Research on the Quantification of Exhaust Emission Volumes in an Opted Road Section

Branislav Šarkan[1], Jozef Pal'o[1], Michal Loman[1], Ondrej Stopka[2,*], Jacek Caban[3], Karolina Čeháková[1], Wojciech Gołębiowski[4] and Jan Pečman[2]

[1] University of Žilina, Faculty of Operation and Economics of Transport and Communications, Department of Road and Urban Transport, Univerzitná 8215/1, 01026 Žilina, Slovakia; branislav.sarkan@fpedas.uniza.sk (B.Š.); jozef.palo@fpedas.uniza.sk (J.P.); loman@stud.uniza.sk (M.L.); cehakova@stud.uniza.sk (K.Č.)

[2] Institute of Technology and Business in České Budějovice, Faculty of Technology, Department of Transport and Logistics, Okružní 517/10, 37001 České Budějovice, Czech Republic; stopka@mail.vstecb.cz (O.S.), pecman@mail.vstecb.cz (J.Pe.)

[3] Lublin University of Technology, Faculty of Mechanical Engineering, Department of Automation, Nadbystrzycka 36, 20618 Lublin, Poland; j.caban@pollub.pl (J.C.)

[4] University of Life Sciences in Lublin, Faculty of Production Engineering, Department of Power Engineering and Transportation, Głęboka 28, 20612 Lublin, Poland; wojciech.golebiowski@up.lublin.pl (W.G.)

* Correspondence: stopka@mail.vstecb.cz

Abstract: The air quality in the urban zone is influenced by many factors, of which transport plays a significant role. Air quality has an impact on the health of inhabitants, demographic, urbanization processes, as well as a whole mobility, and is currently one of the most important challenges faced by municipal authorities. The article focuses on analyzing the impact of exhaust gases and their emissions produced by motor vehicles on the environment in the opted territory, namely Hasičská Street in the city of Trenčín, Slovakia. Investigated and quantified emissions in the context of vehicles' mobility comply with a number of vehicles registered in Slovakia. The primary task of the research is to determine the amount of produced emissions in the researched area without the use of measuring technology. It is a process of modeling emission coefficients on the basis of which it is possible to reliably determine the level of pollution in the monitored area. The research per se is based upon a traffic survey carried out over the period September-October 2021. Following the analysis, obtained values were classified into certain vehicle categories registered in Slovakia while observing the relevant EU Regulations. The research involved measuring the volume of exhaust emissions produced by vehicles when in motion through the examined transport *section. We further compared the resulting exhaust emissions with emissions automatically recorded by the national weather station. The levels of individual harmful substances registered by the Slovak Hydrometeorological Institute were naturally higher than the values achieved by the survey itself, as the weather station records emissions from multiple mobility activities. In regard to emissions obtained by the survey, we achieved related values of indicators as follows: CO, HC, NO_x, and PM. The category of passenger cars topped the list, as automobiles produced 90.17% pollutants of all the recorded vehicles. Bus services capped NO_x emission production. The highest emission rates were detected between 2 and 3 pm due to the peak traffic in the observed section. The analysis has proved significantly lower emission volumes produced by haulage compared to other vehicle categories.*

Keywords: road transport; mobility; exhaust emissions; exhaust gases; weather station

1 Introduction

Thanks to its flexibility, road traffic is the most viable way of people' mobility, ranging from the use of light vehicles to heavy utility combustion engine machines. These engines are powered by fossil fuels emitting harmful gas substances and solid particles, putting the road transport sector on the top of the list of global environmental and health threats [1-3]. Apart from greenhouse gases, exhaust emissions involve evaporative and odorous emissions, the latter stemming from tire, brake lining, clutch and roadway wearoff or vehicle corrosion [4-7]. A recent dramatic population growth, rapid economic development, urbanization and the resulting exponential increase in automotive production incurred proportional health risks [8-10]. It is expected that by 2040, the number of automobiles will nearly have doubled up to 2 bil. Another prognosis suggests that the total of road vehicles will have reached 2 or 3 bil by 2050 [11]. It is predicted that the majority of this massive upsurge will take place in Asian countries, especially China and India, given to the rapid economic development, prosperity and tremendous population growth. A considerable increase in GNP in these regions will boost the demand for motor vehicles including those from the “luxurious” section. It is thereby foreseen that emission rates produced by road traffic will be rising on the global scale through the following years [12].

Traffic in general is responsible for more than 25% of greenhouse emissions in the entire EU, being the largest contributor to the climate change. Cutting down on vehicle emissions is thereby vital for reaching zero exhaust fumes by 2050, as stipulated in EU’s long-term strategies [13]. Currently, software programs and models are used within large cities to determine the magnitude of exhaust gas emissions. Estimated levels of emissions from road transport can be helpful in assessing the overall air quality in urban areas. A lot of urban projects thereby rely on modeling methods to obtain direct results [14]. Testing automobiles involves vehicle certification. Emission measurements and vehicle testing take place using a chassis dynamometer, as producers have to prove that their vehicles comply with emission standards (the approval of a specific type) [15, 16]. For that reason, new vehicles are exempt from a regular emission test for a prescribed period. After the expiration of this time limit, all vehicles have to undergo emission inspection to ensure that the vehicle emissions did not exceed the specified limit.

In the Slovak Republic, the issue of air pollution and emission production is effectively tackled by the Slovak Hydrometeorological Institute, which publishes regular reports on the air quality and emission rates in the country (in selected localities). The institute further provides information on the air quality received from the weather stations. According to the study [17], the correct placement of stations monitoring air quality is essential. The institute further provides information on the air quality received from the weather stations. These sites are laid out throughout the Slovak Republic, regularly recording data on the air quality. However, the stations are very unevenly distributed, and it is not possible to cover the entire territory. The results from these measuring stations can only be accepted for the area that is in the immediate vicinity of the measuring station. The measured results inform about the air quality in the specific place [18]. The similar research carried out in the USA revealed a significant growth in the monitored values, heralding that the air quality deterioration is mainly caused by the road traffic [19]. Research involved a data analysis from the national weather station, focusing on the air quality in the monitored road section.

Research is aimed at measuring exhaust emissions by means of a traffic survey. The examination involved quantifying emission rates for individual vehicle categories when in motion. Subsequently, we compared the obtained results with the values provided by the weather station. The final outcomes informed us about emissions produced by a specific vehicle category regarding mobility. The secondary outputs encompassed the comparison of the recorded data. The research revealed that mobility by using road transport largely contributes to the air pollution in the road section under examination. Our main contribution is the identification of emissions from specific categories of vehicles used in an urban area, which can be important for traffic management enteprises to monitor and manage emissions in a given area. It will also make it possible to decide on the development and deployment of alternative communication and mobility systems in the city zone (e.g., car sharing, city bike system, etc.).

The conducted research was aimed at identifying the production of exhaust gas emissions by road transport. The research points to different levels of pollution depending on the category and number of vehicles that were registered during the research. Currently, the Slovak Republic does not have a universal tool for monitoring air quality in urban areas. Within cities or larger agglomerations, there is no study available on how to monitor and evaluate air quality in a specific section. In the near future, it is planned to create measuring points in selected places that will continuously monitor air quality. The results of the study can serve as a tool for decision making on a correct location of measuring devices to permanently monitor the categorization of vehicles in order to quantify the value of the emissions produced. Based on the results of measurements and current data, specific measures can be introduced (entry ban, restricted entry for selected types of vehicles, alternative mobility approaches and so forth) with the aim of permanently reducing emissions in the urban environment. The research findings further provide support for planning the optimization of air quality management policies toward the creation of sustainable cities. On the territory of the Slovak Republic, there is still no tool for preventing the movement of passenger traffic in the builtup area of cities. To a large extent, the study could be beneficial in building a green policy and permanently reducing emissions due to traffic within cities.

The measured data were compared with the results of the monitoring station of the Slovak Hydrometeorological Institute. Due to the insufficient coverage of the territory, the data results have only informative character. Based on the information on air quality, it is not possible to implement any steps that would lead to the improvement of the current mobility situation in the territory of the Slovak Republic. The research results represent a universal tool based on which the intensity of air pollution can be predicted without the need of installing specific measurement devices. The research conducted is the only one of its kind that, based on the methodology created, can quantify the amount of air pollution in a given area. Compared to an air quality measuring station, it can provide an approach for improving air quality wherever it is placed.

2 Data and Methods

The prerequisite for the correct calculation of exhaust gas emissions was the identification of the number and category of vehicles on the selected section. To obtain data from a specific area, a traffic survey was carried out on the 1st class road no. 61, Hasičská Street in Trenčín, Slovak Republic. The conducted traffic survey serves as the primary source of data, based on which the production of exhaust gas emissions from traffic activity was calculated. The survey was conducted to count vehicles in both traffic directions. The results of the traffic survey can be seen in Figure 1.

The survey results (Figure 1) indicate categories and numbers of vehicles passing through the monitored section. The diagram suggests passenger cars constituting the largest number - 25,802 vehicles, while N1 “LORRY” trucks comprised the smallest amount - 135 vehicles. The total contribution of passenger cars to released pollutants amounts 90.17%. The diagram (red curve) shows that the highest number of vehicles, i.e., the heaviest road load, goes through the section between 2 and 3 pm, followed by 7 and 8 am, which is obviously related to the rush hour in this locality.

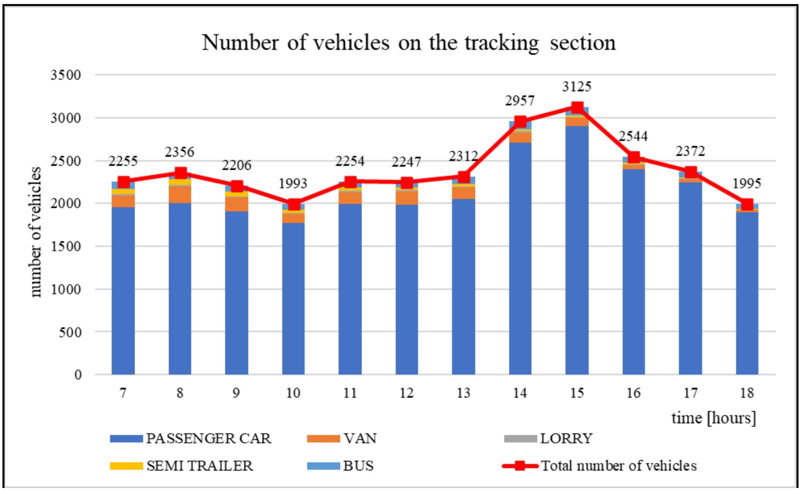

Figure 1
Number of vehicles in the monitored section [authors based on a traffic survey]

On the other hand, the figures fell to a trough between 9 and 11 am and were on a slide again as of 4 pm. We can thereby predict that the monitored section will see increased exhaust emission rates during the rush hour.

In the vicinity of the examined section, it can find the aforementioned weather station (Figure 2) [20]. Based on the data on the concentration of air pollutants received from the hydrometeorological institute and figures obtained by the survey, we can explore the extent to which road traffic is responsible for air pollution within the specific road section.

The survey took place in the time interval of 12 hours on 24.11.2022 from 7am to 7pm on vehicle categories as follows:

- passenger cars,

- N1 category with the maximum permissible load not exceeding 3,5 t (Van),

- N2 category with the maximum permissible load from 3,5 up to 12 t (Lorry),

- N3 category with the maximum permissible load exceeding 12 t (Semi Trailer),

- buses.

Measured emissions were subsequently evaluated and compared to values from the weather station. The survey covered pollutants: CO, HC, NO_x and PM. These harmful substances were emitted from all the monitored vehicle categories, allowing us to draw a close comparison.

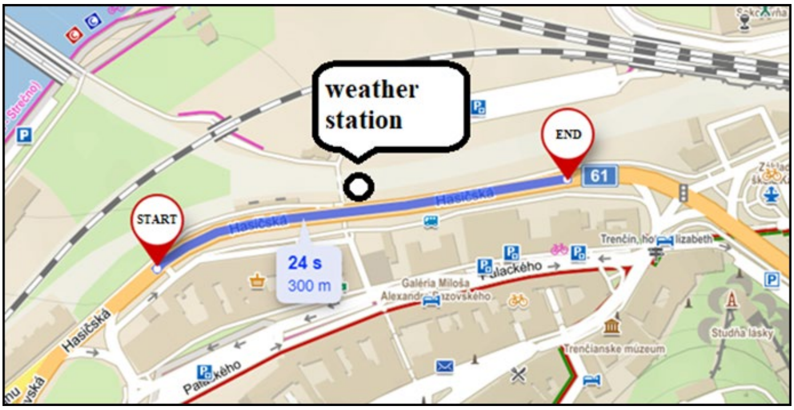

Figure 2
Measured section and location of the weather station (authors according to www.mapy.cz)

Passenger car category included vehicles registered in the territory of the Slovak Republic according to the internal database of the Ministry of the Interior. We further classified the vehicles according to the type of fuel, comprising two categories:

- petrol-powered vehicles, representing 54% of all registered vehicles,
- diesel-powered vehicles, representing 46% of all registered vehicles.

The next step involved the analysis of different categories, followed by a classification according to European emission standards. All categories were assigned emission standards in a range from Euro 3 to Euro 6. Vehicles of Euro 2 standard or less were marked as "older" (see Table 1).

Table 1
Percentage of vehicles registered in Slovakia (internal data of the Ministry of the Interior, Slovakia)

	Petrol %	Diesel %
older	36	19
EURO 3	6	14
EURO 4	22	22
EURO 5	15	27
EURO 6	21	18

The table shows the high proportion of vehicles with the EURO4 emission standard (22% for each type of fuel). In another case, up to 21% of vehicles with the emission standard Euro6 for petrol and 27% of vehicles complying with the emission standard Euro5 - for diesel are registered in the database. In the overall comparison, regardless of fuel, older vehicles represent the highest share of the total number in Slovakia. For this reason, it is possible to claim that the introduction of stricter measures for entry into selected parts and the overall regulation of emissions is necessary for the territory of Slovakia.

The traffic survey identified the overall traffic intensity and the traffic composition within the monitored section. The proportional distribution of the vehicles allowed calculating exhaust emissions in the examined segment. The survey also involved categories of vans and lorries, including N1 class represented by 91% and N2 represented by 9%. The acquired data were processed according to the database of The Ministry of the Interior of the Slovak Republic. N3 category comprised semi-trailers. All the heavy-weight categories (N1, N2 and N3) were classified according to relevant emission standards like in the event of passenger cars (EURO III, EURO IV, EURO V, EURO VI and older).

Various methods were involved in calculating exhaust vehicle emissions, offering multiple ways of application. The traffic survey, which presents a cornerstone of our research, allowed us to classify the vehicles according to their traits. The database of the Ministry of the Interior of Slovak Republic – the total number of registered vehicles in the territory of Slovak Republic – governed the data processing and dividing registered vehicles into categories according to the fuel type (petrol, diesel).

Based on the classification and identification of the exact number of vehicles of individual categories, it is possible to calculate the number of exhaust gases in the monitored section. Each vehicle type and EURO emission class was assigned an emission classification (exhaust emissions), through which it is possible to determine the total volume of emissions produced in the examined section. Based on the average value of emissions detected in the vehicle type approval process (g/km), we decided on the emissions produced by passenger cars registered in the territory of the Slovak Republic. Emission coefficients for buses are calculated map planner Map&Guide. The scheduler is able to simulate the production of exhaust emissions with high accuracy with respect to the required emission standard. The values (emission coefficients, table 3) that are the result of average values from the map planner enter the research. The average values were determined based on the calculation of several conditions in which the vehicle can move on the road. Measurements of bus emissions were largely based on Guo et al.'s research study on regulated pollutants from diesel and CNG buses using selective catalytic reduction in the EURO 5 DIESEL emission class [21].

The following Figure 3 presents an illustrative scheme and the procedure of the conducted research. The picture shows the individual steps that guided the research.

In Tables 2-4, the values of the emission coefficients are quantified, which are further included in the calculation of the total amount of emissions produced by the respective category of vehicles.

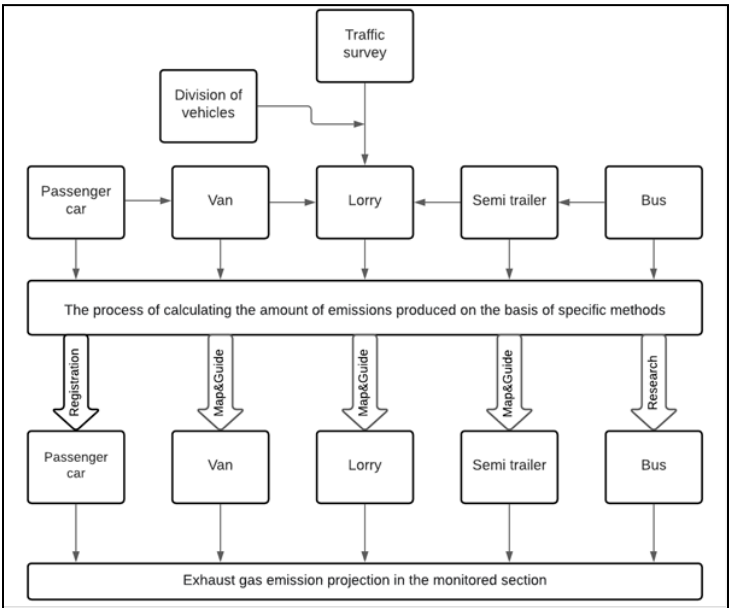

Figure 3
Scheme and procedure of the research [authors]

Table 2
Values of emission coefficients for petrol passenger vehicles entered the calculation [data from the Ministry of the Interior on the results of vehicle type approval]

Passenger car – Petrol [g/km]					
	CO	HC	HC+NO_x	NO_x	PM
Older	0.5795	0.0803	-	0.0593	0.1005
Euro 3	0.5846	0.0784	-	0.0501	0.0845
Euro 4	0.4163	0.0502	-	0.0261	0.0348
Euro 5	0.3992	0.0453	-	0.0251	0.0038
Euro 6	0.3632	0.0357	-	0.0227	0.0019
Passenger car – Diesel [g/km]					
	CO	HC	HC+NO_x	NO_x	PM
Older	0.3077	0.1514	0.4544	0.3594	0.0484
Euro 3	0.2332	0.0356	0.4368	0.4011	0.0407
Euro 4	0.1515	0.0250	0.2369	0.2119	0.0168
Euro 5	0.2323	0.0267	0.1738	0.1471	0.0085
Euro 6	0.1660	0.0280	0.0804	0.0524	0.0030

The data in Table 2 above represent the average values of emission production during type approval of individual emission classes of passenger vehicles. The values are expressed in g/km. The traffic survey took place in 300-meter-long section. The resulting values are thereby converted to g/300 m (gram over 300-meter-long section).

Table 2 depicts emission values for passenger cars. The tables outline the background to calculating exhaust emissions in the monitored segment. In the following Table 3, it is possible to monitor the data on the production of emissions for vehicles of categories N1, N2, and N3. The values in the table are taken from the Map&Guide planner, which pro vides a detailed description of emissions production. Each vehicle category was simulated in different states (empty vehicle, loaded vehicle). The resulting value shown in the table represents the average value of several simulations.

Table 3
Emission coefficients for the individual categories of lorries that entered the calculation [data based on the simulation in the route planner]

Van (N1) [g/km]				
	CO	HC	NO_x	PM
Euro 3	0.0189	0.0126	0.9409	0.0262
Euro 4	0.0127	0.0071	0.5505	0.0010
Euro 5	0.0910	0.0040	0.6956	0.0015
Euro 6	0.0091	0.0040	0.2476	0.0015
Lorry (N2) [g/km]				
	CO	HC	NO_x	PM
Euro 3	0.4745	0.1345	35.0650	0.0657
Euro 4	0.8183	0.0123	16.4790	0.0204
Euro 5	0.0692	0.0135	0.1402	0.0021
Euro 6	0.0692	0.0135	0.1402	0.0021
Semi Trailer (N3) [g/km]				
	CO	HC	NO_x	PM
Euro 3	11.3060	0.2895	58.1140	0.1362
Euro 4	12.7810	0.0195	25.8320	0.0360
Euro 5	12.1980	0.0197	17.3330	0.0366
Euro 6	0.1560	0.0255	0.2254	0.0037

Table 3 illustrates emission values for lorries, providing the background for further calculations. The examined vehicles comprised three categories.

In Table 4, the data on the production of emissions entering into the calculation are summarized. Based on the analysis of the emission class of buses that drive through the measuring point, it was found that all vehicles meet the EURO5 emission standard. For this reason, only one emission limit is sufficient, which will participate in the calculations of the total production of emissions from buses.

Table 4
Emission coefficients for buses that entered the calculation [21]

	Bus - Diesel [g/km]			
	CO	HC	NO_x	PM
Euro 5	2.17	0.06	2.81	0.0015

Table 4 informs about exhaust emissions representing emission values for buses - EURO 5 DIESEL. The presented figures were taken from the conducted study. The data represents the average value of exhaust gas emissions that were identified based on the measurement in real conditions in the studies of Guo et al. [21].

3 Results

The conducted survey yielded results to determine values of CO, HC, NO_x and PM in the monitored section. The bar charts (Figures 4-7) below depict calculated exhaust emissions of passing vehicles. The total amount of illustrated emissions is confined to the road traffic within the monitored section.

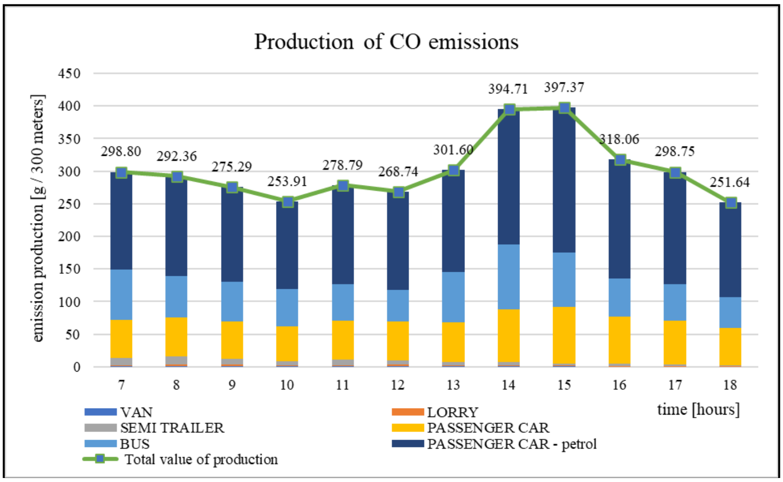

Figure 4
Production of CO emissions in the monitored section [authors]

Figure 4 portrays CO emissions in the examined section, indicating the peak between 2 pm and 3 pm when exhaust emissions reached 397 g/300 m. The largest amount of CO emissions was produced by petrol-powered vehicles and buses. The chart hits the trough at 6 pm when the traffic is the lightest. Vehicles of N1 category (Van) indicated the lowest emission levels.

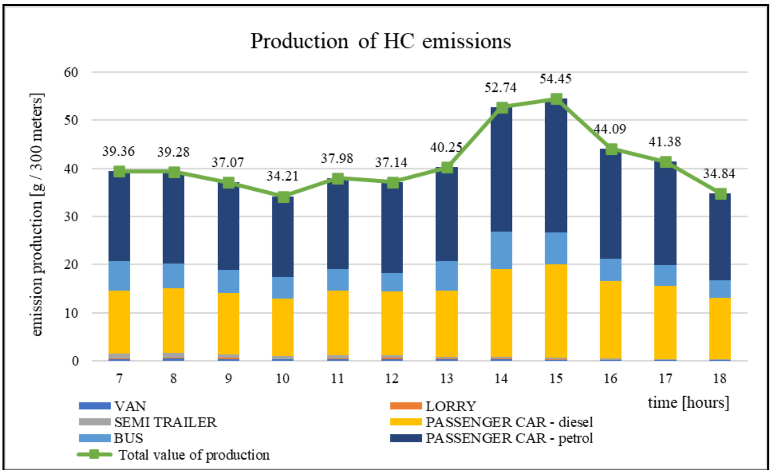

Figure 5

Production of HC emissions in the monitored section [authors]

Figure 5 demonstrates that the production of HC emissions rose to the peak between 2 pm and 3 pm, as in the event of CO. The overall emission value of HC was 54.45 g/300 m at that time. The largest volume of pollutants in the monitored section was produced by passenger cars - 419.86 g/300 m. The lowest emission rates were recorded in N2 category (Lorry), namely 2.02 g/300 m.

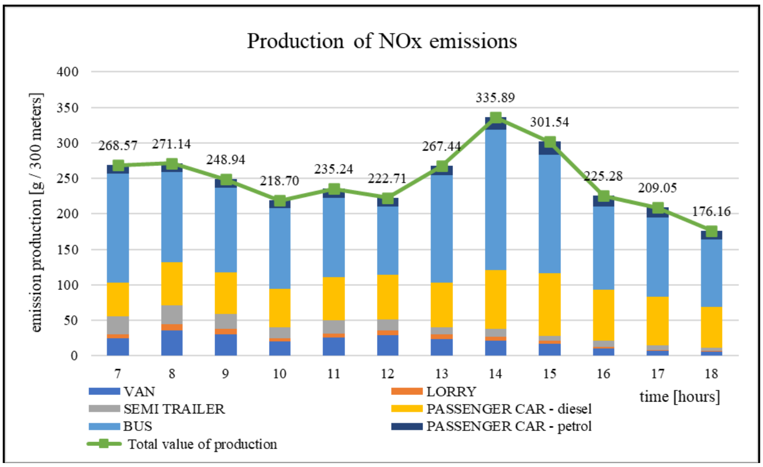

Figure 6

Production of NO_x emissions in the monitored section [authors]

The same scenario unfolds in the event of NO_x emissions. The measured exhaust gases topped the highest values at 2 pm - 335.89 g/300 m, indicating buses as the biggest polluters. As contrasted to previous cases, NO_x rates increased even in other vehicle categories. The total value of production is thereby even. Vehicles of N2 category (Lorry) showed the smallest numbers - 60.36 g/300 m. To make a crude comparison, the difference between emissions produced by buses and Lorries amounts to 1,501.36 g/300 m. This variation was calculated from the overall pollutants produced throughout a one-day survey.

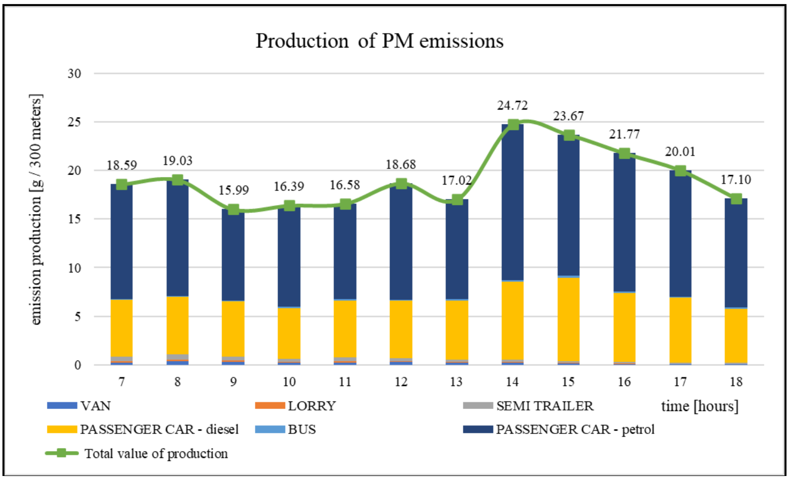

Figure 7
Production of PM emissions in the monitored section [authors]

Figure 7 suggests a situation similar to the previous charts. PM emissions reached the peak 24.72 g/300 m at 2 pm. What strikes the eye is that emission levels are the highest in passenger cars, especially petrol-powered vehicles. The production of other categories is almost negligible. The one-day survey detected the overall PM value 22.54 g/300 m for all vehicle categories, with passenger cars covering 221.04 g/300 m. This value represents 96.5% from the total amount of produced pollutants.

3.1 Survey Results Compared to the Weather Station

For a larger contribution to the science, we compared our results with values recorded by the weather station (NMSKO) located near the measured section. We may thereby suppose that results, i.e., recorded data, reflect the road traffic flow. Analyzing the produced statistics, we can estimate the extent to which the road traffic is impactful on the air quality, detecting the amount of released pollutants. Multiple studies [22, 23] argue that although the road traffic is not the only air polluter, its contribution tops the highest numbers.

The first step involved the data analysis from NMSKO. The weather station is operated by the Slovak Hydrometeorological Institute. The obtained information provided us with values recorded by the weather station during the days of our survey. The statistics on the air quality were updated every hour. We subsequently compared the data on emissions received from the weather station with values achieved by our survey, trying to discover a correlation. Exhaust emissions produced during the survey are expressed in g/300 m and fumes recorded by the weather station are suggested in g/m^3. Although the presented units cannot be fully compared, we can see a simple correlation between individual figures. The compiled statistics on NO_x, HC and PM are comparable only if they comply with the research and values recorded by the weather station. The following Table 5 contains the result of comparing in pairs with the final results.

Table 5
The result of comparison in pairs with the final results

	Weather station [μg/m^3]			Emission calculation [g/300 meters]		
	PM	**CO**	**NO_X**	**PM**	**CO**	**NO_X**
7	49	949	45	19	299	269
8	39	923	32	19	292	271
9	37	949	43	16	275	249
10	39	969	42	16	254	219
11	44	994	63	17	279	235
12	55	984	58	19	269	223
13	63	979	79	17	302	267
14	72	1020	120	25	395	336
15	67	1120	74	24	397	302
16	63	1003	68	22	318	225
17	64	967	53	20	299	209
18	59	989	49	17	252	176

The data determined by the calculation were compared with the data recorded by the measuring station. The results can be seen in Table 5. The data indicates a clear correlation between the observed values. This equivalence is further demonstrated graphically in Figures 8-10.

Table 6
Assessment of dependence between monitored data - correlation coefficients

PM	0.7351
CO	0.7109
NO_X	0.6112

Table 6 shows the values of the correlation coefficients for the monitored values of pollutants. It is an observation of the dependence between the data that was monitored by the air quality station and the data that was obtained by the research. The values of correlation coefficients correspond to direct dependence. For solid PM particles, the value of the correlation coefficient is at the level of 0.7351, which represents a high degree of dependence between the observed data. Similarly, for

CO emissions, the value of the correlation coefficient is at the level of 0.7109. For NO_X emissions, the value of the correlation coefficient is at the level of 0.6112, which represents a slight dependence. Also, in this case, it is possible to assume that the NO_X values are influenced by the passage of road transport vehicles. It is possible that the values declared by the measuring station could have been affected by pollution other than just the influence of road traffic.

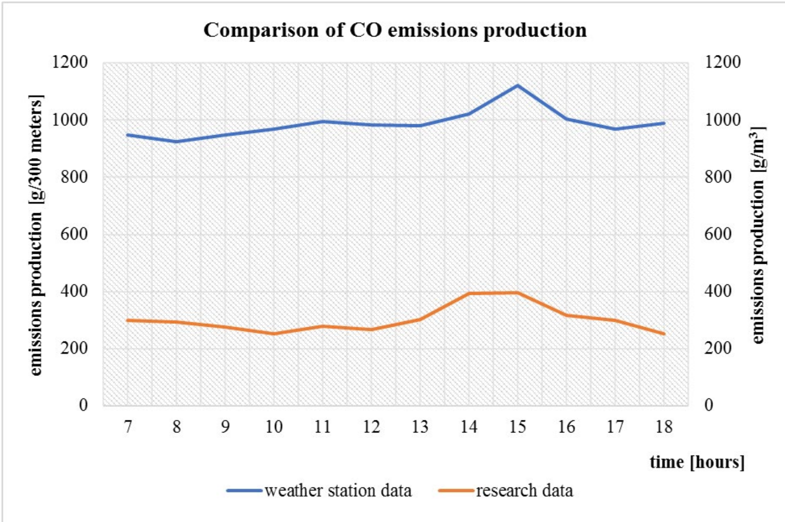

Figure 8
Comparison of CO emissions distribution – weather station vs. research [authors]

Figure 8 portrays the course of CO emissions released to the atmosphere. While the data recorded by the weather station involve emissions from all contributing factors (general value), our research is confined to traffic pollutants. The diagram, however, suggests that both curves reflect similar trends, indicating that road traffic is hugely impactful on the air quality. The weather station curve reaches the peak between 3 pm and 4 pm, whereas the curve tracking our survey tops the values between 2 pm and 3 pm.

Courses describing NO_x emissions depicted in Figure 10 clearly reflect significant changes in investigated values. In general, we may argue that differences between values recorded by the weather station and figures calculated from the survey have compelling reasons. The survey calculations are derived from data reflecting the average city drive, emission class and fuel type. The produced emissions are expressed in g/300 m. The research only deals with emissions produced by monitored vehicles, whereas the weather station includes all air city pollutants, e.g., chimney fumes, industry, etc. Striking variations in the compared values may also involve changeable weather conditions, daily temperature differences, humidity and heat, traffic collisions and other transport situations affecting the air quality.

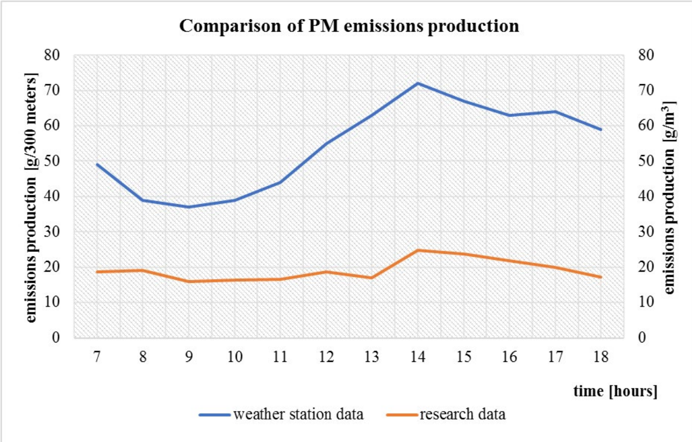

Figure 9

Essential Comparison of PM emissions distribution – weather station vs research [authors]

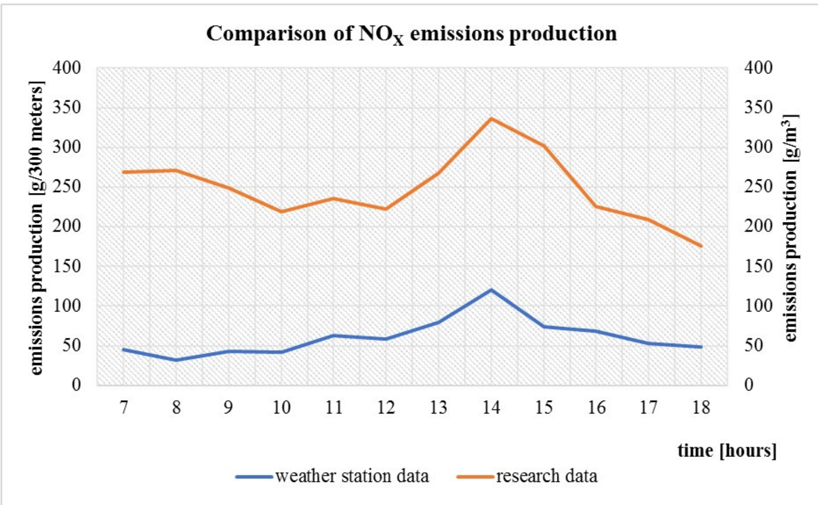

Figure 10

Comparison of NO_x emissions distribution – weather station vs. research [authors]

4 Discussion

Most cities all over the world have recently been witnessing rapid urbanization. Municipalities are making great effort to establish effective transport infrastructure to comply with rapid urban and economic development. The local industrial state heavily depends on good mobility, i.e., how easy is to move people, products and services using an efficient transport system [24-26]. Abdull, et al., [27] carried out identical research on road traffic emissions in urban areas, specifically a freeway in the city of Kyoto, Japan, involving COPERT PC program for making calculations. The traffic survey revealed the heaviest traffic flow of trucks between 7 am and 9 am, whereas passenger cars hit the peak in the morning rush hour. The overall traffic flow fell to the trough around 12 pm. The number of passing passenger cars did not reach the top again until 5 pm, followed by a steady decline until 6 pm. Truck intensity did not increase again until 2 pm and slumped by 6 pm. Analyzing the traffic speed, the authors found out that more than 75% of vehicles did not go under 46 km/h. The growing traffic volume leads to a slowdown, causing minor traffic disruption. Continuous speedup-slowdown adversely affects the traffic dynamics, hugely increasing released emissions. COPERT IV for the emission analysis revealed that heavy traffic at low speed produced the largest quantity of harmful substances, detecting pollutants as follows: PM, C6H6, CO, and NO_x. Trucks produced higher amount of PM and NO_x compared to passenger cars, as truck engines were working to the maximum due to the disrupted traffic flow. Higher emissions create road dust clouds and cause brake, tire and roadway wear-off. C6H6 (benzene) constituted 1% of the volume of petrol, largely contributing to the increased emissions of passenger cars. CO pollutant also scaled with the use of passenger cars, which constituted the largest number of the examined vehicles [28]. The survey involving buses might have been biased by the COVID-19 pandemic on-set. The impact of the crisis on the bus service and the imposed restrictions were analyzed by Czodörová, et al., [29]. Moreover, Mikulski, et al., [30] investigated the reduction of transport-related air pollution and the impact of the COVID-19 pandemic on the level of NO_x emissions in one of the big cities in Poland.

Mostafavi, et al., [31] examined pollution in the city of Arak in Iran. The authors explored the impact of industrial harmful substances and road traffic on air pollution rates, focusing on pollutants including: NO_x, CO and SO2. Annual reports on industrial sectors, vehicle data, traffic flow and weather records comprised the conceptual framework of the analysis. The authors compared the obtained results with real statistics recorded by weather stations. Modeling the input data involved 3 types: information on permanent and temporary sources of pollution, local weather records, topographical data (mountain range height, valley depth, wind speed and direction, temperature and humidity). The analysis proved that road traffic is the largest polluter increasing NO_x, CO and SO2 levels. To change the unfavorable situation would involve supporting public transport, promoting electric vehicles and bicycles, imposing traffic restrictions within the city center or building highways. Industrial companies largely contributing to the air pollution would have to be relocated to the outskirts [31].

Increased exhaust emissions occur particularly strongly in the initial phase of the combustion engine operation, which has been pointed out in many scientific studies [32-35]. For example, Jayaratne, et al., [36] explored a cold start of engines.

The authors revealed that cold starts of petrol cars produce increased CO emissions, lasting several travelled kilometers. The high pollution levels prevailed throughout the night, when the outermost atmospheric layer is sinking down, pressing the air closer to the Earth. Driving vehicles with fully warmed-up engines showed relatively low CO emissions, leading to higher pollutant rates in the evening hours. Vehicles with fully warmed-up engines going to the city center through the measured section in the morning leave the city with cold engines, thus releasing more emissions [35]. The impact of cold starts on emissions and confirming its theory may be developed in further research.

- The survey revealed that road traffic in the monitored part of Trenčín was not re-sponsible for the air pollution to the extent we had expected. It was also proved that passenger cars are the biggest contributor to emission production given their largest representation in the research. The research conducted investigated that passenger cars had the strongest representation (90%) in our experiment. Other categories comprised 10%, out of which the category Lorry constitutes the smallest number (1%). Although haulage releases fewer emissions than passenger transport, certain restrictions on freight transport must be imposed to ensure safety and avoid traffic disruption. These vehicle categories are primarily responsible for excessive roadway wearoff and an increased noise level within the monitored area. Please only use font type Times Roman CE.
- When it comes to reducing emissions and the number of vehicles in motion (limiting the phenomenon of transport congestion) on the inner roads of metropolises, one of the directions of action is, for example, the vehicle rental system, as noted in the works [37] or in the further perspective of transport development, shared autonomous vehicles SAV [38]. Both of these concepts lead to a completely different perception and use of transport in modern cities. The first of them assumes no ownership of the vehicle and greater efficiency in the use of rental vehicles and limits their number in traffic and in parking lots. The second concept goes even further beyond the advantages mentioned in the first concept, it enables automatic driving, increasing traffic flow and thus the capacity of routes, through communication between vehicles and infrastructure, and real-time traffic monitoring, which reduces travel time [39]. Both solutions serve to reduce fuel consumption and therefore emissions. Moreover, the concept of autonomous vehicles assumes that an electric motor will be used to power these vehicles [40]. This is given that it is easier to control the electric motor than the internal combustion engine in the vehicle [41], and the computing power saved in this way can be used to control the vehicle and its orientation in the field [42].

Conclusions

The presented research shows the potential of current conventional drive and conventional driving vehicles to reduce emissions and what is translated into the identification of the overall level of pollution from transport in the urban area. In addition, other directions of reducing emissions in cities were signaled, related not only to the development of electric vehicles, but also autonomous vehicles in the future.

The experimental results of the impact of road traffic mobility on the environment in the 1st class road Hasičská Street No. 61 in the city of Trenčín, Slovakia and complex emission quantification proved that passenger cars are the most distinct category contributing to the air pollution regarding all recorded pollutants, i.e., CO, HC, NO_x and PM.

Road haulage comprising category N3 – SEMI TRAILER hit the road mostly in the late morning hours, arguably supplying local storehouses and logistic centers or transporting goods. Our survey indicated that category N3 is the largest polluter of all monitored freight tiers regarding CO, HC and PM emissions, despite having the smallest representation in our experiment.

The city of Trenčín and its surroundings concentrate numerous logistic storehouses and centers including CT Park Trenčín – 2 km away, Coop Trenčín Logistics Center – 4.5 km away and Sihot Park Chocholná logistic center – 10.5 km away from the examined area. We suppose that vehicles of N3 category transport goods to the storehouses or other logistic and distribution centers through the monitored transport territory of Trenčín.

As for the further research, we suggest that subsequent in-depth analysis of the impact of road traffic mobility emissions on the environment should, inter alia, involve traffic congestions, types and numbers of vehicles classified according to specific emission standards, including the influence of weather conditions and air pressure on the air pollution in the area.

The results of the research declare that the biggest air polluter in the monitored area is precisely passenger vehicles. This is due to the fact that their number represents 95% of the total number of vehicles passed. It is this phenomenon that results in a large amount of pollutants emitted into the air. In the future, it is necessary to focus on ways to reduce these emissions. One of the possibilities is increasing the share of electric cars and vehicles powered by an alternative drive.

This is primarily about reducing emissions directly in urban areas. So far, low-emission zones in cities have not been introduced in the territory of the Slovak Republic. The results of the research can be taken into account as a tool for monitoring pollution caused by road traffic anywhere within the city. The results clearly point to the fact that even passenger vehicles pose a threat in the process of air pollution.

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References

[1] Prideaux, B. (2000) The role of the transport system in destination development. Tourism Management, Vol. 21, No. 1, pp. 53-63, DOI: 10.1016/S0261-5177(99)00079-5

[2] Harrison, R. M., Beddows, D. C. (2017) Efficacy of recent emissions controls on road vehicles in Europe and implications for public health. Scientific Reports, Vol. 7, 1152 DOI: 10.1038/s41598-017-01135-2

[3] Öhrström, E., Skånberg, A., Svensson, H., Gidlöf-Gunnarsson, A. (2006) Effects of road traffic noise and the benefit of access to quietness. Journal of Sound and Vibration, Vol. 295, Nos. 1-2, pp. 40-59, DOI: 10.1016/j.jsv.2005.11.034

[4] Pénard-Morand, C., Annesi-Maesano, I. (2004) Air pollution: from sources of emissions to health effects. Breathe, Vol. 1, No. 2, pp. 108-119, DOI: 10.1183/18106838.0102.108

[5] 5. Achour, H., Carton, J., Olabi, A.G. (2011) Estimating vehicle emissions from road transport, case study: Dublin City. Applied Energy, Vol. 88, No. 5, pp. 1957-1964, DOI: 10.1016/j.apenergy.2010.12.032

[6] Panko, J., Kreider, M., Unice, K. (2018) Review of tire wear emissions: a review of tire emission measurement studies: identification of gaps and future needs. Non-Exhaust Emissions, pp. 147-160, DOI: 10.1016/B978-0-12-811770-5.00007-8

[7] Szczucka-Lasota, B., Węgrzyn, T., Łazarz, B., Kamińska, J. A. (2021) Tire pressure remote monitoring system reducing the rubber waste. Transportation Research Journal Part D Transport and Environment, Vol. 98, 102987, DOI: 10.1016/j.trd.2021.102987

[8] Zum Hagen, F. H. F., Mathissen, M., Grabiec, T., Hennicke, T., Rettig, M., Grochowicz, J., Vogt, R., Benter, T. (2019) Study of brake wear particle emissions: impact of braking and cruising conditions. Environmental Science and Technology, Vol. 53, No. 9, pp. 5143-5150, DOI: 10.1021/acs.est.8b07142

[9] Adamec, V., Liçbinský, R., Cholava, R. (2011) Doprava a zdravotné riziká dopravy. Transactions on Transport Sciences, Vol. 4, No. 3, 115, DOI: 10.2478/v10158-011-0011-y

[10] Krzyżanowski, M., Kuna-Dibbert, B., Schneider, J. (Eds.) (2005) Health effects of transport-related air pollution. WHO Regional Office Europe

[11] McMichael, A. J. (1997) Transport and health: assessing the risks. In Health at the Crossroads. Transport Policy and Urban Health. London School of Hygiene and Tropical Medicine Fifth Annual Public Health Forum

[12] Sustainable transport, https://www.worldbank.org/en//transport/overview, accessed on 2021-09-14

[13] Ooi, G. L. (2008) Cities and sustainability: Southeast Asian and European perspectives. Asia Europe Journal, Vol. 6, No. 2, pp. 193-204, DOI: 10.1007/s10308-008-0176-0

[14] Greenhouse gas emission intensity of fuels and biofuels for road transport in Europe, from https://www.eea.europa.eu/data-and-maps/indicators/greenhouse-gas-emissions-intensity-of/assessment, accessed on 2021-09-15

[15] Harantová, V., Hájnik, A., Kalašová, A. (2020) Comparison of the flow rate and speed of vehicles on a representative road section before and after the implementation of measures in connection with COVID-19. Sustainability, Vol. 12, No. 17, 7216, DOI: 10.3390/su12177216

[16] Pavlovic, J., Marotta, A., Ciuffo, B. (2016) CO_2 emissions and energy demands of vehicles tested under the NEDC and the new WLTP type approval test procedures. Applied Energy, Vol. 177, pp. 661-670, DOI: 10.1016/j.apenergy.2016.05.110

[17] Sun, C., Li, V. O., Lam, J. C., & Leslie, I. (2019) Optimal citizen-centric sensor placement for air quality monitoring: A case study of city of Cambridge, the United Kingdom. IEEE Access, 7, 47390-47400

[18] Slovak Hydrometeorological Institute, available onilne from https://www.shmu.sk/sk/?page=1&id=oko_imis accessed on 2021-09-07

[19] Hitchcock, G., Conlan, B., Kay, D., Brannigan, C., Newman, D. (2014) Air quality and road transport: impacts and solutions. London

[20] Slovak Hydrometeorological Institute 2 - air pollution, from https://www.shmu.sk/sk/?page=2049&id=1093, assessed on 2021.09.14

[21] Guo, J., Ge, Y., Hao, L., Tan, J., Li, J., Feng, X. (2014) On-road measurement of regulated pollutants from diesel and CNG buses with urea selective catalytic reduction systems. Atmospheric Environment, Vol. 99, pp. 1-9, DOI: 10.1016/j.atmosenv.2014.07.032

[22] Landrigan, P. J. (2017) Air pollution and health. The Lancet Public Health, Vol. 2, No. 1, pp. e4-e5, DOI: 10.1016/S2468-2667(16)30023-8

[23] Jaskiewicz, M., Lisiecki, J., Lisiecki, S., Pokropinski, E., Wieckowski, D. (2015) Facility for performance testing of power transmission units.

Scientific Journals of the Maritime University of Szczecin, Vol. 114, No. 42, pp. 14-25

[24] Kwok, R. C., Yeh, A. G. (2004) The use of modal accessibility gap as an indicator for sustainable transport development. Environment and Planning A: Economy and Space, Vol. 36, No. 5, pp. 921-936, DOI: 10.1068/a3673

[25] Stanley, J. K., Hensher, D. A., & Loader, C. (2011) Road transport and climate change: Stepping off the greenhouse gas. Transportation Research Part A: Policy and Practice, 45(10), 1020-1030

[26] Kazancoglu, Y., Ozbiltekin-Pala, M., & Ozkan-Ozen, Y. D. (2021) Prediction and evaluation of greenhouse gas emissions for sustainable road transport within Europe. Sustainable Cities and Society, 70, 102924

[27] Abdull, N., Minoru Y., Yoko S. (2020) Traffic characteristics and pollutant emission from road transport in urban area. Air Qual Atmos Health, Vol. 13, pp. 731-738, DOI: 0.1007/s11869-020-00830-w

[28] Skrúcaný, T., Kendra, M., Čechovič, T., Majerník, F., Pečman, J. (2021) Assessing the Energy Intensity and Greenhouse Gas Emissions of the Traffic Services in a Selected Region. LOGI – Scientific Journal on Transport and Logistics, Vol. 12. No. 1, pp. 25-35, DOI: 10.2478/logi-2021-0003

[29] Cződörová, R., Dočkalik, M., Gnap, J. (2021) Impact of COVID-19 on bus and urban public transport in SR. Transportation Research Procedia, Vol. 55, pp. 418-425, DOI: 10.1016/j.trpro.2021.07.005

[30] Mikulski, M., Droździel, P., Tarkowski, S. (2021) Reduction of transport-related air pollution. A case study based on the impact of the COVID-19 pandemic on the level of NO_x emissions in the city of Krakow. Open Engineering, Vol. 11, No. 1, pp. 790-796, DOI: 10.1515/eng-2021-0077

[31] Mostafavi, S. A., Safikhani, H., Salehfard, S. (2021) Air pollution distribution in Arak city considering the effects of neighboring pollutant industries and urban traffics. International Journal of Energy and Environmental Engineering, Vol. 12, No. 2, pp. 307-333, DOI: 10.1007/s40095-020-00379-5

[32] Ambrozik, A., Ambrozik, T., Kurczyński, D., Łagowski, P., Trzensik, E. (2014) Cylinder pressure patterns in the SI engine fuelled by methane and by methane and hydrogen blends. Solid State Phenomena, Vol. 210, pp. 40-49, DOI: 10.4028/www.scientific.net/SSP.210.40

[33] Cui, Y., Peng, H., Deng, K., Shi, L. (2014) The effects of unburned hydrocarbon recirculation on ignition and combustion during diesel engine cold starts. Energy, Vol. 64, pp. 323-329, DOI: 10.1016/j.energy.2013.10.083

[34] Figlus, T., Konieczny, Ł., Burdzik, R., Czech, P. (2015) The effect of damage to the fuel injector on changes of the vibroactivity of the diesel engine during its starting. Vibroengineering Procedia, Vol. 6, pp. 180-184

[35] Giechaskiel, B., Zardini, A. A., Clairotte, M. (2019) Exhaust gas condensation during engine cold start and application of the dry-wet correction factor. Applied Sciences, Vol. 9, No. 11, 2263, DOI: 10.3390/app9112263

[36] Jayaratne, R., Thai, P., Christensen, B., Liu, X., Zing, I., Lamont, R., Dunbabin, M., Dawkins, L., Bertrand, L., Morawska, L. (2021) The effect of cold-start emissions on the diurnal variation of carbon monoxide concentration in a city centre. Atmospheric Environment, Vol. 245, 118035, DOI: 10.1016/j.atmosenv.2020.118035

[37] Koller, T., Tóth-Nagy, C. Perger, J. (2022) Implementation of vehicle simulation model in a modern dynamometer test environment. Cognitive Sustainability, Vol. 1, No. 4, DOI: 10.55343/cogsust.29

[38] Zöldy, M. (2019) Improving heavy duty vehicles fuel consumption with density and friction modifier. International Journal of Automotive Technology, Vol. 20, No. 5, pp. 971-978, DOI: 10.1007/s12239-019-0091-y

[39] Salisu, U. O., Oyesiku, O. O. (2020) Traffic Survey Analysis: Implications for Road Transport Planning in Nigeria. LOGI – Scientific Journal on Transport and Logistics, Vol. 11, No. 2, pp. 12-22, DOI: 10.2478/logi-2020-0011

[40] Faryński, J. J., Żardecki, D. P., Dębowski, A. (2021) Study of the problem and the idea of operation of four-wheel-steering cars. The Archives of Automotive Engineering – Archiwum Motoryzacji, Vol. 94, No. 4, pp. 39-59, DOI: 10.14669/AM.VOL94.ART4

[41] Tucki, K., Orynycz, O., Wasiak, A., Świć, A., Mruk, R., & Botwińska, K. (2020) Estimation of carbon dioxide emissions from a diesel engine powered by lignocellulose derived fuel for better management of fuel production. Energies, Vol. 13, No. 3, Art. no. 561, DOI: 10.3390/en13030561

[42] Zöldy, M., Baranyi, P. (2023) Definition, Background and Research Perspectives Behind "The Cognitive Mobility Concept". Infocommunications Journal, Special Issue: Internet of Digital & Cognitive realities, Vol. 2023, pp. 35-40, DOI: 10.36244/ICJ.2023.SI-IODCR.6