ANALYSIS OF THE TRAFFIC PARAMETERS ON A SECTION IN THE CITY OF THE NATIONAL ROAD DURING SEVERAL YEARS OF OPERATION

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Resume

The study carried out an analysis of the vehicle traffic parameters on a national road in 2011-2016. The variability and uncertainty of results were evaluated. An analysis of traffic data recorded on the city's entry and exit lanes was carried out. The variations in traffic volume are of interest e.g. in dynamic traffic management systems and navigation services, examining the benefits of flexible work time and places and assessing the environmental effects of traffic congestion. Research has shown that the assumption that lanes perform equally is not always true. Traffic volume models should be periodically calibrated taking into account the shape of the daily profile, which may, for example, allow public transport timetables to be more responsive to the needs of travelers.

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1 Introduction

Studies on the nuisance of transport for people and nature are currently presented in numerous publications around the world [1-2]. The authors most often present their considerations either as a part of the idea and policy of "Sustainable transport development" or "Smart City" or as a part of the methodology associated with the "Intelligent Transport System" [3]. Air pollution, noise and vibration, as well as other phenomena that create environmental hazards, e.g. road accidents, depend to a large extent on traffic parameters: vehicle traffic intensity, vehicle speed, vehicle structure [4-5]. Therefore, the basis for all the research in this area must be the measurement and analysis of data, as a part of monitoring the road traffic [6-9]. For these reasons, the project "Expansion of Sciegiennego Str. along National Road No. 73 in Kielce" obtained funding from the European Regional Development Fund under the Operational Program Infrastructure and Environment 2007-2013 priority: VIII Transport safety and national networks transport action: 8.2. National roads outside the TEN-T network. The entire investment was located within the administrative boundaries of the city of Kielce on the section from Popieluszki Av. to the city limits along the national road No. 73, Figure 1.

Popieluszki Av. is a road with four lanes of traffic. The road is a part of the eastern bypass around Kielce and part of the national road No. 73 (Warszawa/Lodz - Kielce - Tarnow - Krosno), which is directly connected with the Trans-European Transport Networks (TEN-T). As a part of the project, the widening and strengthening of the pavement was carried out by making a bituminous overlay of the existing western roadway, construction of the second eastern roadway. Over the extended road, 5 km of pedestrian-bicycle paths and 3 bridge structures were created. A rainwater sewage system, acoustic screens, street lighting, traffic lights were built, the existing water supply system was rebuilt and secured. Implementation of such a large investment contributed to increase in safety but also caused a lot of acoustic nuisance for local residents and road users during the construction. This paper presents an analysis of results of the traffic volume measurements recorded by monitoring stations in period from 2011 up to 2016.

2 Related works

The overview of the traffic data collection systems were presented by Bennett at al. [11] and Gajda at al. [12]. Such systems can be divided into intrusive, e.g. inductive loop detectors, magnetic sensor, pneumatic tubes, weight-in-motion sensor, or non-intrusive sensors, e.g. microwave systems, cameras, GPS based systems. The recorded traffic volume data are the most often

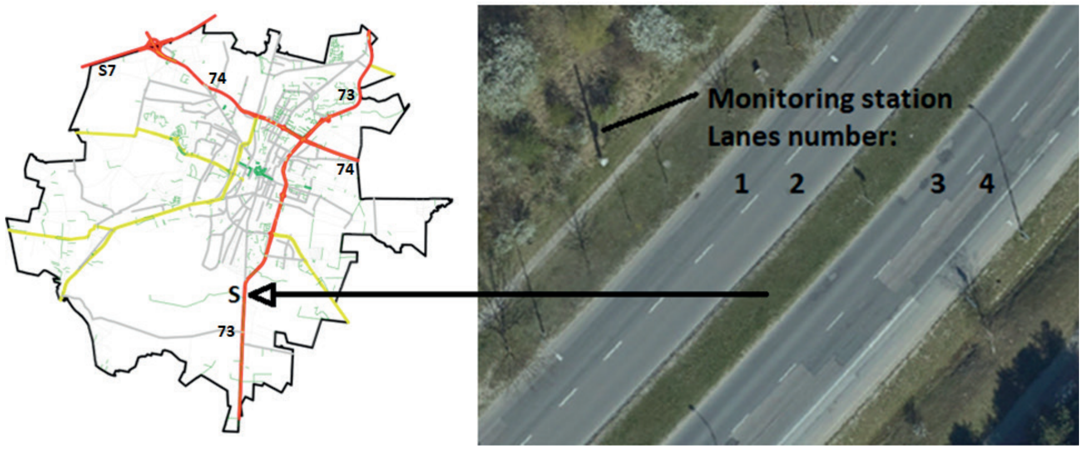


Figure 1 *Layout of streets in Kielce [10]*

analyzed using statistical or computational intelligence methods [13]. Analysis of the distribution of the traffic volume showed that in the case of uninterrupted traffic flows, e.g. on motorways, the normal distribution [14] occurs and in the case of interrupted traffic flows, e.g. in urban areas, it is usually non-normal [15]. Traffic in urbanized areas is characterized by high variability, which significantly hinders traffic management, e.g. route planning and vehicle travel time. The problem of variability can be analyzed depending on the adopted time interval and location of the road in the communication system of an urbanized area. In the period of one year, one can notice the so-called seasonality of vehicle traffic. Within one week, the traffic volume on weekdays differs significantly from the traffic on weekends and holidays. The period of one day can be divided into 24 hours. In each subsequent hour of the day, vehicle traffic parameters may be different [16]. It is also possible to increase the detail of measurements and divide the day into a larger number of sub-intervals [17], e.g. 48, 96 or even 1440, which however, makes analysis of results more complicated. Many studies in the literature are related to influence of the pre-determined parameters on changes in the traffic volume. One such parameter is the day of the week. Rakha and van Aerde [14] found that on Mondays and Fridays the traffic volume was different from the core weekdays (Tuesday-Thursday), but speeds and occupancy were not. They also examined the traffic flow, speed and occupancy histograms and showed that they have a normal distribution. Stathopoulos at al. [18] investigated the daily traffic volumes and found no significant differences between weekdays. However, the weekend days differed significantly from weekdays. The results indicate that the temporal distributions of traffic volumes are non-normal. The analyzed traffic volume data exhibit different patterns depending on the direction of movement (toward, in, or away from the central business district) and the periods of the day. Chrobok at al. [19] compared the patterns of the daily traffic volume based on the measurement error. They pointed to four distinctive groups: weekdays from Monday until Thursday, Friday and days before holidays, Saturday and holidays and presented that the traffic volume pattern from Monday until Thursday has asymmetry due to the traffic tidal flow. Weijermars [20] showed differences in the traffic volume for each day of the week using the cluster analysis. The clustering based on the 15 minutes' traffic volumes resulted in a classification into five clusters (four clusters of weekdays were identified: Mondays, core weekdays, Fridays and days within holiday periods) that show distinct daily flow profiles and are representative for the days within the clusters. Besides the general shape of the daily flow profile, the shape of the pick periods is important for the traffic management, as well. Weijermars was the first to suggest the need to study the shape of the traffic volume profiles. The study concluded that shape of the daily volume profiles may differ between different type of days and motivates the need for such an analysis of the traffic patterns based on their inherent shape characteristics. Calafate at al. [16] detected the traffic volume patterns according to the day of the week, hour and type of street. To achieve this goal, he applied a clustering technique in order to automatically classify streets according to their daily traffic pattern. The problem of differences in the traffic shape and magnitude was continued by Guardiola et al. [21]. The method Functional Principal Component Analysis was used to identify the three Principal Components. The first appears to separate working from non-working days, the second may relate to the year and the third may be a seasonal factor. Crawford at al. [22] used the Functional Linear Regression Models for estimating the effect of the predictable variability, due to known explanatory factors, on the daily traffic flow profiles, for example the day of the week. The contribution of the research of Kayani [15] is use of the Mathematical Morphology tools to achieve proper classification of daily traffic profiles. Through the employment of such tools development of an analysis of shape is carried out in an effort to generate interpretable classification of historical daily traffic profiles. Use of the Partition Around Medoids (PAM) algorithm is employed to carry out the classification of daily profiles.

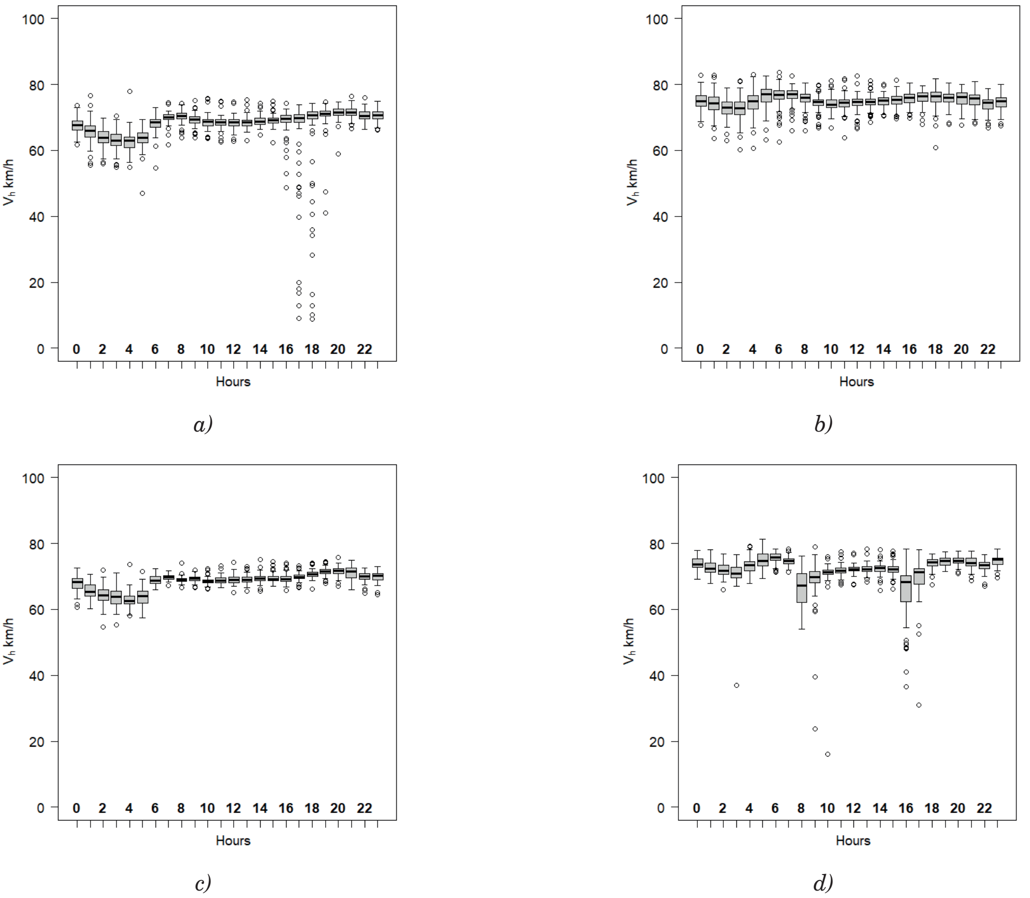


***Figure 2** Box plots for weekdays of relation between the median average of annual hourly traffic speed and time for 24 h period a) in 2011 on lanes L_{12}, b) in 2011 on lanes L_{34} c) in 2016 on lanes L_{12}, d) in 2016 on lanes L_{34}*

The goal of this research was to obtain an insight into the traffic volume, measurement uncertainty, detecting traffic patterns according to the day of the week, hour and lanes and in particular on weekdays. For this purpose, the aggregated data for the period from 2011 to 2016 in the 24-hour interval have been divided into 4 sub-intervals of various lengths. To evaluate the results, a traffic volume model using the linear regression method was proposed.

3 Traffic volume measurements

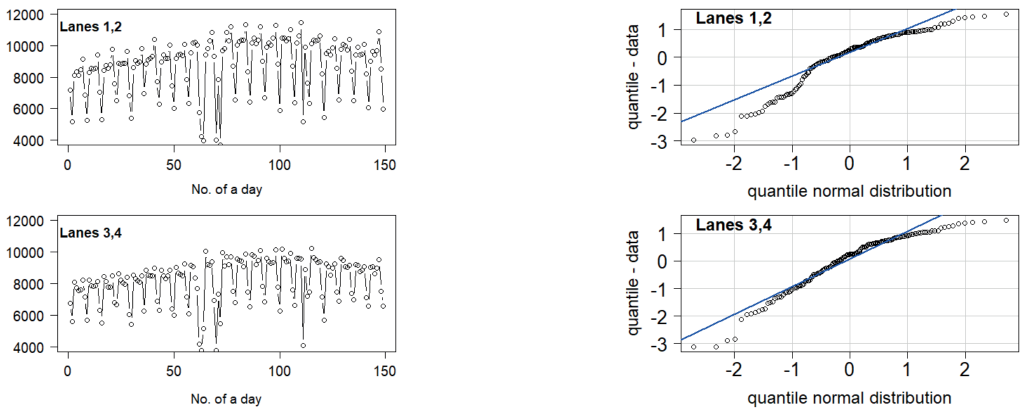
The traffic volumes analyzed in this study were measured by the permanent station recording traffic volume and sound pressure levels, located in Popieluszka Av. in Kielce. The Popieluszka Av. is the main part of the outward route from the centre of Kielce towards Tarnow. The traffic monitoring station is located between the two intersections at a distance of about 500 m. The station includes a road radar box, a sound level meter and a weather station. The traffic volume was measured by WAVETRONIX digital radar with an operating frequency of 245 MHz [23]. The measurements were carried out for 24 hours a day throughout the year 2011-2016. The traffic volume and speed data were recorded every minute (buffer) and the averaged results were reported every hour. Owing to various technical problems, the monitoring station did not always correctly record traffic parameters and the database was incomplete. The counts were used to calculate the traffic volume (understood as the sum of the number of vehicles: passenger, heavy, medium heavy, two wheelers recorded within a time interval at all four lanes) and speed, split into seven days of the week, hours. As for some of the days no data were reported, only the days for which the traffic was recorded every hour for the whole 24-hour period were taken into account in the analysis. In this way, 803 days were selected for further analysis, i.e. 19,272 records, at various seasons of the year. Parameters such as: traffic volume, standard uncertainty of the measurement results (u_a), coefficient of positional variation of traffic volume (V_q), relative traffic volume, were determined in accordance with the procedure presented in [24]. The relative traffic volume was determined according to formula:

$$VOL_{rel}(d,L) = VOL(d,L)/VOL_{max}(d,L), \quad (1)$$

where:
$VOL(d,L)$ - median of the traffic volume,
$VOL_{max}(d,L)$ - the maximum median of the traffic volume of the vehicle set analysed on road lanes L_{12} and L_{34},
d - day of week.

a) b)

Figure 3 *Median of annual daily traffic volume in the years 2011-2016*



a) b)

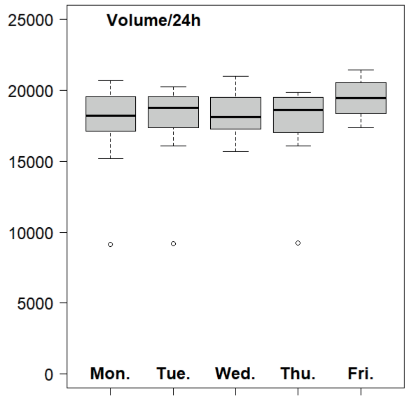
Figure 4 *Traffic volume in 2011 a) values on individual days (data from 19.02. to 31.07.) for lanes L_{12} and L_{34}, b) quantile graph for lanes L_{12} and lanes L_{34}*

4 Measurements and calculations results

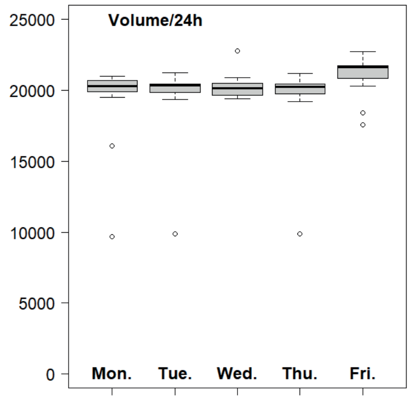
The median of average vehicle speed in the period studied from 2011 to 2016 slightly changed, which is shown in Figure 2. Nevertheless, the intersections of the road with traffic lights and speed cameras built as part of the renovation contributed to a decrease in its value, especially during the traffic rush hours. One can also see that the amount of outliers has decreased significantly. It is worth noting that the speed charts on entry lanes (L_{12}) and exit lanes (L_{34}) from the city and for different years have different courses, especially in 2016. In 2016, in lanes L_{12} from midnight, the median speed decreases to its minimum value at 4 AM and then increases to 7 AM. Then, in the subsequent hours, its value changes slightly and the highest occurs at 8 PM. On the other hand, for the lanes L_{34}, both the shape of the speed graph and values in individual hours, especially in traffic rush hours, are different.

The deteriorating condition of the road and the nuisance associated with its renovation contributed to a decrease in traffic in the years 2011 to 2016 by 9.7%. There was a 43.7% decrease for heavy vehicles, 10.7% for medium heavy vehicles and 3.3% for passenger vehicles. However, in 2016 there was an increase in traffic (compared to 2011) of all vehicles by 13.1%, passenger vehicles by 19.3%, medium heavy vehicles by 12%, as shown in Figure 3.

Examples of traffic volume measurement results, after aggregation for 24-hour intervals, before and after the road renovation, are presented in Figure 4. In 2011, there is some increase in traffic volume in the middle of the year (the so-called seasonality known in the literature [25]). However, after the road renovation, such seasonal growth was not recorded in 2016. The Shapiro-Wilk statistical tests carried out, which are based on the positional statistics of the sample, allow to reject the H0 hypothesis about compliance of the measurement data distribution with the normal distribution at the significance level of 0.05. In the cases raising doubts as to the normality of the tested distribution, the Jarque-Bera test was additionally carried out, which belongs to the group of tests based on the moments from the sample. For this purpose, measures of the shape of the distribution were calculated, such as skewness and kurtosis, whose values should be close to zero and three. The Jarque-Bera test results also allow to reject the H0 hypothesis.



a)



b)

Figure 5 *Box plots for traffic volume determined for weekdays a) in 2011, b) in 2016*

The statistical calculations carried out showed that in 2011 on lanes L_{12} skewness was -0.99 and kurtosis 3.31, while on lanes L_{34} skewness was -0.94 and kurtosis 3.52, which confirms that distribution of the traffic values deviates from normal. The quantile charts, shown in Figure 4b confirm these conclusions. A deviation from the normal distribution may cause the calculated values of certain parameters, e.g. standard deviation, measurement uncertainty to be incorrect [26-27].

For this reason, the authors decided to split the results for the entire year into seven groups representing the measurement of the weekdays and weekends, as shown in Figure 5. The plots show that in 2011, from Monday to Thursday, the traffic volumes change slightly up and down, increase on Friday and decrease on weekend. The nature of these changes is consistent with the literature of the subject [20, 25]. In 2016, however, changes in traffic on weekdays and weekend, as well as the ranges between the C75 and C25 percentiles, were much smaller than in 2011. Statistical tests carried out showed that on some days of the week, e.g. Fridays in 2012, Saturdays and Sundays in 2013, Mondays in 2014, there were no grounds for rejection H0 hypotheses. Values in 2011 of the daily traffic volume parameters for each day of the week are presented in Table 1. The median traffic volume on lanes L_{12} in each day except Sundays is higher than on lanes L_{34}. These differences are less than 10% (taking into account the measurement uncertainty) and their value for each day is different, e.g. on Thursdays 3.6%, Fridays 9.8%. Values of the traffic volume measurement uncertainty was ranging from 133 to 312 veh/24 h on lanes L_{12} and 141 to 239 veh/24 h on lanes L_{34}. The coefficient of variation V_q was ranging from 4.4% to 8.5% on lanes L_{12} and from 4.9% to 7.9% on lanes L_{34}. Differences in values of the coefficient V_q in both directions and on individual days are about 1%, except for Saturdays when they are about 3.4%.

On Sundays, the median traffic volume of vehicles is lower than on Saturdays by approximately: 2000 veh. - on lanes L_{12}, 800 veh. - on lanes L_{34}.

In 2016, values of the median traffic volume on lanes L_{12} and L_{34} are similar, as shown in Table 2. There are only significant differences on Fridays and weekend. The coefficient V_q and the measurement uncertainty for both lanes are similar. Values of the traffic volume measurement uncertainty on lanes L_{34} was ranging from 91 to 422 veh/24 h. After the road renovation in 2016, the coefficient V_q was ranging from 1.0 to 4.4% and was much lower than in 2011.

Knowledge of the statistical measures' values of the

Table 1 *Values of statistical measures of traffic volumes on lanes-L_{12} and L_{34} determined for each average annual day of the 2011*

	2011 lanes-L_{12}			2011 lanes-L_{34}		
Day	Median veh/24 h	Vq %	u_a veh/24 h	Median veh/24 h	Vq %	u_a veh/24 h
			Weekday			
Monday	9188	7.1	293	9037	6.0	237
Tuesday	9612	5.9	312	9074	6.4	215
Wednesday	9419	5.0	170	8702	6.0	148
Thursday	9711	6.7	240	8911	5.6	239
Friday	10379	4.4	133	9199	5.7	141
			Weekend			
Saturday	8019	8.3	183	7144	4.9	165
Sunday	6041	8.5	160	6302	7.9	202

***Table 2** Values of statistical measures of traffic volumes on lanes L_{12} and L_{34} determined for each average annual day of the 2016*

	2016 lanes-L_{12}			2016 lanes-L_{34}		
Day	Median veh/24 h	Vq %	u_a veh/24 h	Median veh/24 h	Vq %	u_a veh/24 h
			Weekday			
Monday	9966	2.5	415	10333	1.5	370
Tuesday	10146	1.3	419	10155	1.0	309
Wednesday	10100	2.0	142	10040	2.2	91
Thursday	10132	1.2	356	10063	2.1	422
Friday	11055	2.4	164	10412	2.0	169
			Weekend			
Saturday	8221	3.8	229	7557	3.8	240
Sunday	6660	3.6	151	7253	4.4	223

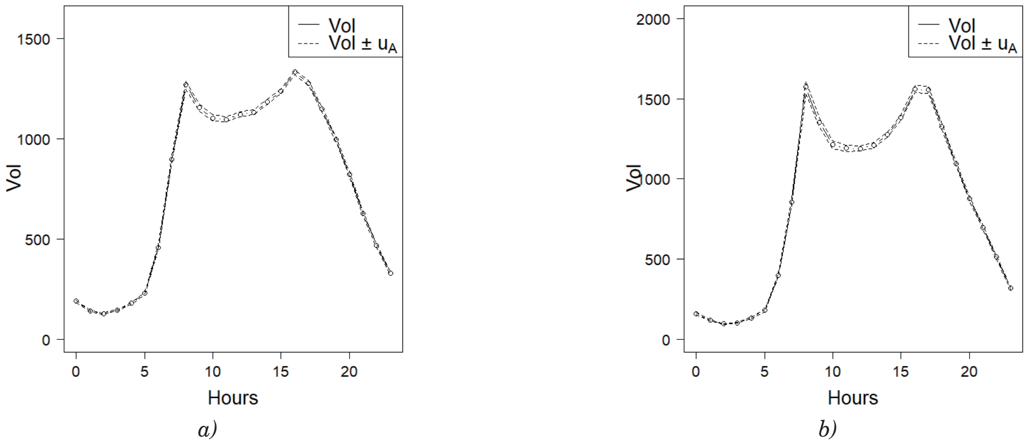


***Figure 6** Relation between the median (solid line) and median with standard uncertainty (dashed line) of annual hourly traffic volume and time for weekdays a) in 2011, b) in 2016*

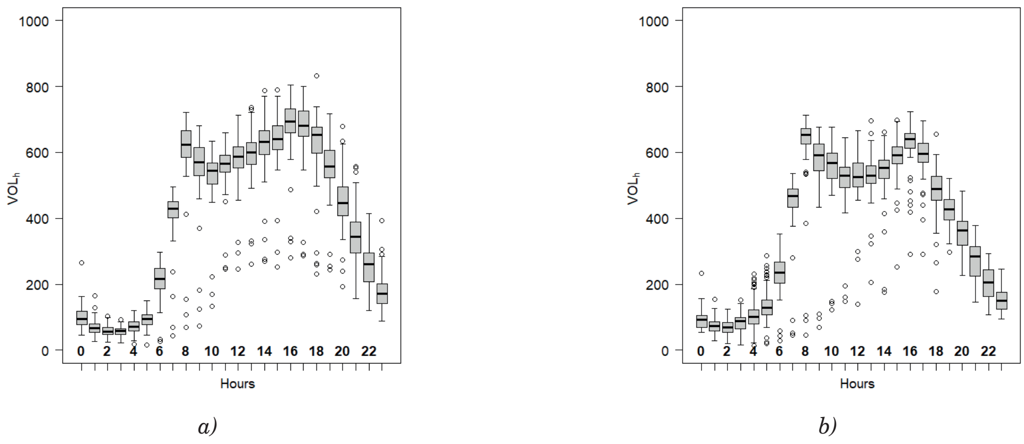
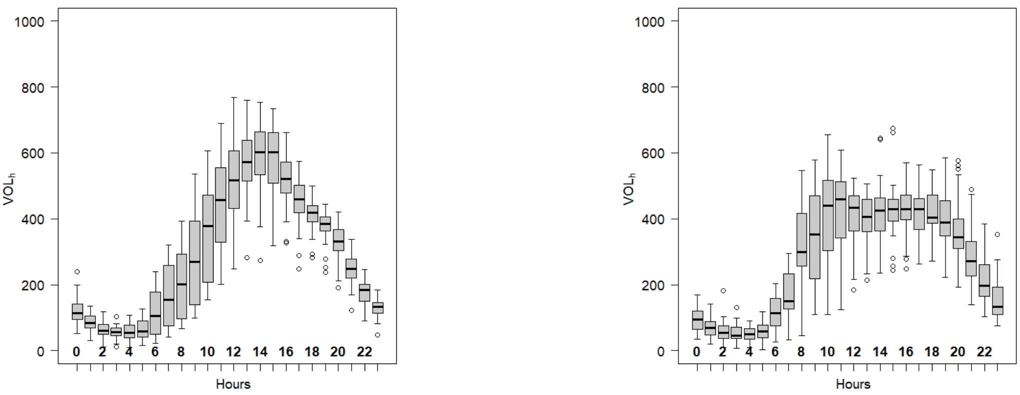


***Figure 7** Box plots of relation between the annual hourly traffic volume and time for 24 h period in 2011 for weekdays: a) on lanes L_{12}, b) on lanes L_{34}*

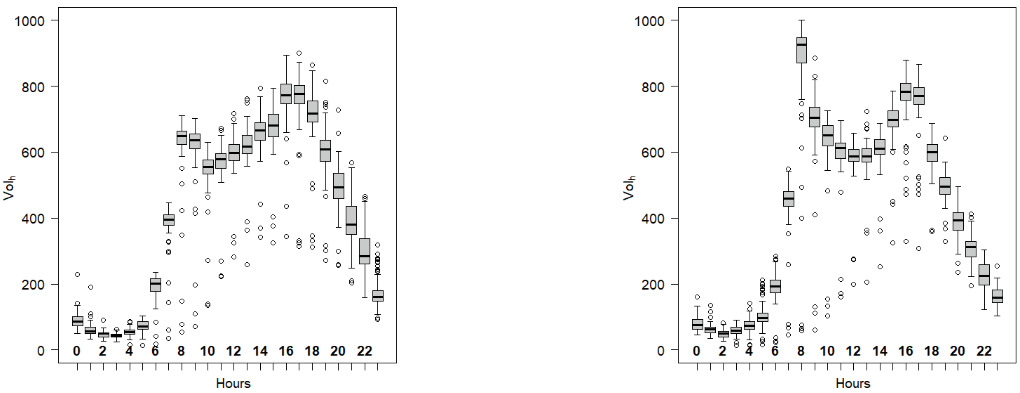
traffic volume, determined for each average annual day, is essential, e.g. for road design and public transport organization [28]. An additional complement to it is the knowledge of annual hourly traffic volume and time for 24 h period. Figure 6 shows the experimental relationships between the median of annual hourly traffic volume and time for weekdays before and after the road renovation.

The charts in Figure 6 show that the traffic peak hours are at 8 AM and 4 PM. In the morning hours from 5 AM to 10 AM, the increase in traffic volume and the decrease after 8 AM in 2016 is greater than in 2011. The decline in traffic volume after the afternoon peak is similar every year. The uncertainty of measurements is variable and the maximum values occurs during the



a) b)

Figure 8 *Box plots of relation between the annual hourly traffic volume and time in 2011 for weekends: a) on lanes L_{12}, b) on lanes L_{34}*



a) b)

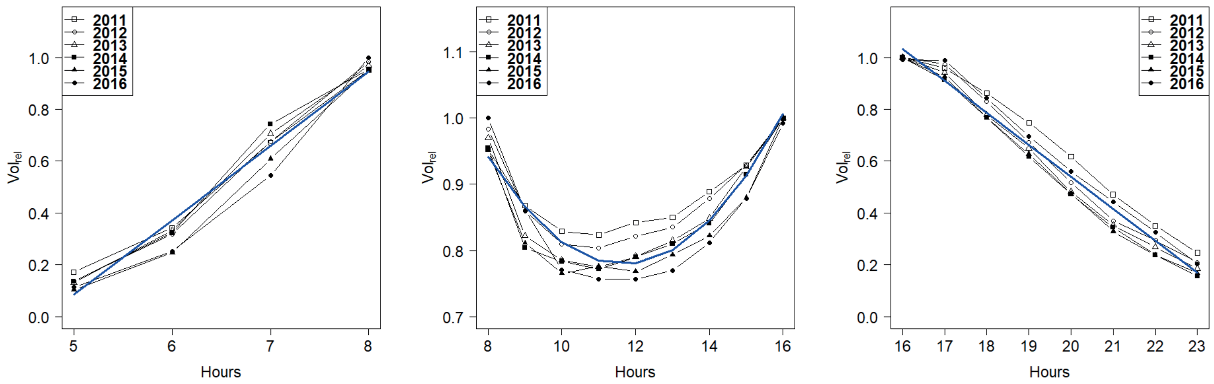
Figure 9 *Box plots of relation between the annual hourly traffic volume and time in 2016 for weekdays: a) on lanes L_{12}, b) on lanes L_{34}*

traffic peak hours. The box plots of relation between the annual hourly traffic volume and time for weekdays in 2011 are presented in Figure 7.

There are two local extreme points of traffic volumes on each lanes occurring at 8 AM and 4 PM. When comparing Figure 7a and Figure 7b, it can be noticed that during the morning traffic peak hours, until about 8 AM, the volume of vehicles on lanes L_{34} is higher than on lanes L_{12}. From 10 AM to 4 PM the volume of vehicles on lanes L_{12} (leaving Kielce) increases to a maximum value of approximately 660 veh/h. It seems that the assumption of symmetry between the time distribution of traffic volume entering and leaving the city is not always true. The relation between the annual hourly traffic volume and time in 2011 but only for weekends is presented in Figure 8.

On weekends, the traffic volume on lanes L_{12} increases from 5 AM to 2 PM (about 600 vehicles), there is only one peak of traffic at 14.00 but it lasts 2 hours, then the volume gradually decreases until 11 PM. On the other hand, on the lanes L_{34} the traffic volume increases from 5 AM to 1 AM (approx. 450 vehicles) and then decreases to approx. 420 vehicles at 2 PM and from 4 PM it decreases to 11 PM. It should be noted that the graphs in Figures 8a and 8b differ not only in values but also in shape. In 2016, the traffic volume increased, which contributed to a change for weekdays in the shape and value of traffic volume in the charts shown in Figure 9. The traffic rush hours have not changed. There is also some similarity between the graphs in Figures 7 and 9. The qualitative changes in traffic volumes before the morning- and after the afternoon rush hour on individual lanes are similar. However, between the traffic rush hours, these changes vary, especially on lanes L_{34}.

On weekends in 2016, changes in the traffic volume on individual lanes are similar to 2011. Analysis of the box plots presented relation between the annual hourly traffic volume and time shows that some of the recorded data can be regarded as atypical. The authors of this paper did not remove the atypical data from the samples analysed. Figure 9 confirms the previously observed phenomenon of traffic asymmetry between vehicles entering and leaving the city (Figures 2, 7 and 8) [29]. The amount of outliers in Figures 7 (in 2011) is almost the same as in Figures 9 (in 2016). Both before and after the road renovation shape differences can be seen between the morning and afternoon peaks for each



a) b) c)

Figure 10 *Relative annual hourly traffic volume and time for weekdays in 2011-2016, with the regression models marked (line marked in blue) a) sub-interval from 5 AM to 8 AM, b) sub-interval from 8 AM to 4 PM, c) sub-interval from 4 PM to 11 PM.*

lanes and between the lanes (Figures 7 and 9). The morning peak is characterized by a rapid rise and fall and the afternoon peak is characterized by a slow rise and fall in traffic. On weekends, the graphs of changes in traffic volume versus time in each traffic direction differ in terms of both the values and shape. On the other hand, one can notice some similarity of shapes between the graphs shown in Figures 7a and 9a and in Figures 7b and 9b. The uncertainty of measurements in sub-interval from 8 AM up to 4 PM is in the range from 12 to 20 veh/h depending from time.

5 Discussion

Figure 6 shows relation between the relative annual hourly traffic volume versus time at weekdays in 2011 and in 2016. Such charts were made for each year from 2011 to 2016. The traffic volume diagrams in Figure 6 can be divided into four phases [18]. From 00 AM to 5 AM - the traffic volume is at least five times lower than in rush hours and does not create any serious logistical problems. From 5 AM to the morning peak at 8 AM a very high rate of the traffic volume increase can be described by a linear relationship. Between the morning and the afternoon peak at 4 PM it can be described by the second order polynomial. From the afternoon peak to 11 PM it can be described by a linear relationship. In order to compare these equations for different years, the data was normalized according to Equation (1) and for the further analysis this parameter, the so-called relative traffic volume, was used. These equations were then derived for each year. Values of the coefficients appearing in these equations depend on the year for which an analysis was performed and presented in [30]. The advantage of this model is that the coefficient of fitting the model curves to the experimental data is approximately $R^2 = 0.99$. The weakness, however, is the necessity to use different values of the coefficients in each year.

In this work, the authors decided to describe the relative traffic volume for particular time ranges by the regression models. When determining the regression coefficients for each hourly range, data from 2011 to 2016 was used. The models presented in Figure 10 (blue line) describe the data obtained over several years.

The presented graphs for individual sub-intervals are described with the following equations:

- from 5 AM to 8 AM (model 1):
$$VOL_{rel} = 0.29x - 1.35, \tag{2}$$
- from 8 AM to 4 PM (model 2):
$$VOL_{rel} = 0.012x^2 - 0.28x + 2.42, \tag{3}$$
- from 4 PM to 11 PM (model 3):
$$VOL_{rel} = -0.12x + 3.01. \tag{4}$$

It is worth noting that the model curve describes changes in value of the VOL_{rel} in the analyzed period from 2011 to 2016. In all the sub-intervals, the satisfactory compliance of the model with the measurement data was obtained, which is confirmed by the high value of the R^2 coefficients, amounting to 0.97, 0.87 and 0.97, respectively. The calculations were performed using the R packet and the obtained coefficients can be considered statistically significant, which was indicated by the small value of the significance level (p-value). The advantage of such a modified model is the possibility of using it as a reference base for analysis of changes in the shape and value of experimental traffic volume graphs as a function of time for each day of the week. It is also less computationally intensive compared to clustering algorithms. The weakness, however, is the worse adjustment of the model to the experimental data. The discrepancies between the curves determined experimentally and according to the regression models were assessed based on the RMSE parameter value [28]:

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left[VOL_{rel}(h) - VOL_{rel\_model}(h)\right]^2}, \tag{5}$$

where:
N - number of hours in analysed period,
$VOL_{rel}(h)$ - experimental relative traffic volume for hour h,

VOL_{rel_model} - relative traffic volume for hour h according to the regression model.

The ability to compare the experimental and model curves in the graphs makes it easier to see the differences between the relative number of vehicles at the same time in different years. Figure 11 shows the graphs of relative annual hourly traffic volume versus time at weekdays, with marked measurement uncertainty and curves according to the proposed regression model.

Comparing Figures 11a and 11b and the RMSE values, it is possible to see both the similarity, as well as differences in the shapes of the graphs and different values of the relative median traffic volume at the same times of the day before and after the road renovation. For example, the traffic flow from 7 AM to 8 AM in 2016 is about 40% higher than in 2011. These observations are confirmed by different RMSE values for each sub-interval. In the range from 5 AM to 8 AM: in 2011 RMSE = 0.05 and in 2016 RMSE = 0.09. In the range from 8 AM to 4 PM in each of the examined years, RMSE = 0.03. In the range from 4 PM to 11 PM in 2011 RMSE = 0.07 and in 2016 RMSE = 0.04. The RMSE parameter indicates

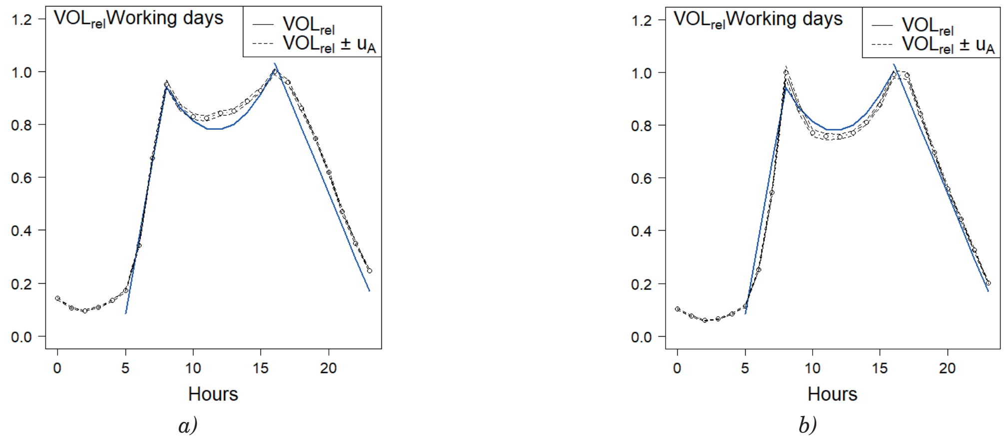


Figure 11 *Relative annual hourly traffic volume versus time at weekdays: for median -solid line, for median with uncertainty $u_{a(rel)}$ - dashed line, for regression models - blue lines a) in 2011, b) in 2016*

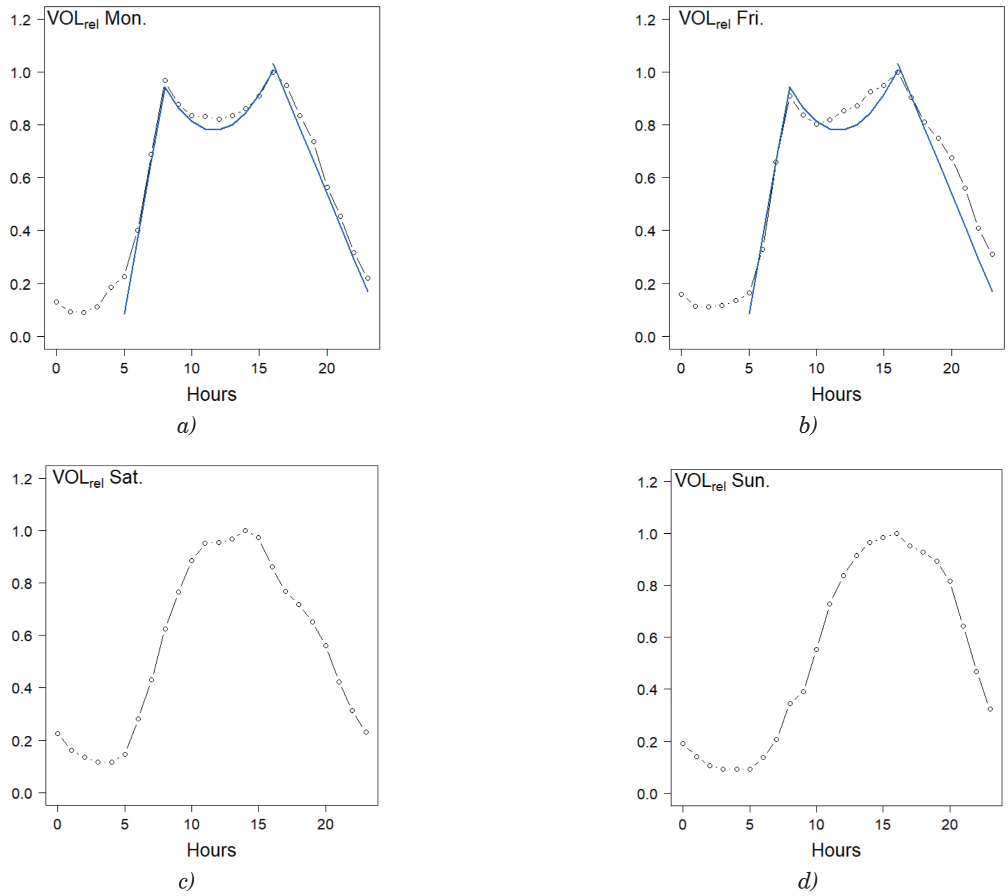
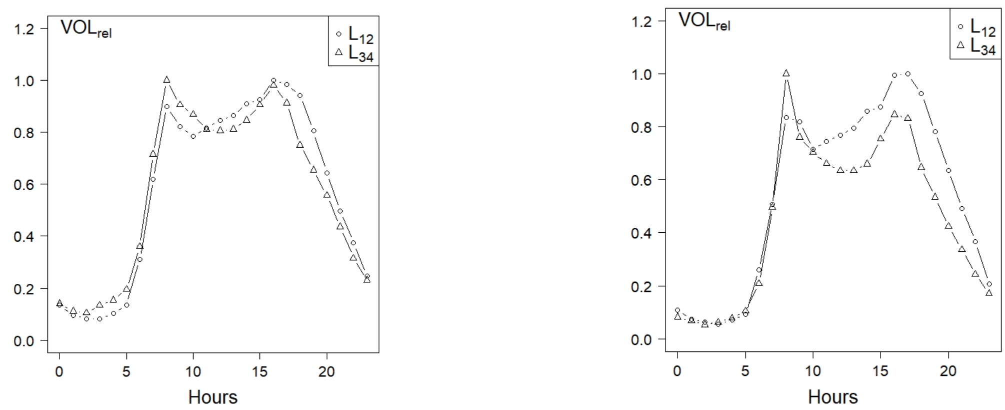


Figure 12 *Relation between the relative median of annual hourly traffic volume and time in 2011 a) on Monday, b) on Friday, c) on Saturday, d) on Sunday*



a) b)

Figure 13 *Relation between the relative annual hourly traffic volume and time for 24 h period at weekdays on entry lanes (L_{12}) and exit lanes (L_{34}) from the city a) in 2011, b) in 2016*

the discrepancies between the experimental data and those determined based on the model. The weakness of this parameter is that it does not explain their causes. It facilitates the qualitative analysis but only slightly supports the quantitative one.

The use of intelligent transport systems, e.g. to optimize route planning and travel time, fuel consumption and exhaust pollutant, requires more detailed data than the annual average hourly values, even split into weekdays and weekends. It is required to know the values of traffic parameters for each day of the week and with time resolution e.g. every 5 min, or 15 min, or 60 min, [31]. This relatively new issue was analyzed in [5, 22, 29], but mainly for the entire road, i.e. without taking into account direction of the traffic. In this study, the analysis is carried out for both traffic directions. For this reason, in the further part of the work, analyses of the relative annual traffic volume registered every hour on individual days of the week were carried out, also taking into account both traffic directions, i.e. lanes L_{12} and L_{34}. For this purpose, the proposed regression model was also used.

Figure 12 shows the charts of relation between the relative median of annual hourly traffic volume and time for selected days of the week in 2011. Mondays and Fridays are characterized by the high value of traffic volume and large changes in the V_q coefficient. One can notice large differences in the time distribution of traffic on Monday and Friday in each of the sub-intervals. On Monday in the morning there are large deviations from the model values. On Friday, however, such deviations occur from 10 AM to 4 PM and then after 6 PM. In Figure 12b one can see an increase in the traffic volume after 6 PM, which may be due to the beginning of the weekend. On the weekend days, the traffic volume is much lower and there is only afternoon (at 2 PM or 4 PM) traffic volume peak. The shapes of the charts for Saturdays and Sundays differ significantly.

Figure 13 shows relation between the relative annual hourly traffic volume and time on entry lanes (L_{12}) and exit lanes (L_{34}) from the city in 2011 and in 2016. The traffic volume analysis carried out shows differences in the traffic volume of vehicles entering and leaving the city. Asymmetry of traffic volume in 2016 is greater than in 2011. Figures 13a and 13b show a similarity of the curves until 8 AM. However, in 2016, after the morning peak - from 10 AM, there are significant differences in traffic volume between the directions of traffic.

Figure 14 shows a comparison of the model curves to the experimental ones on selected days of the week in 2011, taking into account the direction of traffic. These comparisons show that on each day of the week the traffic volume changes differently on lanes L_{12} than on lanes L_{34}. One can also see that on each of the lanes changes in the traffic volume are different every day. Particularly large differences are visible for Sundays - both the shape of the charts and the time of occurrence of the maximum values are different for each lane. The uncertainty value depends on the time of the measurement. In the morning rush hours, the uncertainty of VOL_{rel} on the lanes L_{12} is about 4% and is 1% lower than on the lanes L_{34}. On the other hand, in the afternoon rush hours, the uncertainty on the lanes L_{34} is about 3% and is 1% lower than on the lanes L_{12}. In the remaining hours of the day, the uncertainty is much smaller. Comparing the uncertainty calculated for weekdays (shown in Figure 11) to the uncertainty for Mondays on lanes L_{12} in 2011 (Figure 14a), differences in values can be seen. This is due to the fact that for Mondays there were statistically 5 times less data, so the uncertainty is increasing. The discrepancies between the curves, determined experimentally and according to the models, were assessed based on the RMSE parameter value. Table 3 summarizes values of this parameter for weekdays and each direction of traffic. Comparing the RMSE values in of the weekdays on the lanes L_{12} for individual models, it can be seen that they increase slightly from Monday and on Friday reach the highest values RMSE = 0.16. The greatest discrepancies in RMSE values occur for model 3, i.e. from 4 PM to 11 PM. In the case of the lanes L_{34}, almost all the RMSE values are between 0.03 and 0.15 and change irregularly. Analyzing the RMSE in 2011, e.g. for Mondays and Tuesdays in the corresponding time periods from 8 AM to 11 PM, it can be seen that they have similar values. This does not mean, however, that the shapes of the VOL_{rel} diagrams are similar in the same time intervals, as shown in Figure 14. The RMSE values in 2016 are higher than in 2011, especially for the lanes L_{34}. This justifies validating traffic volume models every few years.

6 Conclusions

The deteriorating condition of the road and the nuisance associated with its renovation, contributed to a decrease in the traffic volume in the years 2011 to 2016 by 9.7%. It was only in 2016 that traffic volume increased (compared to 2011) of all the vehicles by 13%. Research on the share of vehicle groups in the traffic structure showed that passenger and medium

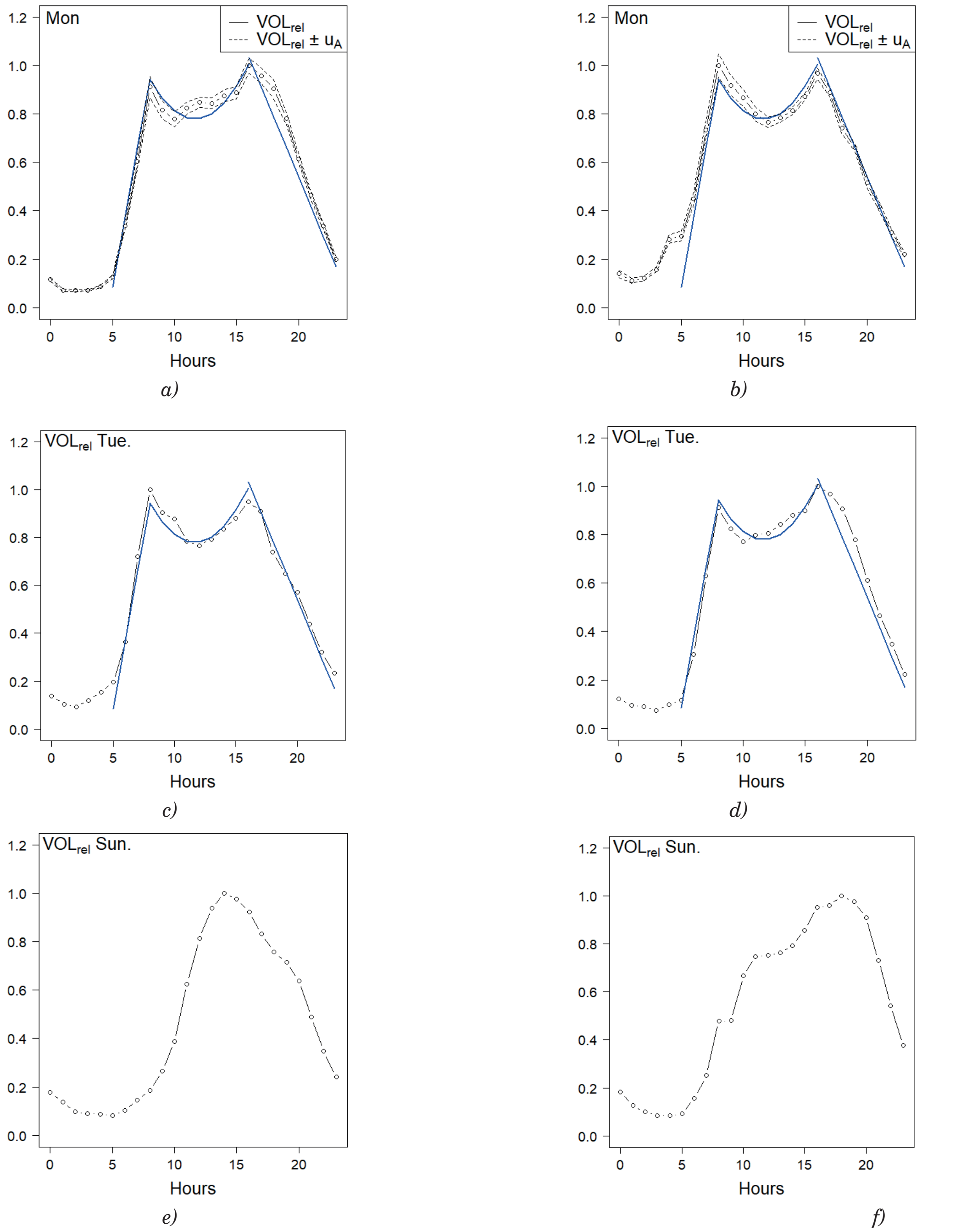


Figure 14 *Relation between the relative median of annual hourly traffic volume and time in 2011 (for median -solid line, for median with uncertainty* $u_{a(rel)}$ *- dashed line , model - blue lines) a) on Monday on lanes* L_{12}*, b) on Monday on lanes* L_{34}*, c) on Tuesday on lanes* L_{12}*, d) on Tuesday on lanes* L_{34}*, e) on Sunday on lanes* L_{12}*, f) on Sunday on lanes* L_{34}

Table 3 *Analysis of the RSME values between the traffic volume models and experimental data for the relative median of annual hourly traffic volume and time in 2011 and 2016 on weekdays taking into account the direction of traffic*

	RMSE for lanes L_{12}			RMSE for lanes L_{34}		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
			2011			
Monday	0.04	0.04	0.07	0.12	0.04	0.04
Tuesday	0.04	0.03	0.08	0.07	0.04	0.05
Wednesday	0.04	0.04	0.09	0.06	0.03	0.03
Thursday	0.06	0.04	0.11	0.07	0.03	0.03
Friday	0.07	0.07	0.16	0.06	0.05	0.04
			2016			
Monday	0.09	0.05	0.07	0.10	0.14	0.12
Tuesday	0.11	0.07	0.07	0.12	0.14	0.11
Wednesday	0.11	0.06	0.09	0.12	0.15	0.12
Thursday	0.11	0.06	0.09	0.13	0.15	0.12
Friday	0.14	0.08	0.16	0.13	0.12	0.09

heavy vehicles dominate and their share is about 90%. The statistical tests carried out allow to reject the H0 hypothesis about the compatibility of the measurement data distribution with the normal distribution. The lack of normal distribution, the large amount of outliers results in the fact that the uncertainty of ADT in 2016 (after the road reconstruction) on lanes L_{34} ranges from 91 to 422 veh/24 h. The coefficient V_q in 2016 ranges from about 1% to 4% and is much lower than in 2011. The C95 ADT percentile value changes by 10% and depends on the group of vehicles analyzed and the day of the week. The median average speed during the period considered from 2011 to 2016 slightly changed. However, the speed charts on lanes L_{12} and L_{34} and for different years have different courses.

Research on the relationship between the annual hourly traffic volume and time in 2011-2016 showed that there is a lack of symmetry between the time distribution of the traffic flow of vehicles entering and leaving the city. The proposed regression model was used as a reference base for the analysis of changes in the shape and value of experimental traffic volume graphs for each day of the week. From comparison of the model curves to experimental ones it results that on each day of the week the traffic volume changes differently on lanes L_{12} than on lanes L_{34}. On each of the lanes the changes in traffic volume are different every day. Particularly large differences are visible for Sundays - both the shape of the charts and the time of occurrence of the maximum values are different for each lane. The discrepancies between the curves determined experimentally and according to the regression models were assessed based on the RMSE parameter value. These analyses showed that the similar RMSE values do not mean, however, that the shapes of the VOL_{rel} plots are similar at the same time intervals. The RMSE values in 2016 are higher than in 2011, especially for the lanes L_{34}, which justifies the validation of the traffic volume models every few years.

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