the tunnel construction methods, New Austrian Tunneling Method (NATM) and give some constructed and under construction tunnel project examples from Czech Republic and Slovakia as examples of shortening travel time in railway operation.

1. NATM tunnel construction method

Construction of railway tunnels are one of the efficient ways to shorten travel time and reach out far distances due to enlargement of cities. One of the tunnel construction methods is called NATM and it was used in many tunnel construction projects around the world (Aygar&Gokceoglu 2020, Xu&Huang 2004). Rabcewicz is the principle inventor of NATM and he has been explained the method as an international recognition in 1964 (Rabcewicz 1964, Rabcewicz 1965, Rabcewicz&Golser 1973). Furthermore, it was developed by many scientists in the following years. Historical background of NATM, definitions and development of it according to different scientists and some teoretical and technical explanatios about it have been gathered together very well by Karakus (Karakus&Fowell 2004).

One of the important point in NATM type of tunnel construction is soil-structure interaction which is between disturbed area around tunnel excavation (protective zone) and bearing capacity of the excavation support system (skin resistance) (Rabcewicz 1964). Mathematical definition of this interaction was described by Fenner-Talobre and Kastner and can be seen in Rabcewicz (1964) as:

$$p_i = -c\cot\varphi + p_0\left[c\cot\varphi + (1-\sin\varphi)\right]\frac{r^{\frac{2\sin\varphi}{1-\sin\varphi}}}{R}$$

Neglecting the value of cohesion, the equation can be simplified as:

$$p_i = p_0\left[c\cot\varphi + (1-\sin\varphi)\right]\frac{r^{\frac{2\sin\varphi}{1-\sin\varphi}}}{R} = np_0$$

where;
p_i: skin resistance,
c:cohesion,
φ: angle of internal friction,
R: radius of the protective zone,
r: radius of cavity,
p_0: γH
H: overburden,

This relation can be seen schematically in Fig. 1 below.

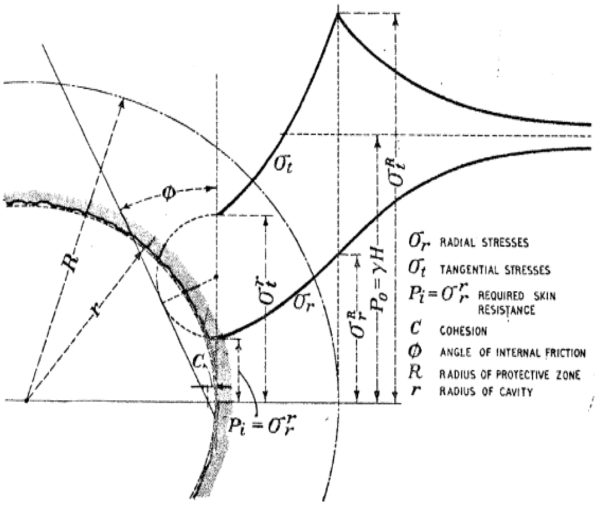

Fig. 1. Schematic representation of stresses around a circular cavity with hydrostatic pressure (quoted by Rabcewicz, 1964; after Kastner)

There is a relationship between skin resistance and deformation due to excavation shown in Fig. 2 (Rabcewicz, 1973). It can be seen that if a support system is applied in a short time period after the cavity opening, it will obviously prevent most of the deformation which will cause that the support system will carry a big amount of load. If the support system is applied in the right time of displacement, then it will carry the minimum amount of load (see Fig. 2).

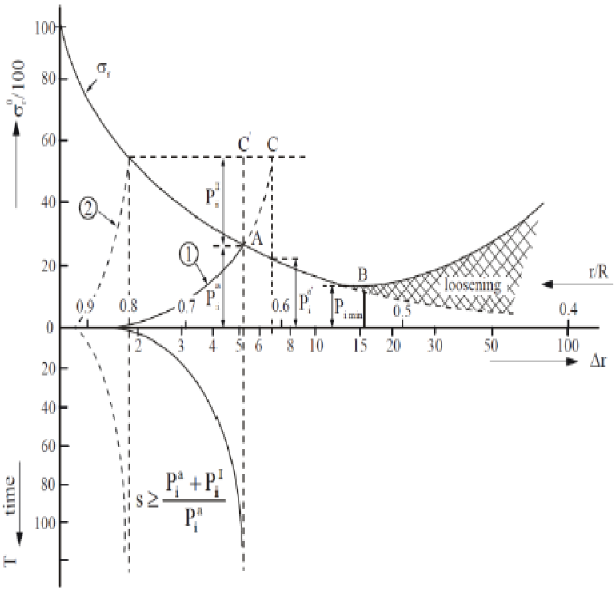

Fig. 2. Ground-support interaction curve (after Fenner & Pacher, quoted by Rabcewicz 1973)

2. New tunnel examples on existing railway lines

There are some railways which route have been changed with new tunnels in Czech Republic. One of them is tunnel Ejpovice which locates in railway line Rokycany - Pilsen as it can be seen in Fig. 3 below.

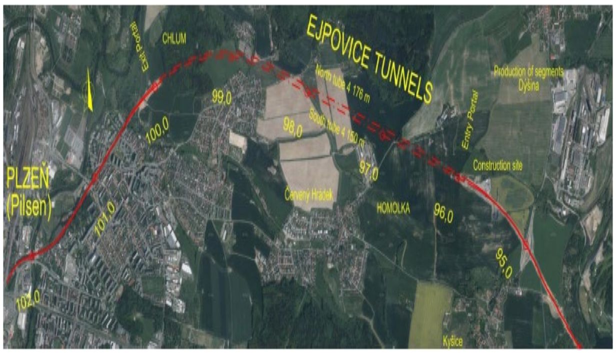

Fig. 3. Ejpovice tunnels (Marek M. et al.)

Due to the geological and geotechnical conditions, tunnels can be excavated in different soil types and in different geological soil profiles. NATM is a suitable method to apply tunnel construction in different soil types. In Fig. 4 it can be seen below that the profile of southern tunnel of Ejpovice tunnels has different soil types.

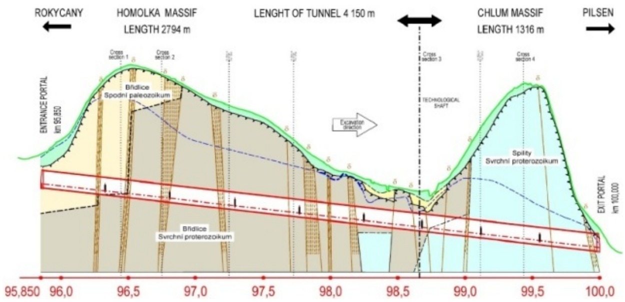

Fig. 4. Longitutional section of southern Ejpovice tunnel (Marek M. et al.)

Length of southern and northern tunnels are 4 176 m (4 134 m bored) and 4 150 m (4 110 m bored) respectively (Marek M. et al.). The planned speed limit is 160 km/h (Marek M. et al.), which is the maximum allowed speed limit in Czech Republic as indicated in Network Statements of Czech Republic 2022, and prospectively 200 km/h which was tested succesfully as indicated in annual report of Sprava Zeleznic, which is Railway Administration of Czech Republic, in 2020 and it is the current longest railway tunnel in the country (Annual report, Sprava Zeleznice, Czech Republic 2020).

There is also another tunnel which name is Turecký Vrch railway tunnel and it was constructed in Slovakia as a result of modernisation of main railways. A schematic representation of the tunnel can be seen in Fig. 5 below.

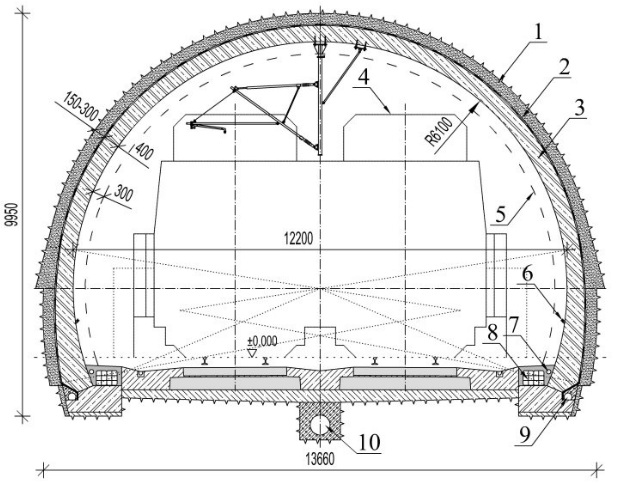

Fig. 5. Schematic representation of Turecký Vrch railway tunnel (Metroprojekt)

Total lenght of the tunnel is 1 775 m (1 740 m bored) with 35 m cut-and-cover sections and maximum overburden depth is 100 m. This tunnel was constructed with NATM which was mentioned above and for 160 km/h design speed. It is expected to use in 200 km/h design speed prospectively as in the Ejpovice tunnel (Metroprojekt). An enterance of Turecký Vrch tunnel can be seen in Fig. 6. It is a one tube tunnel with two railway lines inside.

Fig. 6. An enterance of Turecký Vrch railway tunnel (Metroprojekt)

Some other tunnels which are under construction in Slovakia are Milochov tunnel and tunnel Diel which have 1 082 m and 1 861 m length respectively (Annual Report, Zelenice Slovenskej Republiky, 2020). They are constructed also with NATM (Zelenice Slovenskej Republiky).

These tunnels were designed with the aim of modernisation of railway corridors in Europe. Each of them shortens the travel time with different durations on its railway.

3. Impact of new tunnels to train operation

General impact of new tunnels is connected to the reduction of riding time as well as travelling time from passengers' point of view. Ejpovice tunnel shorten the route length about 6 kilometres and the travelling time is about 11 minutes shorter than previous route. Ejpovice tunnel costs were about 280 million € therefore the shortening score is almost 25 millions € per 1 spared minute. Building of Ejpovice tunnel was a little bit controversial due to financing and delays as well as unpredictable technical and technology problems. There were not enough experiences with tunnels with this length and modern technology in the Czech Republic yet.

Tunnel Turecký Vrch in Slovakia was built as a part of modern corridor main railway line from Bratislava to Žilina but its impact to travelling time is very limited. It was built mostly due to environmental reasons such as noise and animal corridors near this area. On the same railway line, there is a new tunnel Diel near Púchov, which has very positive impact to travelling time. System of these tunnels on mentioned railway line enables to use the maximum speed of 160 kph in the whole section, what significantly shorten the whole travel from Bratislava to Žilina and vice versa.

Conclusions

1. One of the tunnel construction methods is NATM and it has some important points due to tunnel excavation and bearing capacity of excavation support system.
2. There are some tunnels which are still under construction and already constructed by NATM as a result of modernisation of existing railway roads to shorten the travel time.
3. New tunnels were built and some are already in construction in the Czech Republic as well as Slovakia. These tunnels have various direct impact to train operation such as reduction of riding time and travelling time.
4. New tunnels have also indirect positive impacts, mostly to environment, for example reduction of noise or animal corrdiors without any barriers.
5. Particular impacts of new tunnels to train operation as well as their construction method are mentioned in the text above.

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DRIVING DURATION DIFFERENCE IN ROAD FREIGHT TRANSPORT BETWEEN VEHICLES UP TO AND OVER 3.5 TONNES

Abstract. Working conditions for drivers in the European Union and Slovakia are governed by European and National regulations. Regulations lay down rules on driving times, breaks and rest periods for drivers of lorries and buses to improve working conditions and road safety. There is no doubt that with increasing freight performance, the number of carriers and vehicles in the field of road freight transport is also increasing. Therefore, in connection with the current EU legislation, which aims to increase road safety, attention is paid to adopting regulations for all road haulage operators and carriers. The purpose of this paper is to show difference between road freight transport performed by vehicles up to 3,5 tonnes and vehicles transporting goods where the maximum permissible mass of the vehicle, including any trailer, or semi-trailer, exceeds 3,5 tonnes.
Keywords: road freight transport, social legislation, driving time, road safety

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Introduction

Under European Union legislation, the working regimes of road haulage drivers are geared to the conditions for road haulage operators with vehicles over 3.5 tonnes gross vehicle weight. The conditions are further subdivided into national and international services, which are set out in Regulation no. 561/2006 and Regulation no. 165/2014. In the Slovak Republic, the work of road freight transport drivers is regulated by Act no. 462/2007 on the organization of working time in transport and Decree 208/1991 on occupational safety and technical equipment in the operation, maintenance and repair of vehicles.

The work of drivers on vehicles up to 3.5 tonnes is currently not regulated and controlled in the Slovak Republic and most EU countries in a similar way as for drivers and trucks over 3.5 tonnes. Regulation (EC) No 561/2006 of 15 March 2006 on the harmonization of certain social legislation relating to freight road transport. This Regulation lays down rules on driving times, breaks and rest periods for drivers engaged in road haulage and passenger transport, with a view to harmonizing the conditions of competition between inland transport modes, in particular with regard to the road transport sector, improving working conditions and road safety. This Regulation also aims to promote better monitoring and enforcement by Member States and improved working practices in the road transport sector. This Regulation applies to road transport and an amendment to the Regulation was adopted on 20 August 2020, which modifies Article 2 on the vehicles covered by this Regulation. The adopted amendment to the Regulation will apply from 1 July 2026 to all vehicles involved in the carriage of goods in international or cabotage transport operations, where the maximum permissible weight of the vehicle, including each trailer or semi-trailer, is more than 2.5 tonnes (Regulation 561/2006, 2021).

In the following section, the differences in road freight transport realized by trucks over 3.5 tons, and by vehicles up to 3.5 tons will be presented in more detail. One part of the work presents the theoretical time difference between drivers on vehicles up to and over 3.5 tons. In the next part, the actual transport performed by a real company operating in road freight transport with vehicles up to 3.5 tons is analyzed in detail and is compared with the same transport designed using the Map and Guide program. This work also describes in more detail the traffic accident rate of vehicles engaged in road freight transport and analysis of the development of transport performance in freight transport and the development of the number of registrations.

1. Traffic accidents road freight transport

To begin with, the very concept of a traffic accident is needed. This is an unpredictable event that arose during operations and resulted in damage to life, health or property (Chmelík, 2009). The relationship between an adverse consequence and an event in operation is a necessary conceptual feature. Another necessary condition for us to be aware of the accident that the incident occurred during the operation. We can operate as a traffic and transportation and movement. From the point of view of unpredictability, it is possible at the same time about an event with an element of irresponsibility, negligence, indifference, about events unpredictable, unexpected, it also contains an element of surprise. A traffic accident is characterized by an accident and an accident. The action of the participant in the traffic accident creates an accident procedure and the manifestation of the traffic accident is an accident event. In this case, we are talking about a collision, an accident, an impact. From the above, it is relevant that the causal link between the accident and the accident (Konečný, 2011).

Figure 1 shows an overview of fatal accidents in EU countries caused by trucks up to 3.5 tonnes. The data recorded and evaluated in Figure 1 represent the period from 2000 to 2018. If an individual country did not have data available for at least a ten-year period, it was excluded from these statistics. The countries that have been excluded are Malta, Estonia, Bulgaria and Luxembourg. The following countries did not publish complete data for all years, but had data for at least 10 years, so they are included in this analysis: Croatia, Italy, Cyprus, Lithuania, Hungary, and Slovakia. Other countries, more than 80% of the countries included in these statistics, provide complete data for all following years.

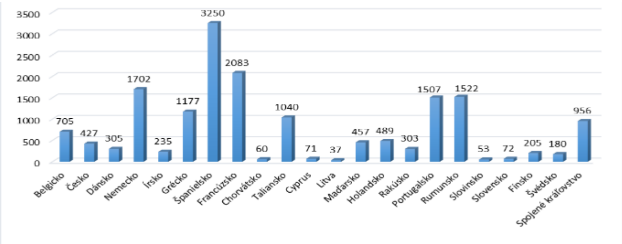

Fig. 1. An overview of fatal accidents in the EU between 2000 and 2018 (Source: author)

Figure 2 shows a comparison of the total number of traffic accidents in 2019 and 2020 in the Slovak Republic caused by vehicles of categories N1, N1G with a total weight of up to 3,500 kg, N2, N2G with a total weight of up to 12,000 kg and N3, N3G with a total weight of over 12,000 kg. During the years 2019 and 2020, 25,616 traffic accidents occurred on Slovak roads. Of these traffic accidents, 9,402 resulted in death and health, with 469 people killed. The most common cause of all traffic accidents was a violation of the driver's duty, of which failure to fully drive the vehicle and failure to monitor the situation in road traffic was the most common reason. The other most common reasons were not giving way to a pedestrian who entered the road and crossing a pedestrian crossing and driving if the driver's ability to drive is reduced, in particular by accident, illness, nausea or fatigue.

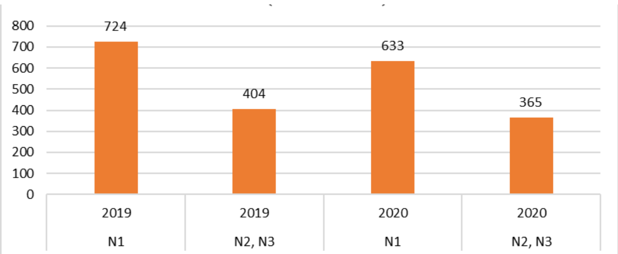

Fig. 2. Number of truck accidents in 2019 - 2020 (Source: author)

2. Analysis of the current state of legislation in freight road transport

In all countries, transport is subject to regulations, which are fully addressed by current legislation. It is a set of measures regulating traffic regulations and the work regime of drivers. The technical base of the carrier is also regulated by law, vehicles, and their technical parameters. It is also important to consider the differences between the legislation of the countries directly affected by the transport aspect in terms of the driver's work in national and international transport. It is necessary to distinguish when this transport is affected by the AETR Agreement, a European Union Regulation, or a national regulation. The driver of a transport company from the Slovak Republic must comply with the provisions of:

1. EU Regulations (Regulation (EC) No 561/2006 of the European Parliament and of the Council; Council Regulation (EHS) No 3821/85) which apply to carriage performed exclusively within the Community or between the Community, Switzerland and countries which: are Contracting Parties to the Agreement on the European Economic Area. This means that EU regulations apply to all shipments whose starting or ending destination are in a Member State of the European Union, Switzerland, Norway, Liechtenstein, and Iceland. In the Slovak Republic, the regulations also apply to domestic road freight transport.
2. The European Agreement concerning the Work of Crews of Vehicles engaged in International Road Transport (AETR Agreement) shall apply to carriage performed by vehicles registered in any Member State or to any country party to the AETR Agreement for the entire section of the journey when such carriage takes place between the Community and third countries (with the exception of Switzerland, Norway, Liechtenstein, and Iceland) or when the journey takes place through these countries. That is, the provisions of this Agreement shall apply to shipments to third countries which are Contracting Parties to the AETR Agreement: Albania, Andorra, Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Montenegro, Kazakhstan, Macedonia, Moldova, Russian Federation, Serbia, Turkey and Turkmenistan, Ukraine, and Uzbekistan.
3. Act no. 462/2007 on the organization of working time in transport - is valid in relation to Slovak drivers, respectively provides for sanctions for breaches of social legislation. In some provisions, it complements the EU Regulations and lays down the working rules for bus services on bus routes up to 50 km.
4. Decree of the Slovak Office for Occupational Safety and the Slovak Mining Office no. 208/1991 on safety of work and technical equipment in the operation, maintenance and repair of vehicles - sets the working regime of drivers in the operation of company vehicles, which are not covered by other legislation. (For example, vehicles up to 3.5 t gross weight) (Poliak and Gnap, 2015).

3. Theoretical comparison of transport by vehicles up to and over 3.5 tons

In this part of the work, we describe in more detail the individual transports carried out by vehicle up to 3.5 tons, as well as the planned transports by vehicle over 3.5 tons using the Map and Guide program. Based on freely available data and using Google maps, we planned a trip for a vehicle up to 3.5 tons performing road freight transport. Using the Vietor internet browser, we received a non-binding offer for the transport of goods by vehicle up to 3.5 tons from Liptovský Ján to Madrid, Spain.

Approximate delivery time was calculated at 35 hours, see Figure 3.

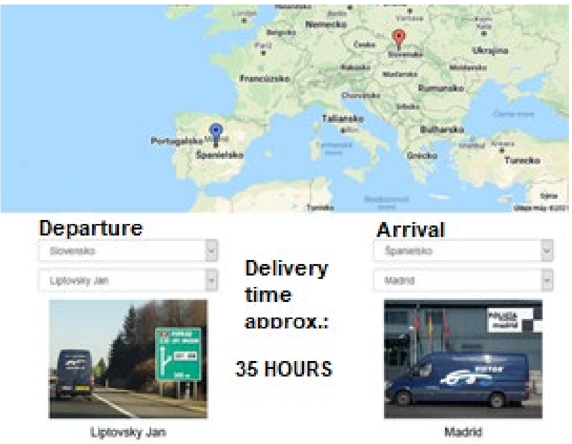

Fig. 3. Transport by vehicle up to 3.5 tons (Source: author based on Vietor website [13])

In the second part of the task, using the Map and Guide browser, we found out what would be the length of the same transport of a single driver with a vehicle over 3.5 tons performing road freight transport. Based on the calculated data, the transport would take 71 hours and 9 minutes, of which the total driving time was calculated to be 38 hours and 54 minutes. The transport route is shown in Figure 4. In the third part of the same task, using the Map and Guide program, we found out what would be the length of transport of a two-member crew (drivers) by a vehicle over 3.5 tons performing road freight transport. Based on the calculated data, we found that the transport would take 47 hours and 54 minutes, of which the total driving time was calculated the same as in the previous case for one driver. The transport route is the same and is shown in Figure 4.

Fig. 4. Transport by vehicle over 3.5 tons (Source: author)

4. Practical comparison of realized transport by vehicles up to and over 3.5 tons

Actual transport of goods by vehicle up to 3.5 tons. The transport of goods was carried out by an unnamed company operating in the field of road freight transport by vehicles up to 3.5 tons. After personal communication with the driver working for this company and providing detailed information about the transport of goods, we obtained a realistic view and information about the actual transport by vehicle up to 3.5 tons. The transport was carried out on a FIAT DUCATO vehicle, category N1, with a maximum technically permissible total weight of 3,500 kg. The vehicle's emission class is EURO 5. The average fuel consumption was calculated at 10.20 liters per 100 kilometers.

Fig. 5. Fiat Ducato (Source: author)

The route was planned to start on Wednesday 10.03.2021 at 14:15 in Dolný Kubín, Slovakia. 10 stops were planned on the route, where loading or unloading of goods took place at selected places in Germany and the Slovak Republic. The total number of kilometers traveled at the end of the realized transport by vehicle up to 3.5 tons was 2426 km. The total transport time after the breaks in loading, unloading, refueling, and waiting time was 37 hours and 45 minutes. The route ran through four countries. Table 1 shows the number of kilometers traveled and the times between individual stops.

Table 1. List of stations for the transport of goods by vehicle up to 3.5 tons (Source: author)

Stops	State	Date of arrival	Time of arrival	Duration (hh:mm)	Km	Distance difference	Description
1	SK	10.03.2021	14:15	0:00	0	0	SK 026 01 Dolný Kubín - loaded 2 pallets
2	SK	10.03.2021	14:50	0:10	31,6	31,6	SK 029 01 Námestovo - +1 pallet
3	D	11.03.2021	4:00	2:30	989	1020,6	68766 Hockenheim Talhaus - -1 pallet
4	D	11.03.2021	7:30	0:05	99,4	1120	D 555** Bad Kreuznach - total unloading
5	D	11.03.2021	10:35	0:10	241	1361	D 72202 Nagold - + 1 pallet
6	D	11.03.2021	11:50	0:10	98	1459	D 740** Heilbronn - + 1 pallet
7	D	11.03.2021	13:00	0:50	62	1521	D 74532 Ilshofen - + 1 pallet
8	D	11.03.2021	16:45	0:15	207	1728	D 93073 Neutraubling - - 1 pallet
	D	11.03.2021	17:05	0:25	3	1731	D 93073 Neutraubling - refueling
	SK	11.03.2021	23:05	0:25	474	2205	Bratislava
9	SK	11.03.2021	23:58	0:17	25,4	2230,4	SK 900 55 Lozorno - total unloading
10	SK	11.03.2021	0:15		253	2483,4	SK 026 01 Dolný Kubín
		11.03.2021	4:00	END	Overall	2483,4	

Detailed description of the actual transport of goods by vehicle up to 3.5 tons. Upon arrival at the vehicle, the driver took over the already loaded vehicle with 2 pallets and on Wednesday, March 10, 2021, at 2:15 p.m., set off for the second loading location in Námestovo. After loading and securing the goods, he set out for Hockenheim in Germany at 15:00, where the first pallet was unloaded. The driver drove the vehicle continuously for 13 hours, except for one short break of 15 minutes. The driver arrived at the place of unloading two hours before the opening and unloading. He used this time to rest. After unloading the first pallet, he continued to the town of Bad Kreuznach, where he unloaded the remaining two pallets. Subsequently, he moved with an empty vehicle to the city of Nagold, where at 10:35 he loaded 1 pallet weighing 100.29 kg. He continued to loading place No. 2 in Heilbronn, where he loaded 1 pallet (178 kg) and continued to Ilshofen, where at 13:00 he met the second vehicle, from which he loaded (transferred) another pallet (85 kg). Subsequently, at 13:50 fully loaded, he set off in the direction of SR. Along the way, he stopped in Neutraubling to unload 1 pallet weighing 100.29 kg. After unloading the pallet and refueling at 5:30 pm, he set off in the direction of Lozorno, SR. After arriving in Slovakia, the driver stopped at a gas station near Bratislava to refuel. Subsequently, he arrived at the place of unloading of goods in the town of Lozorno, after which at 00:15 he continued directly home to the town of Dolný Kubín. The vehicle was parked at the company's headquarters at 04:00 on March 12, 2021. At the end of the ride, he recorded the total mileage and fuel consumption in liters. The total distance traveled was 2426 km and fuel consumption on this route was 237, 85 liters of diesel. It follows that the average consumption of the vehicle was 10.20 liters of diesel per 100 kilometers.

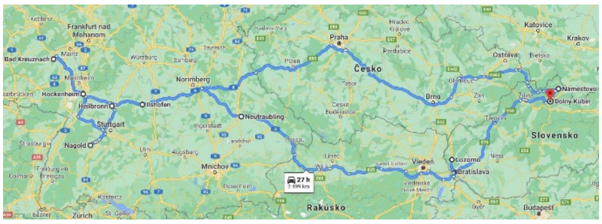

Fig. 6. Map preview of the realized transport (Source: author)

Transport of goods by vehicle over 3.5 tons. The transport of the goods was planned using the Map and Guide Truck Route Planner, where the actual dimensions and values of the vehicle were set and installed. However, it is important to note that the shipment did not actually take place. With the help of this planner, we determined the potential costs for the implementation of the above-mentioned transport of goods, which was carried out by a vehicle up to 3.5 tons. It was also our task to identify the length of the transport in compliance with the currently applicable social legislation and the basic costs associated with this transport. The transport was planned on a Renault Midlum 220.12 vehicle, a type of flatbed with tarpaulin, category N2 with a maximum technically permissible total weight of 12,000 kg. The emission class of the vehicle is EURO 5. The average fuel consumption was chosen at the level of 20 liters per 100 kilometers.

The route was planned to start on Wednesday 10.03.2021 at 14:15 in Dolný Kubín, Slovakia. 10 stops were planned on the route, where loading or unloading of goods took place at selected places in Germany and the Slovak Republic. The total planned number of kilometers traveled at the end of the transport would be 2687.73 km. The total transport time, considering safety breaks and reduced daily rest periods of 9 hours, would be 69 hours and 38 minutes, with a travel time of 35 hours and 23 minutes. The route would run through three countries, where the highest tolls would be paid in Germany, where the longest distance would have been covered. Table 2 shows the number of toll kilometers traveled and the amount in euros that must be paid when crossing the planned sections. The amount needed to carry out the transport and meet all tolls would be EUR 324.08.

Table 2. Tolls (Source: author)

State	Distance (km)	Toll (EUR)
SK	450,36	77,53
CZ	890,7	84,08
DE	1169	162,47
Total	2510,06	324,08

A more detailed record with places of loading, unloading, safety breaks and daily rest is shown below in Table 3. The table also shows the distance traveled and the time between the individual stops as it was presented when transported by vehicle up to 3.5 tons.

Table 3. List of stations for the transport of goods by vehicle up over 3.5 tons (Source: author)

Stops	State	Date of arrival	Time of arrival	Duration	Km	Distance (km)	Description
1	SK	10.03.2021	14:15	00:20	0	0	SK 026 01 Dolný Kubín - loading and departure
2	SK	10.03.2021	15:37	00:10	45,33	45,33	SK 029 01 Námestovo - loading
	CZ	10.03.2021	19:15	00:45	250,85	205,52	687 74 Vápenice - 45 min. break
	CZ	10.03.2021	0:30	00:45	587,8	336,96	Svatý Jan pod Skalou Záhrabská - 45 min. break
	CZ	11.03.2021	2:15	09:00	672,94	85,13	330 25 Blatnice - 9 hours pause
	D	11.03.2021	15:45	00:45	1050,96	378,03	68766 Hockenheim Talhaus - 45 min. break
3	D	11.03.2021	16:38	00:20	1059,49	8,53	D 68766 Hockenheim - unloading
4	D	11.03.2021	18:27	00:10	1174,27	114,78	D 555** Bad Kreuznach - unloading
	D	11.03.2021	21:30	00:45	1404,02	229,75	71083 Ammerbuch Sägmühle - 45 min. break
5	D	11.03.2021	22:34	00:10	1424,63	20,61	D 72202 Nagold - loading
	D	11.03.2021	23:25	09:00	1471,54	46,91	70569 Stuttgart Buchrain - 9 hours break
6	D	12.03.2021	9:20	00:10	1536,67	65,13	D 740** Heilbronn - loading
7	D	12.03.2021	10:20	00:10	1596,51	59,84	D 74532 Ilshofen - unloading
8	D	12.03.2021	13:10	00:10	1814,48	217,97	D 93073 Neutraubling - Unloading
	D	12.03.2021	13:25	00:45	1819,08	4,6	93098 Mintraching Rosenhof - 45 min. break
	CZ	12.03.2021	18:40	00:45	2196,75	377,67	582 55 Herálec Kamenice - 45 min. break
	CZ	12.03.2021	20:25	09:00	2281,41	84,66	664 41 Omice - 9 hod. pause
9	SK	13.03.2021	6:50	00:20	2398,65	117,24	SK 900 55 Lozorno - unloading
	SK	13.03.2021	10:15	00:45	2636,43	237,79	013 24 Strečno - 45 min. break
10	SK	13.03.2021	11:53	-	2687,73	51,3	SK 026 01 Dolný Kubín - arrival

The following Figure 7 shows a map view of the planned route, also indicating the places of loading and unloading stops in the order as planned.

Fig. 7. Map preview of the planned transport (Source: author)

5. Evaluation of compared transport

In the first part, only the time differences between the planned transports of vehicles to and over 3.5 tons were compared. When comparing both vehicles with one driver, we can state that the transport of goods by a vehicle over 3.5 tons would take more than twice as long as a vehicle up to 3.5 tons without the use of a recording device. However, if we look at the net driving time of both vehicles and compare it, we find that there is a difference in driving time of three hours. When comparing the transport performed by a vehicle over 3.5 tons with a two-member crew, the total transport is 13 hours longer compared to a vehicle up to 3.5 tons. In the second art, we compare the actual transport, which was carried out by a vehicle up to 3.5 tons. The first difference is in the distance traveled, where a vehicle over 3.5 tons would have to make a route more than 200 km longer to serve and make the same stops as a vehicle up to 3.5 tons. Based on this fact, the costs of transport associated with fuel consumption, tolls, financial costs for the driver, vehicle wear, etc. will increase. If we look at it from a time point of view, transport with one driver would take about two days longer than with transport by vehicle up to 3.5 tons. Due to the different consumption of vehicles, where a vehicle over 3.5 tons Renault Midlum has twice the consumption as a vehicle up to 3.5 tons Fiat DUCATO, we can assume that fuel consumption will double. Nor can we forget to mention tolls, which are different and higher for a vehicle over 3.5 tonnes compared to a vehicle under 3.5 tonnes.

One solution for road carriers' companies with vehicles up to 3.5 tonnes could be to change the fleet to vehicles up to 2.5 tonnes, a good example being the Citroen Berlingo with a load capacity of 0.6 tonnes and a load capacity of 2.5 tonnes. m3. This type of vehicle can carry a maximum of 2-euro pallets (75 cm high) or 1-euro pallet (110 cm high), or 1 ISO pallet (110 cm high) (company browser Vietor).

Fig. 8. Citroen Berlingo (Source: author based on Vietor website [13])

6. Analysis of the development of transport performance in freight transport and the development of the number of registrated carriers

In the Slovak Republic, 7,398 carriers and 49,625 lorries were registered in road freight transport in 2018. There were 299,235 carriers registered in all European Union countries with a total of 2,117,994 lorries. The share of carriers registered in the Slovak Republic thus represents a 2.5% share of carriers registered in other European Union countries (Eurostat 2018). Based on the current development of freight transport performance in the Slovak Republic, further growth in road freight transport performance can be expected in the future, according to analyzes prepared by the European Commission (Transport 2018, Europe, 2018). Road freight transport grows as the gross domestic product of countries grows (Varjan et al., 2017, Gnap et al., 2018). At present, part of the transport performance in road freight transport is performed by trucks up to 3.5 tons of total weight, and their share is also increasing in international road freight transport over long distances. The share of transport performance is not statistically monitored, and therefore can only be estimated through an increase in the number of registered vehicles up to 3.5 tons of total weight.

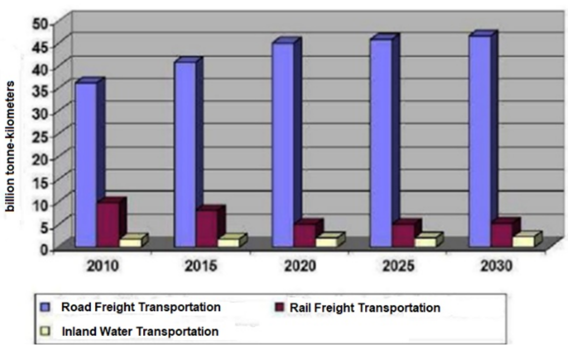

Fig. 9. Expected development of transport performance in freight transport by 2030 (Source: author based on Ministry of Transport and Construction of the Slovak Republic [11])

7. Development of the number of registrations of vehicles up to 3.5 tonnes in the Slovak Republic

The Association of the Automotive Industry of the Slovak Republic (ZAP SR) regularly publishes statistics on the registration of new vehicles of categories M and N on its website. Figure 10 is the development of the number of registrations of new N1 vehicles in the Slovak Republic during the years 2017 to 2019.

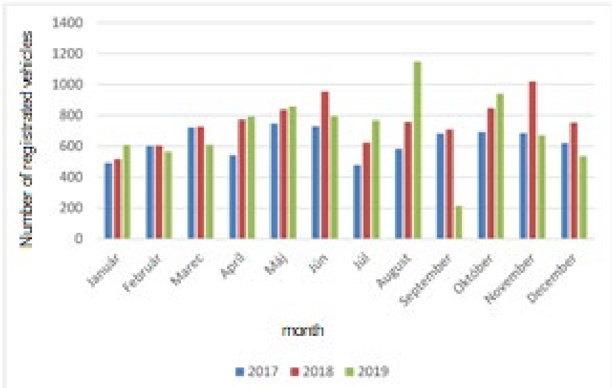

Fig. 10. Development of the number of registrations of new vehicles of category N1 in the years 2017 to 2019 (Source: author based on The Association of the Automotive Industry of the Slovak Republic [15])

The most registered vehicles of the given category during the monitored years were in August 2019 (1148 vehicles). On the contrary, the least registered vehicles were a month later, in September 2019, when the number of registered vehicles fell by more than 81% compared to the previous month (216 vehicles). This decrease may have been influenced, among other things, by the fact that, as of 1 September 2019, some vehicles could not be placed on the market, made available on the market, registered or put into service due to the entry into force of new emission limit requirements under which they were not approved (Ministry of Transport and Construction of the Slovak). Since June 2018, when 25,530 N1 trucks were registered in the Slovak Republic, their number increased to 2,64470. 165 854 business entities.

Conclusion

In this paper, we analyzed the number of traffic and fatal traffic accidents in the EU and Slovakia. On average in the last 5 years in the Slovak Republic, 13 people have died in traffic accidents caused by N1 vehicles. Compared to other truck categories, N1 vehicles caused the highest number of accidents each year. Similarly, market harmonization and the provision of competition in road haulage have been prompted by non-uniform market access conditions in the specification of the business of vehicles up to 3.5 tonnes and over 3.5 tonnes gross vehicle weight.

Conditions will be unified in certain areas from May 20, 2022, which may complicate business for sole traders, as well as other companies operating in road freight transport up to 3.5 tons. The uniform conditions will be access to the international transport market, which will oblige current traders to obtain a Community license, which is accompanied by the issue of a CND business license. Two transports are evaluated and compared in this work. The first transport was carried out from the Slovak Republic to Spain, where it was proved that the direct transport performed by the vehicle N1 would last approximately 35 hours, unlike transport by vehicle N2, where it would last more than 71 hours with one driver, with two-member crew 48 hours. During the actual transport, which was carried out in the form of delivery, multiple loading and unloading, vehicle N2 lasted significantly longer than N1. The main reason for extending the transport time by two days is compliance with social legislation by truck drivers over 3.5 tons. In view of the changes adopted in the field of social legislation, which will soon also apply to drivers of vehicles over 2.5 tonnes, companies operating express services up to 3.5 tonnes will have to consider changing their fleet to vehicles up to 2.5 tonnes, as drivers of these vehicles will not be obliged to use a recording device - tachograph, so they will be able to work as before the changes adopted. It should be noted that the benefits of operating freight transport with vehicles up to 3.5 tonnes will change significantly following the adoption of the mobility package by the EU.

A major change is planned, where new rules will apply to vehicles from 2.5 tonnes, and in addition to the obligation to install a digital tachograph, drivers of "classic vans" transporting goods will soon have to travel in international transport under the same conditions as bus or truck drivers. The proposal so far concerns international road haulage. The main advantage in terms of operating a truck up to 3.5 tons total weight will thus significantly change, reduce, and especially their use in the automotive industry for express transport throughout Europe, as well as almost no control of compliance with the working regime or. a ban on taking a weekly rest period in a vehicle (Czodorová et al., 2019). The advantage of vehicles over 3.5 tons may be that they can transport larger quantities of goods and thus load more small consignments compared to vehicles up to 3.5 tons, which may ultimately endanger and affect companies with vehicles up to 3.5 tons.

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EXAMINATION OF THE SHARE OF MEDIUM AND HEAVY TRUCKS IN THE SR

Abstract. The state of the environment is deteriorating due to human activity. Today, almost no major international forum can avoid addressing environmental issues. Environmental protection has therefore become a mandatory issue for every responsible politician. In addition to contributing to economic growth, the role of road transport should be to ensure sustainable transport and solutions for people and goods around the world. The European Parliament has adopted Directive 2019/1161 on the promotion of environmentally friendly and energy-efficient road transport vehicles, which defines the obligations and forms of support for the procurement of environmentally friendly vehicles. In addition to these transport tasks, there is also a challenge to reduce CO_2 emissions in transport through the use of new technologies in transport. Also in road freight transport, there are currently vehicles that use alternative fuels with a more favorable environmental impact. In connection with the current EU legislation, which aims to increase the share of these vehicles, attention is paid to the contribution of this area, analysis and examination of the current situation with trucks with alternative propulsion.
Keywords: road freight transport, alternative fuels, directive EU, environment.

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Introduction

The European Union is striving to achieve a sustainable, competitive, secure and decarbonized energy system. The European Union has set ambitious commitments to further reduce greenhouse gas emissions by at least 40% by 2030 compared to 1990 levels, increase the share of renewable energy consumption by at least 27%, and increase energy security, competitiveness and sustainability in the Union. The decarbonization of the transport sector must be accelerated and it will therefore be necessary to steadily reduce greenhouse gas and air pollutant emissions from transport in order to reach zero levels by the middle of the century. In addition, there is an urgent need to significantly reduce transport emissions of air pollutants that are harmful to health and the environment (EU Directive 2019/1161).

Innovations in new technologies help reduce CO_2 emissions from vehicles and reduce air pollution and noise pollution, while supporting the decarbonization of the transport sector. Increased use of low- and zero-emission road vehicles will reduce CO_2 emissions as well as certain pollutants (particulate matter, nitrogen oxides and hydrocarbons other than methane) and thus improve air quality in cities and other polluted areas (EU Directive 2019/1161).

The availability of sufficient charging and pumping infrastructure is also essential for the introduction of alternative fuel vehicles. The European Parliament has called on Member States to promote green public procurement policies through the purchase of zero-emission and very low-emission vehicles by public authorities for their own fleets or through public or mixed vehicle-sharing schemes, and to phase out new vehicles by 2035 vehicles emitting CO_2 emissions (EU Directive 2019/1161).

The use of ecological vehicles in road freight transport to a greater extent can help to meet the EU objectives, therefore the paper focuses mainly on examining the current share of ecological vehicles in road freight transport in the Slovak Republic and abroad.

1. Application of EU Directive 2019/1161 on the promotion of clean and energy efficient road transport vehicles

The EU requires Member States, through the transposition of EU Directive 2019/1161, to ensure that contracting authorities and contracting entities take into account energy and environmental impacts during the lifetime of a vehicle when procuring certain road transport vehicles, including energy consumption and CO_2 emissions and certain pollutants, in order to promote and stimulate the market for clean and energy efficient vehicles and improve the contribution of the transport sector to the Union's environment, climate and energy policies.

EU Directive 2019/1161 states for each EU Member State what the minimum percentages of clean vehicles in the total number of road transport vehicles should be included in the sum of all contracts subject to that EU directive.

It is the responsibility of EU Member States to ensure that the required minimum procurement targets for clean vehicles are met when procuring vehicles and services falling within the scope of EU Directive 2019/1161. These percentages are given separately for each EU Member State and depending on the reference period. These are two reference periods, the first being the period from 2 August 2021 to 31 December 2025. The second reference period is the period from 1 January 2026 to 31 December 2030.

In some EU Member States, compared to the Slovak Republic, the required procurement targets are higher for the share of environmentally friendly vehicles in the N1, N2, N3 vehicle category. In Fig. 1 sets out the minimum required values under EU Directive 2019/1161 for each Member State. Figure 1 also shows data for the United

Kingdom. It is clear from the data that higher percentages of clean vehicles will be required especially in the countries of Western and Northern Europe or in the countries that are part of the so-called EU-15, as these countries already make much more use of alternative propulsion vehicles or vehicles that meet the conditions of the definition of an environmentally friendly vehicle. In the category of N2 and N3 trucks, these shares are in most cases at 10% in the first reference period and in most cases the required value is 15%.

Conversely, for some countries, lower minimum procurement targets are set for the share of clean vehicles. These are in particular the Baltic States, the V4 States and the Balkans and South-Eastern Europe. According to EU Directive 2019/1161, the stated required values are only minimal, and each state can commit to higher values through its own legislation. The Slovak Republic is also among the countries where the required target value for the procurement of ecological vehicles is lower compared to the countries of Western and Northern Europe. As the United Kingdom was until recently an EU Member State, the minimum procurement targets for the share of clean vehicles were also set, and the same as for most Western European countries.

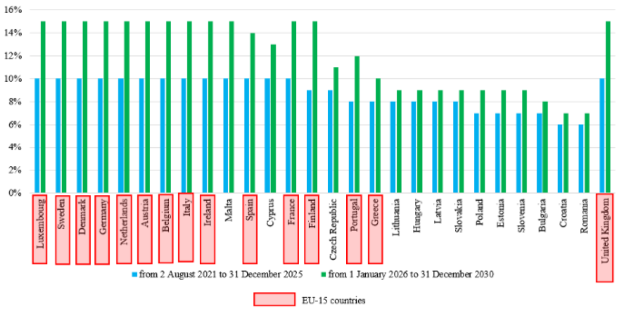

Fig. 1 The absolute and relative number of trucks with alt. fuel in the SR (Source: author based on Directive EU 2019/1161)

The aim is to increase the share of clean vehicles in road freight transport also through this legislation.

2. Truck fleet analysis in Europe

Alternative fuels are gradually being used in road freight transport in the EU. In the N1 truck category, electricity or liquefied petroleum gas may be an available alternative to conventional propulsion. In the category of N2 and N3 trucks, currently the most used vehicles with alternative types of CNG or LNG propulsion are.

Vehicles in this category (N2 and N3) powered by hydrogen or electricity are also becoming available to carriers. But at present there are very few of these vehicles, e.g. in Europe, the first 10 hydrogen fuel cell-powered Huyndai XCIENT Fuel Cell trucks are already driving. They are used by customers in Switzerland, where tax incentives for hydrogen vehicles and a good hydrogen infrastructure create the space for this new technology to be put into practice (Transport 2020). Due to the low number of other vehicles in the N2 and N3 category with alternative propulsion, only CNG / LNG vehicles predominate in the statistics on trucks using alternative fuels.

Truck manufacturers offer these alternative propulsion vehicles (CNG / LNG) to their customers, and some customers have requirements for carriers to use these vehicles. At present, the construction of the vehicle is of great importance, especially its ecological operation, respectively reducing the ecological burden on the environment.

Manufacturers of LNG trucks, namely Scania, Volvo and Iveco, state that operating LNG trucks can reduce CO_2 emissions by 15% to 20% compared to Euro VI, up to 95% if biogas is used, 95% less solids, 25% to 70% less nitrous oxide and, of course, a significant reduction in noise pollution. The percentage reduction in emissions is declared by the manufacturers for in-service car emissions, known as "tank-to-wheel" (Iveco 2020, Volvo trucks 2020, Hagos et al. 2018).

According to Danish transport research, in which the authors looked at the prospects for gas in transport in Denmark, using LNG can reduce greenhouse gas emissions by at least 15% per km if it is a well-to-wheel expression, a comprehensive expression taking into account greenhouse gas emissions, gases from the extraction of the raw material to its final consumption. By using renewable components, this effect can be several times higher (Hagos et al. 2018).

A study by the Oxford Institute for Energy Studies (2014) sees the greatest potential for natural gas in transport in heavy goods transport. It notes that, compared to heavy goods vehicles and diesel buses, emissions taking into account other greenhouse gases in terms of CO_{2e} (carbon dioxide equivalent) per km by 2030 may be 15% lower in a well-to-wheel mode. This is confirmed by a recent study by the Oxford Institute for Energy Studies from 2019. CO_{2e} emissions can be even lower when using bio-LNG. Values are given in g CO_{2e}/km (Oxfordenergy 2019).

Table 1. Well-to-wheel CO_{2e} g/km LNG truck (Source: Oxfordenergy 2019)

Heavy Trucks	Diesel	CNG	LNG	80% CNG + 20 % bio	80% LNG + 20 % bio
CO_{2e} [g/km]	1,074	908	912	738	749

The number of trucks over 3.5 tonnes is increasing every year in the EU. Importantly, the number of road freight vehicles using alternative CNG or LNG fuels is also gradually increasing, and this trend has been due to support from the EU or individual Member States. The ACEA report, January 2021, provides a comprehensive overview of the European vehicle fleet. For each country, it shows the number of vehicles used in each segment - including passenger cars, light commercial vehicles, medium and heavy commercial vehicles and buses and the development of this vehicle fleet in recent years, including a breakdown by type of fuel used.

Diesel-powered light commercial vehicles are dominant in all EU countries. Almost 90% of the EU's light commercial vehicle fleet ride on diesel, 7.8% use petrol as fuel and only 0.3% of light commercial vehicles in the EU use electricity (ACEA Vehicles in use Europe January 2021).

At present, as many as 97.8% of all medium and heavy trucks in the EU still use diesel, while petrol uses 1.3% of the EU truck fleet. The number of medium and heavy-duty trucks using alternative fuels is still minimal, as diesel is the dominant type of fuel. This is understandable given the technologies available, the infrastructure and the impact of procuring an alternative vehicle on the transport company's costs. Overall, 0.4% of trucks in the EU use natural fuel and natural gas use liquefied petroleum gas (ACEA Vehicles in use Europe January 2021).

An overview of the number of medium and heavy commercial vehicles is given in absolute terms in the following table without data for the United Kingdom.

Table 2. An overview of the number of medium and heavy trucks in the EU (Source: ACEA Vehicles in use Europe January 2021, ACEA Vehicles in use Europe 2019, ACEA Vehicles in use Europe 2018)

Year	2014	2015	2016	2017	2018	2019
Total number of vehicles	5,533,777	5,765,018	5,881,445	6,020,307	6,143,333	6,229,282

An overview of the number of medium and heavy commercial vehicles with alternative fuel types LNG and CNG is given in absolute numbers in the following table without data for the United Kingdom.

Table 3. An overview of the number of LNG and CNG medium and heavy trucks in the EU (Source: ACEA Vehicles in use Europe January 2021, ACEA Vehicles in use Europe 2019, ACEA Vehicles in use Europe 2018)

Year	2017	2018	2019
CNG/LNG vehicles	24,081	24,573	24,917

3. GDP growth

The procurement of new N2, N3 trucks with alternative propulsion is certainly essential and important in meeting the EU's emission reduction commitments. The decision to buy this type of vehicle may depend on several factors. The awareness of human society about the need to look for ecological methods in transport, the level of development of countries and, to a large extent, the political strategies and directions of individual states, but also from the size of GDP, certainly contributes to this. Therefore, data have been calculated and reported between the gross domestic product of each region of Europe per capita in 2019 and the percentage of trucks with alternative propulsion in these areas, which show that the higher the GDP, the more registered the freight vehicles with alternative propulsion.

Table 4. GDP/cap. and trucks in selected areas of the EU (Source: ACEA Vehicles in use Europe January 2021, 12. Eurostat. GDP and main components (output, expenditure and income))

	V4	EU-15 countries	Nordic countries
GDP/cap. [€]	15,603	36,520	51,021
Trucks with alt. fuel [%]	0.13	0.39	0.63

4. Trucks in the SR by type of propulsion

In the Slovak Republic, carriers are also starting to procure trucks with an alternative type of drive. This fact can be influenced by a number of factors, e.g. striving to be more environmentally friendly, possible cost reduction and savings, customer pressure to procure these vehicles, legislation, etc. From the available data obtained from the Police Force of the SR (Police Force of the SR), the following table analyses by region the vehicle fleet of the SR. The analysis is focused on trucks of categories N2 and N3 in the Slovak Republic and obtaining data on the number of vehicles with an alternative type of fuel, which can be considered an ecological vehicle according to EU Directive 2019/1161.

Table 5. Vehicles of categories N2 and N3 by region (Source: Police Force of the Slovak Republic, STATdat.)

	SR	BA	TT	TN	NR	ZA	BB	PO	KE
Total	79,685	14,738	9,428	8,017	11,335	9,701	9,110	8,836	8,520
CNG	40	7	2	12	3	7	4	4	1
LNG	85	45	6	3	1	0	9	1	20
LPG	14	0	0	2	0	0	9	3	0
Electricity	2	0	0	0	1	1	0	0	0
Petrol	109	28	13	18	4	19	12	7	8
Diesel	79,435	14,658	9,407	7,982	11,326	9,674	9,076	8,821	8,491
Vehicles with alt. fuel	141	52	8	17	5	8	22	8	21
	0.18%	0.35%	0.08%	0.21%	0.04%	0.08%	0.24%	0.09%	0.25%
The population	5,459,781	677,024	565,324	582,567	671,508	691,136	643,102	827,028	802,092
Vehicles with alt. fuel/ 100,000 inhabitants	2.58	7.68	1.42	2.92	0.74	1.16	3.42	0.97	2.62

From the available analysed data, it can be seen that in the Slovak Republic there are currently 141 trucks of categories N2 and N3, which use an alternative fuel, liquefied or compressed natural gas, or liquefied petroleum gas as their source of propulsion. With a total of 79,685 vehicles, the number of vehicles in this category is 0.18% in relative terms. Compared to the EU average, this number is lower in the Slovak Republic, as in the EU on average 0.6% of medium and heavy trucks using alternative fuel are natural or oil gas.

Looking at the more detailed statistics by region, it is visible that the highest number of trucks of category N2 and N3 with an alternative type of drive within the distribution by region of the Slovak Republic is in the Bratislava region. There are 52 trucks with an alternative type of drive registered in this region. Even in relative terms, there is the highest share of ecological trucks, namely 0.35%, which is almost twice the average of Slovakia 0.18%. The Košice, Banská Bystrica and Trenčín regions are also at approximately the same level (21, 22 and 17 cars). The lowest number of ecological trucks is in Prešov, Trnava, Žilina (8 vehicles) and the Nitra region (5 vehicles). With the decreasing number of vehicles with alternative propulsion in absolute terms, the decrease in ecological vehicles in relative terms is also visible. In addition to the Bratislava region, the share of ecological vehicles in the Košice, Banská Bystrica and Trenčín regions is above the Slovak average. These data are also graphically expressed in Figure 2.

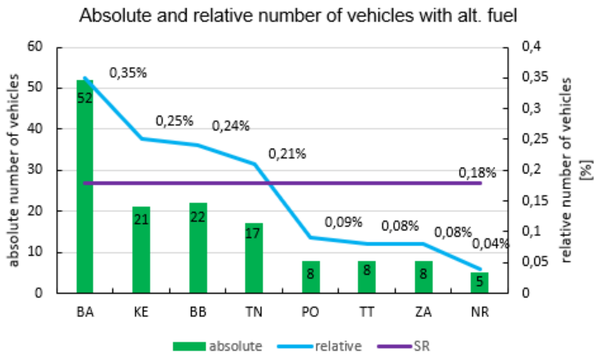

Fig. 2 The absolute and relative number of trucks with alt. fuel in the SR (Source: author)

The number of ecological trucks in individual regions per 100,000 inhabitants was also examined. Also in this statement, there are significantly the most environmentally friendly trucks in the Bratislava region, namely 7.68 vehicles/100,000 inhabitants. The national average represents a value of 2.58 vehicles/100,000 inhabitants. The Banská Bystrica, Trenčín and Košice regions are still higher than the average for the whole of Slovakia. The data show that from every part of the Slovak Republic (west, middle, east) there is at least one region with the number of ecological vehicles per 100,000 inhabitants. above the SR average. On the contrary, below this average value are again the regions Trnavský, Žilinský, Prešovský and the least ecological trucks per 100,000 inhabitants is in the Nitra region (Fig. 3).

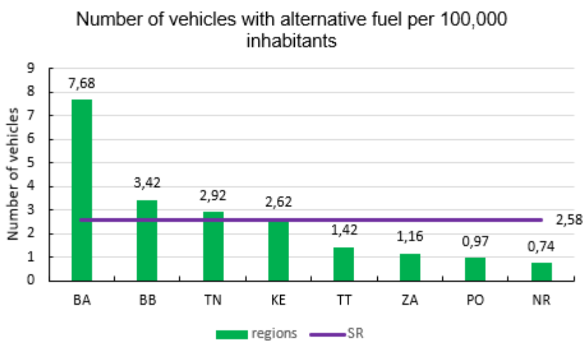

Fig. 3 Number of vehicles with alternative fuel per 100,000 inhabitants. (Source: author)

The decision to buy an eco-friendly truck can be influenced by several factors. The situation and development of the economy in individual areas can also be one of them. The relationship between the number of clean trucks and the GDP of each region was therefore examined. As GDP grows, so does the transport performance of road freight transport and thus the need to procure new trucks (Gnap et al. 2018). An analysis of the European V4 regions, the EU-15 and the Nordic countries shows that the higher the GDP, the higher the number of vehicles using alternative fuels. GDP was converted per capita for each region. Data on the population of individual regions and the level of GDP were obtained from sources (STATdat.). A similar course can be seen in a certain part of the examined sample of Slovak regions. The highest GDP is the highest in the Bratislava region and also in this region there are the most registered ecological trucks. Compared to the Bratislava region, GDP is lower in the remaining regions, between which there are no significant differences in terms of per capita. There is also a comparable number of ecological trucks in the Košice, Banská Bystrica and Trenčín regions. In the remaining regions (Prešov, Trnava, Žilina, Nitra), the number of ecological trucks is much lower, despite the comparable level of GDP with the Košice, Banská Bystrica and Trenčín regions.

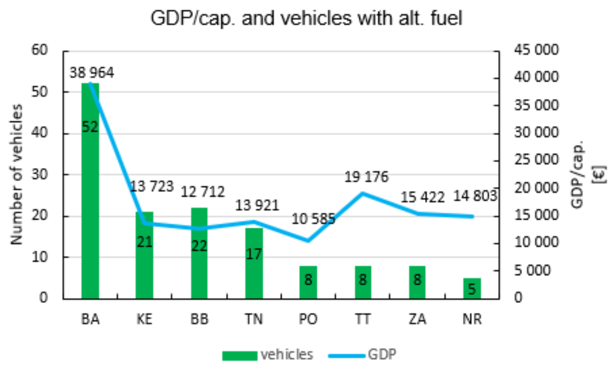

Fig. 4 GDP/cap. and vehicles with alt. fuel (Source: author)

Conclusion

The EU's ambitious goals of reducing greenhouse gases, producing CO_2, increasing the share of energy from renewable sources, making greater use of alternative energy sources and, in order to achieve these goals, it is important to pay close attention to the tools that can ultimately lead to them. One option is to create policy initiatives that can put positive pressure on the procurement of more environmentally friendly road transport vehicles. Gradually, vehicles with alternative modes of propulsion are also being used in road passenger or freight transport, and further measures may lead to this trend in a positive direction.

Public procurement can influence and strengthen the market for green vehicles. As public expenditure on goods, works and services accounted for 16% of GDP in the EU in 2018, the EU decided to adopt Directive 2019/1161, which sets minimum requirements for clean vehicles for Member States when procuring vehicles or providing specific services. The use of this tool is also expected to increase the use of vehicles with alternative fuels in road freight transport, as in this area the market is currently absolutely dominated by vehicles with conventional propulsion, which can be claimed based on analysed data for the EU and Slovakia.

European countries with a higher share of GDP per capita also have a higher share of green truck registrations.

How this area will be affected in the context of the COVID - 19 pandemic will need to be thoroughly investigated at the end of this period.

There are not many alternative solutions available for road freight transport in the N2 and N3 vehicle categories. The use of CNG or LNG in heavy goods vehicles certainly represents a contribution to CO_2 reduction in the transport sector. In a study (Smajla et al. 2019), data were tested on 18 trucks for LNG over 15 months, and the authors concluded that LNG as a fuel reduced costs and harmful emissions. Similar fuel consumption based on equivalent energy was achieved for liquefied natural gas trucks during the study period. On average, fuel costs for LNG trucks were about 48% lower than for diesel trucks. With such cost estimates, the payback period is less than three years (Smajla et al. 2019).

The EU's ambitious targets for reducing CO_2 emissions from transport can benefit the environment and human society in the future. The aim of the paper was to find out the current state of the vehicle fleet in the EU and in the Slovak Republic. The number of trucks that use alternative fuels in absolute, relative terms and per 100,000 inhabitants is also examined. The relationship between the number of ecological vehicles and GDP per capita is also examined. The survey focused on vehicle categories N2, N3 and areas were divided by region.

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