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Analysis of Urban Traffic for Various Sets of Vehicles

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Abstract. The paper analyses the results of traffic flow measurements recorded by road traffic and noise monitoring station. The station is located in a medium size city in Poland (Kielce) situated at the national road to Cracow. The traffic flow was measured over the period between January and December 2013 for twenty-four hours a day. The measurements were documented at one hour intervals throughout the 24-hour period (0:00-23:00). Statistical analysis methods were used to determine the variability and uncertainty of the results. The measurements from two vehicular lanes running towards the town (L_{12}) and two lanes running towards Cracow (L_{34}) were analysed. Different vehicle sets (G(i)) were taken into account: i= cars, trucks, delivery vans and motorcycles. The coefficients of variation and positional variation were proposed for the analysis of traffic data scattering. It was found that in some cases the distribution of the tested variable was not normal. Differences in traffic intensity on opposite road lanes for particular sets of vehicles were demonstrated. Box plots were used to assess whether outliers occurred in the recorded data. The times of the day at which the parameters describing the variability of the recorded traffic stabilized were identified. The results obtained for the data recorded on working and non-working days were compared. Type A uncertainty was evaluated.

1. Introduction

Reliable estimates of traffic volume are essential for transportation engineering activities, air quality evaluations or crash statistics [1]. Average daily traffic (ADT) - the average 24 hours' volume – recorded continuously throughout the year and adjusted for each day of the week provides the most accurate values that should not, however, be interpreted without regard to the extent of variability inherent in traffic volume measurements [2,3]. This study aimed at quantifying the variability and uncertainty of traffic volume measurements performed in a medium-sized Polish city, Kielce. Kielce has a population of about 200,000 and is the capital of the region situated in the central part of Poland. Transportation resources comprise approximately 111,000 motor vehicles registered in the city, including 21,000 trucks and 145 buses operated by Kielce Municipal Transportation Enterprise. The proportion of vehicles in the overall road traffic in Kielce is as follows: passenger cars - 82%, trucks - 15%, buses - 2%, other - 1%. Passenger cars and buses each carry about 27% of all residents. About 45% of the population travels on foot. Kielce has several permanent automatic traffic monitoring stations, internal to the town or located at entrances. In this paper, the results of the traffic volume measurements from one of these stations are discussed. Statistical analysis of data variability was performed with the use of commonly available R software.

2. Monitoring stations – traffic measurements

Traffic analysed in this study were measured by the permanent station recording traffic flow and sound pressure levels, located in Krakowska Street in Kielce. The four-lane Krakowska Street is the main part of the outward route from the centre of Kielce towards Kraków, and carries both urban and transit traffic

[4]. The traffic monitoring station is located between 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 flow was measured by WAVETRONIX digital radar with an operating frequency of 245 MHz [5]. The weather data were recorded by means of a VAISALA WTX 510 automatic weather station.

The measurements were carried out for 24 hours a day throughout the year 2013. The traffic volume data were recorded every 1 minute (buffer) and the averaged results were documented every 1 hour [6]. Owing to various technical problems, the database was incomplete and comprised 8,375 counts. The counts were used to calculate the traffic intensity, split into seven days of the week and 1 hour periods of a 24-hour interval. As for some of the days no data were reported, only the days for which traffic was recorded every hour for the whole 24-hour period were taken into account in the analysis [7]. The final database with correctly recorded values had 6,096 counts from 254 measurement days. The traffic volume was calculated according to following equation:

$$VOL_{N,p} = \sum_{i=1}^{N} \sum_{h}^{p} VOL_{p,d} \quad (1)$$

where $VOL_{p,d}$ is the traffic volume for *d* – day of week (*d*=1, 2, 3, 4, 5, 6, 7), *h* is the start of the time interval (h=0-23) and *p* is the end of the time interval expressed in hours (*p*=0-23), *N* is the number of measurement days. In this paper *d*=3, 4 or 7 represent working or weekend days. In this paper the parameters h and p have the same values (between 0 and 23) because the traffic volume is counted for one-hour intervals. The average daily traffic volume was determined as the expected value from:

$$\overline{Vol} = \frac{1}{N} VOL_{N,p} \quad (2)$$

Standard deviation of the measurement results was then calculated from:

$$\sigma_{VOL} = \sigma = \sqrt{\frac{1}{N-1} \sum_{i=1}^{i=N} \left(VOL_{N,p} - \overline{Vol}\right)^2} \quad (3)$$

The variability of traffic volume [8] was evaluated with the use of the coefficient of variation determined from:

$$COV_{VOL} = COV = \frac{\sigma_{VOL}}{\overline{Vol}} \cdot 100\% \quad (4)$$

The coefficient of variation (4) is a dimensionless relative measure of traffic volume dispersion. If we do not want to use the arithmetic mean, for example when large deviations of extreme values occur in a series of data, the quartile deviation (Q_{31}) or quartile coefficient of dispersion can also be adopted as a parameter of variability [9]. The quartile deviation (Q_{31}) was determined from equation (5):

$$Q_{31}(VOL_{N,p}) = 0.5 \cdot IQR = 0.5 \cdot (Q_3(VOL_{N,p}) - Q_1(VOL_{N,p})) \quad (5)$$

where $Q_1(VOL_{N,p})$ –first quartile, $Q_3(VOL_{N,p})$ –third quartile of traffic volume.

The quartile deviation is an absolute and dimensional measure of volume. When referred to the median, quartile deviation provides positional variation, which was determined from:

$$V_q = \frac{Q_{31}}{Med} \cdot 100\% \quad (6)$$

Standard uncertainty of the parameter $VOL_{p,d}$, determined in the type *A* evaluation, was calculated from the following relationship:

$$u_A = \sqrt{\frac{1}{N(N-1)} \sum_{i=1}^{N} \left(VOL_{p,d} - \overline{Vol}\right)^2} \quad (7)$$

where $VOL_{p,d}$ is the traffic volume. The relative traffic volume can be defined as follows

$$VOL_{rel}(p,d,G(i),L) = VOL(p,d,G(i),L)/VOL_{max}\ (p,d,G(i),L) \tag{8}$$

where G(i) - vehicle sets, i= cars, trucks, vans and motorcycles, $VOL_{max}(p,d,G(i),L)$ - the maximum traffic volume of the vehicle set analysed on road lanes L_{12} and L_{34} on a selected day of the week.

3. Test results

Figure 1 compiles the time-dependent traffic intensity, its coefficients of variation, COV and V_q, and U_a measurement uncertainty for the vehicle sets under analysis for all Thursdays in 2013. These relationships, and in particular the one in figure 1a, confirm the qualitative compliance with the results reported in [4] and in the literature. The morning peak period starts at about 05:00 and lasts until approximately 08:00; the afternoon peak period starts at about 16:00. Analysis of coefficients of variation and measurement uncertainties indicates that in order to determine the average annual values, e.g., ADT, traffic "snapshot" measurements should be carried out in the time period between 11:00 and 14:00. The results of Shapiro – Wilk tests provide enough evidence to reject the null hypothesis (H0) about the normal distribution of the traffic volume measurement data because the calculated limit significance levels, p-values, are below 0.05 – the value adopted as the required level of significance.

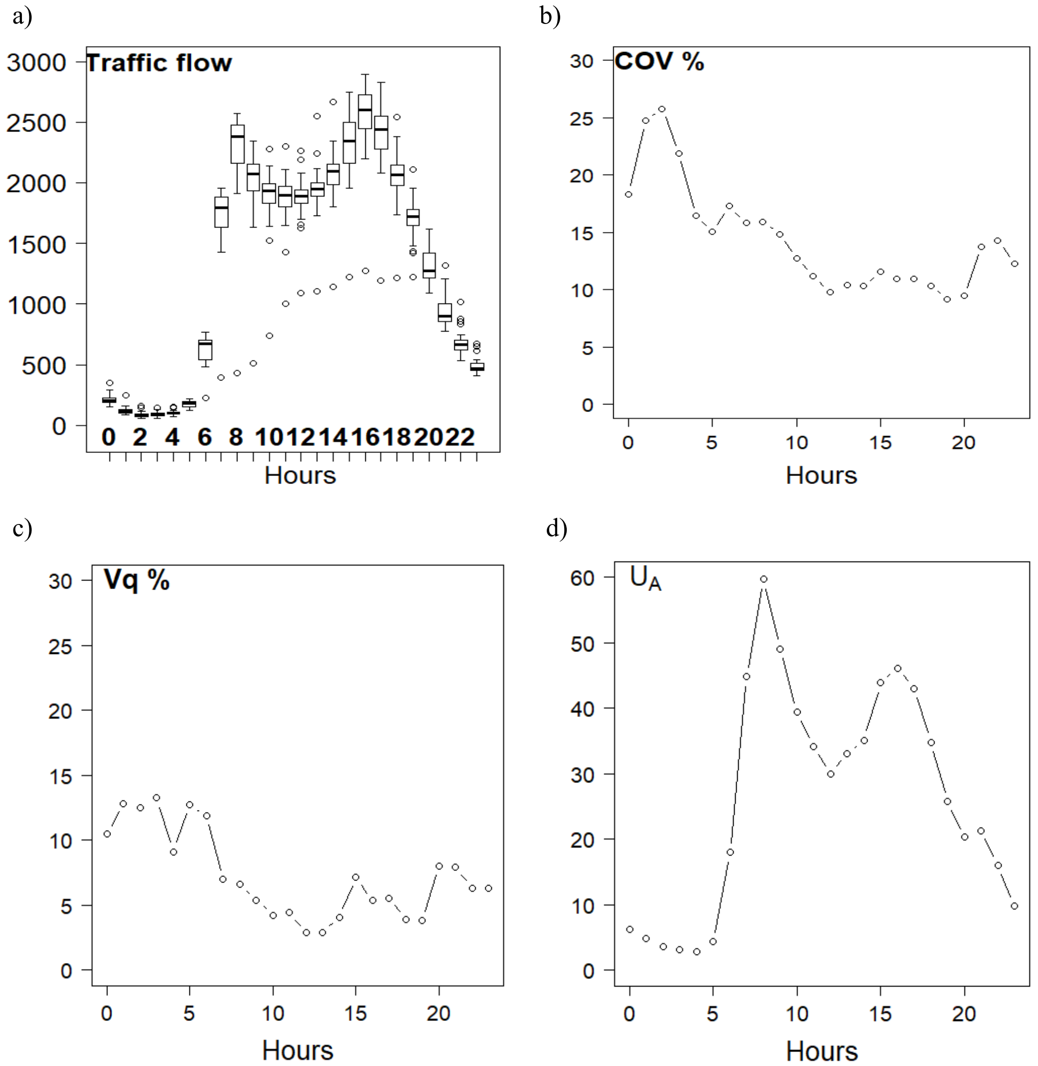

Figure 1. Traffic flow parameters versus time for all vehicle sets on both traffic lanes for Thursdays: a) traffic volume, b) coefficient of variation, c) coefficient of positional variation, d) type A standard uncertainty

The investigations of the null hypothesis discussed further in this paper were performed for this level of significance. Additionally, in doubtful cases, the Jarque-Bera test was performed to check whether the distribution was normal, which did not provide enough evidence to reject the null hypothesis for the same hours (for example 04:00 and 05:00).

The purpose of this work was to answer the question about the impact of particular sets of vehicles on the total amount of traffic, parameters of variation and uncertainty of measurements. A separate issue is whether the traffic direction - to Kielce (lane L_{12}) or to Kraków (lane L_{34}) affects the values of these parameters. The box graphs in Figure 2 show time-dependent Thursday passenger car traffic flow towards Kielce (figure 2a) and towards Kraków (figure 2b). The comparison of these figures indicates a difference in the nature of traffic changes, especially until 12:00 (no evident morning peak period on L_{34}). Traffic analysis computations show that within 24 hours, the number of passenger cars entering Kielce was 2,525 higher than the number of cars heading for Kraków. The results of statistical tests provided enough evidence to reject H0 about the normal distribution of the traffic data. Additionally, in doubtful cases, the Jarque-Bera test was performed to check whether the distribution was normal, which did not provide enough evidence to reject the null hypothesis for the same hours (for example 05:00 and 20:00).

Figure 2c shows V_q versus time on the L_{12} lane and figure 2d shows the same relationship for lane L_{34}. Slightly different results of traffic volume changes and Vq coefficients were obtained for Wednesdays – there were 2,394 more passenger cars on lane L_{12} than on lane L_{34}.

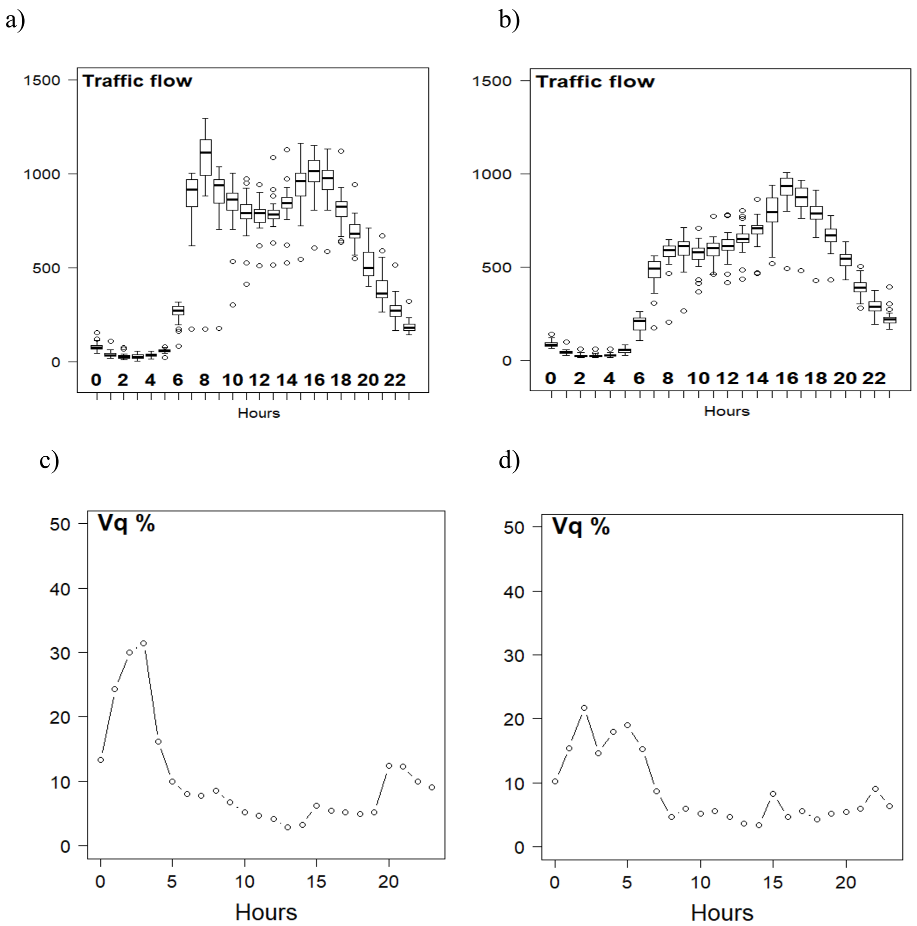

Figure 2. Traffic flow parameters versus time for Thursdays: a) on lane L_{12}, b) on lane L_{34}, c) coefficient of positional variation on L_{12}, d) coefficient of positional variation on L_{34}

The character of time-dependent changes in traffic volume and V_q coefficients was different on Sundays, as shown in figure 3. The afternoon peak period started at about 17:00 on lane L_{12} and at about 15:00 on lane L_{34}, probably due to weekend returns. Traffic analysis computations show that there were 1,072 more cars on L_{12} than on L_{34} on Sundays. The values of Vq for both lanes between about 13:00 to about 19:00 were similar and amounted to about 8%, with irregular changes of a few percent observed at other hours.

a) b)

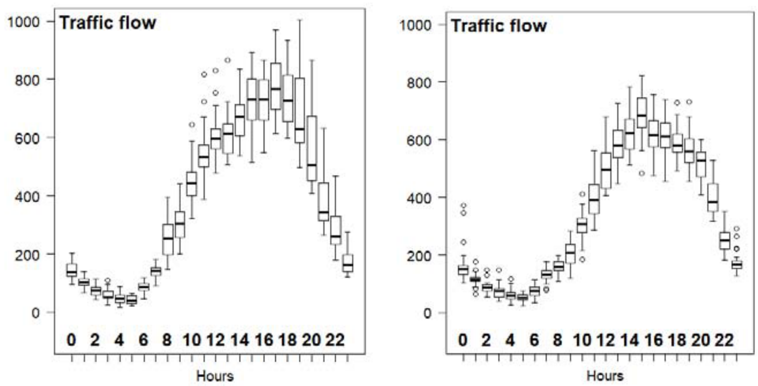

Figure 3. Traffic flow versus time for passenger cars, Sundays: a) on lane L_{12}, b) on lane L_{34}

Figure 4 shows box plots of time-dependent truck traffic volume for Thursdays on lane L_{12} (figure 4a) and on L_{34} (figure 4b). From the comparison of these figures it follows that there was a difference in the nature of traffic changes, in particular after 12:00 (no evident afternoon peak period on L_{12}). Traffic analysis computations show that within 24 hours on Thursdays, 574 trucks entered Kielce and 116 more trucks travelled to Kraków. The value of V_q was about 13%, but there were also numerous local maxima with values by a dozen or so percent higher. Wednesdays showed slightly different results of traffic volume changes. The number of trucks on lane L_{34} on Wednesdays was higher by 112 vehicles. The V_q coefficients on Wednesdays were higher by a few percent compared to those for Thursdays with numerous local maxima. The values of V_q for truck traffic on Sundays between 00:00 to 05:00 were about 50% and about 30% between 08:00 to 23:00. Traffic on Sundays on L_{12} ranged from 1 to 11 vehicles per hour, and on L_{34} there was a local maximum of 14 vehicles/h at 15:00. The median of the vehicle number was 144 on L_{12}, that is, 29 fewer vehicles were recorded than on L_{34}.

a) b)

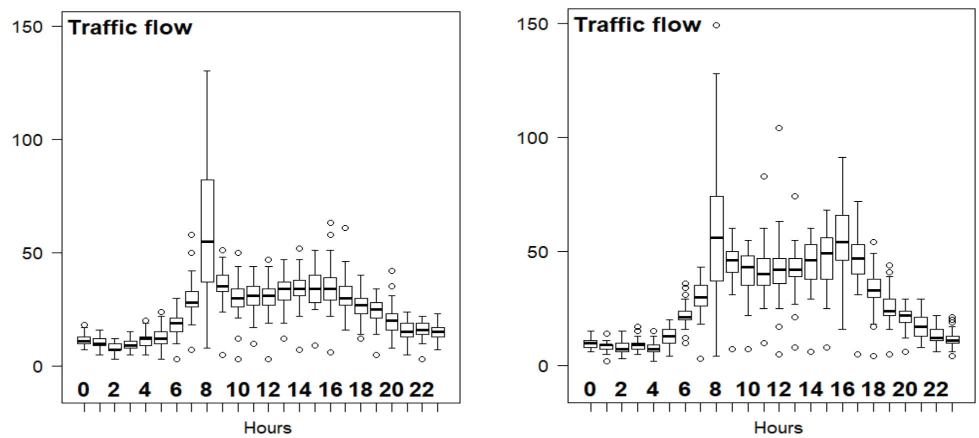

Figure 4. Traffic flow versus time for trucks, Thursdays: a) on lane L_{12}, b) on lane L_{34}

The box plots in Figure 5 show the flow of delivery vehicles versus time for Thursdays on L_{12} (figure 5a) and L_{34} (figure 5b). It can be seen from these figures that there was a difference in the nature of traffic changes, in particular after 12:00 (no evident afternoon peak period on L_{12}). Traffic analysis computations show that within 24 hours 1711 delivery vans entered Kielce and 2045 more cars left Kielce for Krakow. Changes in traffic volume V_q on L_{34} between 07:00 to 20:00 were less than 10%, but at other hours of the 24-hour period there were numerous local maxima with values of a dozen or so percent higher. Slightly different changes were obtained for Wednesdays. A total of 1967 more cars were recorded on L_{34} than on L_{12}. The values of V_q coefficients on Wednesdays and Thursdays were similar and amounted to a minimum of 8%; numerous local maxima were about 30%. The values of variation coefficient V_q for delivery vehicles on Sundays were about 20% between 10:00 to 23:00 and about 30% between 00:00 to 10:00. Traffic on Sunday on L_{12} ranged from 3 to 30 vehicles per hour and on L_{34} there was a local maximum of 149 at 15:00. Traffic analysis computations show that within 24 hours on Sundays, 385 delivery vans entered Kielce and 1008 more vehicles left for Krakow.

a) b)

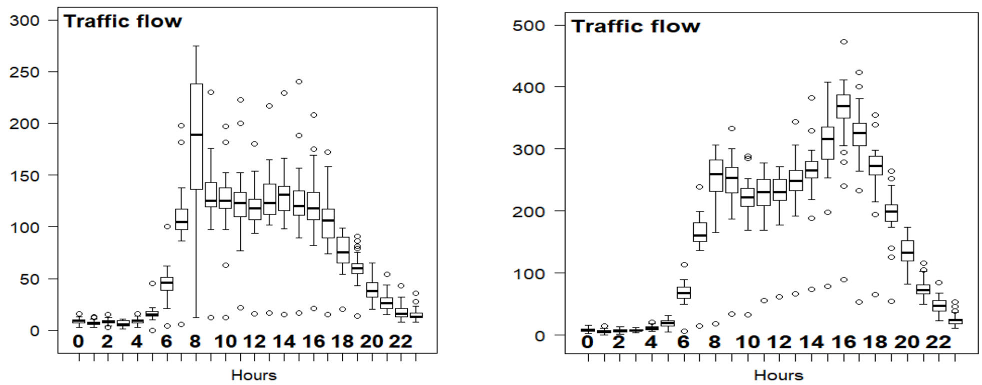

Figure 5. Traffic flow versus time for delivery vehicles, Thursdays: a) on lane L_{12}, b) on lane L_{34}

The box plots in figure 6 show delivery vehicle traffic versus time for Thursdays on L_{12} (figure 6a) and on L_{34} (figure 6b). It can be seen from these figures that the character of traffic changes was similar on both lanes. The morning peak on L_{12} started at about 9:00 and at about 8:00 on L_{34}. The afternoon peak occurred at about 16:00 on both lanes. The motorcycle traffic counts indicate that within the 24-hour period 430 motorcycles entered Kielce and 437 motorcycles left for Kraków. Slightly different changes were recorded on Wednesdays, when 453 motorcycles were recorded on L_{34}, i.e., 20 more than on L_{12}. The V_q coefficients on Wednesdays and Thursdays were similar and accounted for 18% in the time period of 7:00 to about 19:00. Measurement uncertainty of V_q coefficients of motorcycle traffic on Sundays between 10:00 and 18:00 was about 25% with about 40% between 0:00 and 10:00. The Sunday traffic volume was lower than 20 motorcycles/hour. The motorcycle traffic counts indicate that within the 24-hour period on Sunday 188 motorcycles entered Kielce while 60 more motorcycles travelled towards Kraków.

4. Discussion

Figure 7a illustrates the relationship between the relative passenger car traffic volume $VOL_{rel}(G(i = passenger\ cars), L)$ and the time period on Thursdays on lanes L_{12} and L_{34}, calculated according to equation (8). Figure 7b shows the measurement uncertainties on the same lanes. Figure 7a indicates an evident difference between the traffic volume of vehicles travelling towards Kielce and vehicles travelling toward Kraków. These differences increased significantly in the time period from 7:00 to 14:00. The traffic up to 14:00 was considerably more intense on lane L_{12} than on lane L_{34}, whereas from 16:00, the traffic movement decreases in the same manner on both lanes. The measurement uncertainty for up to 12:00 on lane L_{12} was far higher than on lane L_{34}. The uncertainties were similar in the time period of 12:00 to 19:00 on both lanes.

a) b)

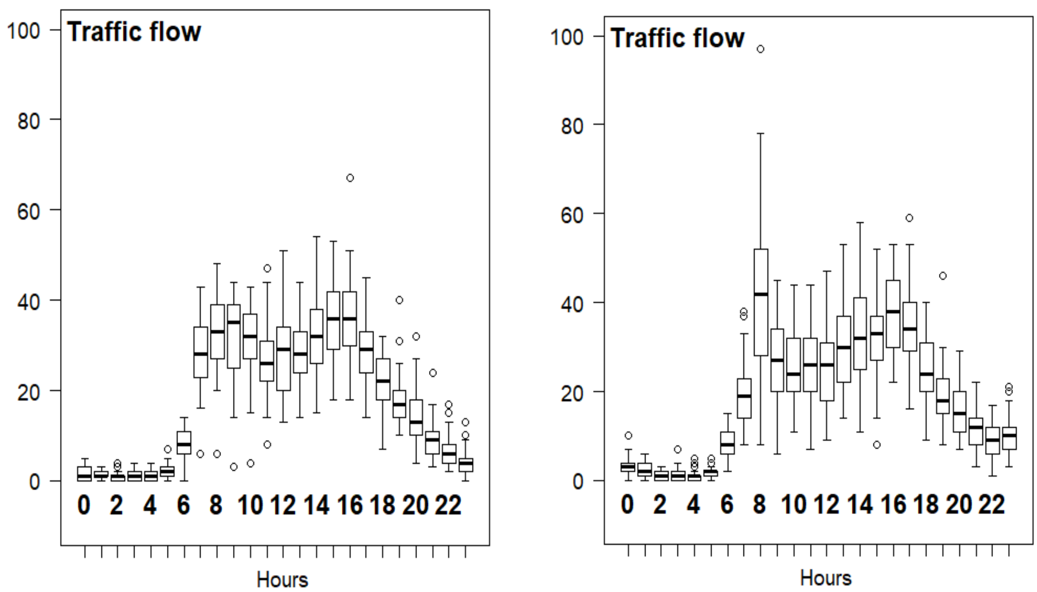

Figure 6. Traffic flow versus time for motorcycles, Thursdays: a) on lane L_{12}, b) on lane L_{34}

a) b)

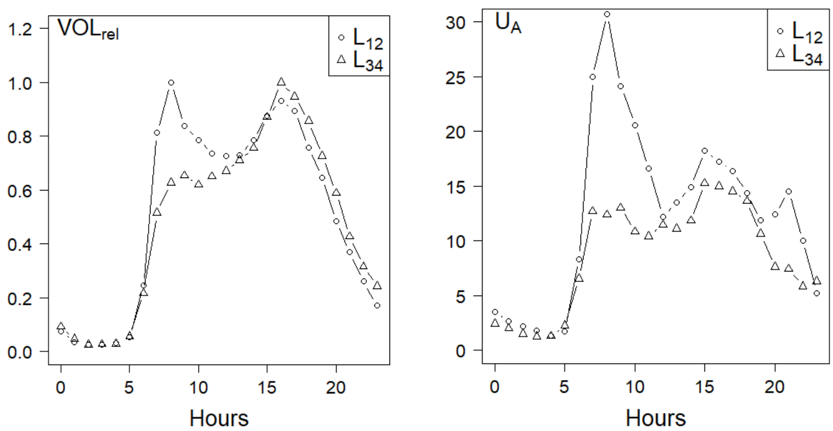

Figure 7. Traffic of passenger cars versus time, Thursdays: a) relative traffic volume $VOL_{rel}(G(i = passenger\ cars), L)$, b) traffic volume measurement uncertainty.

The relative traffic of passenger cars on Sundays, figure 8, increased gradually but far more slowly than on the working days and can be written as follows: between the hours 0:00 to 15:00 with determination coefficient R^2=0.9914

$$VOL_{rel}(Sundays, G(i = passenger\ cars), L_{34}) = -0.0004p^3 + 0.017p^2 - 0.1076p + 0.2537 \quad (9)$$

between the hours 0:00 to 17:00 with determination coefficient R^2=0.9914

$$VOL_{rel}(Sundays, G(i = passenger\ cars), L_{12}) = -0.0008p^3 + 0.0238p^2 - 0.1252p + 0.2189 \quad (10)$$

Between 16:00 and 20:00, the relative traffic volume decreased, but the lanes were affected differently. From 20:00 to 23:00, the changes were very similar on both lanes. Measurement uncertainty values of the period between 12:00 to 14:00 varied only slightly.

a) b)

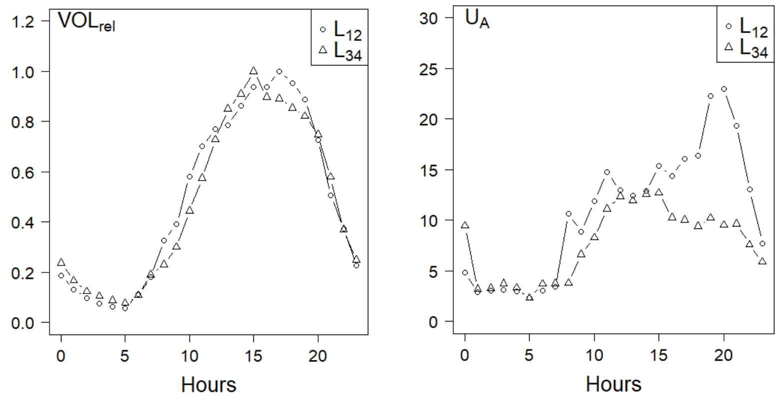

Figure 8. Traffic of passenger cars versus time, Sundays: a) relative traffic volume $VOL_{rel}(G(i = passenger\ cars), L)$, b) traffic volume measurement uncertainty.

The relative traffic volume of trucks varied slightly up to the morning peak period, which started at 8:00. Between 9:00 and 17:00, the difference increased to become small again at 20:00. The measurement uncertainty for trucks in the period from 9:00 to 16:00 was from 1 to 2 vehicles/hour.

a) b)

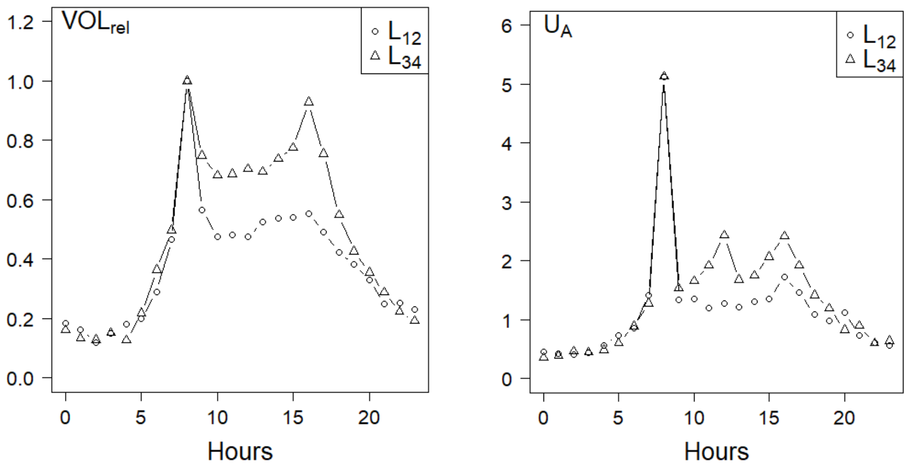

Figure 9. Traffic of trucks versus time, Thursdays: a) relative traffic volume $VOL_{rel}(G(i = trucks), L)$, b) traffic volume measurement uncertainty.

In the case of delivery vehicles, the local traffic maximum occurred at 8:00 on L_{12} and at 16:00 on L_{34}, as shown in figure 10a. The character of changes in the relative delivery vehicle movement in the morning was similar to that of passenger cars on Wednesdays or Thursdays. The uncertainty for the period up to 8:00 on both lanes was similar and at later hours – up to 17:00, the differences increased, as shown in figure 10b.

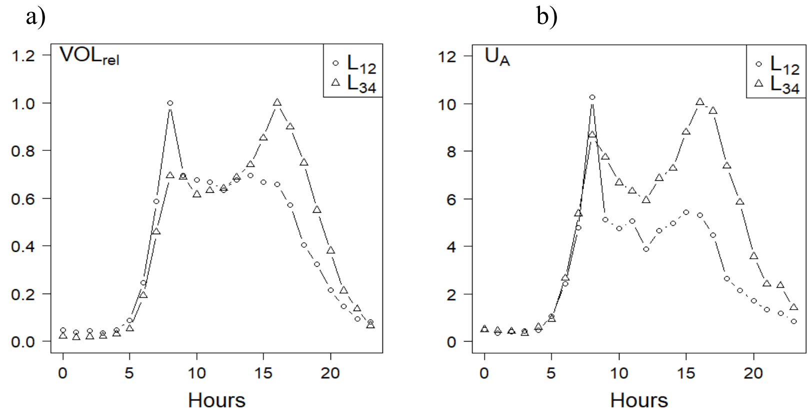

Figure 10. Traffic of delivery vehicles versus time, Thursdays: a) relative traffic volume $VOL_{rel}(G(i = delivery\ vehicles), L)$, b) traffic volume measurement uncertainty.

The relative traffic of motorcycles on both lanes in the morning (up to 8:00) and afternoon (from 17:00) was nearly identical. Between 9:00 and 16:00, the character of the time-dependent relative traffic changes was similar on both lanes. The measurement uncertainty of traffic volume on both lanes, except for at 8:00, was nearly identical and amounted to 1 or 2 motorcycles/hour.

5. Conclusions

This article analysed the vehicle traffic counts recorded by the stationary measuring station located on the outskirts of Kielce. The vehicle movement was recorded on the lanes running in opposite directions - two lanes towards Kielce and two lanes towards Kraków. The vehicles were classified in four sets: passenger cars, trucks, delivery vans and motorcycles. The analysis included traffic volume, its variation and measurement uncertainty. In the majority of cases, on working days the periods of morning and afternoon peak started at the same time for all sets of vehicles (8:00 and 16:00). Sundays had only the afternoon peak period. The overall traffic volume was based mainly on passenger cars (about 82%) and delivery vehicles (about 11%). On Sunday, the share of passenger cars was about 93%. There were significant differences within the 24-hour period between the number of vehicles arriving at and departing from Kielce. These differences were particularly pronounced for passenger cars (about 2,500 more cars entered Kielce) and delivery vans (about 2,000 more vans left Kielce). The values of traffic volume variation coefficients and the uncertainty of measurements were dependent on the vehicle set, day of the week, measurement time and lanes. The proposed parameter, relative traffic volume, facilitated the comparison of traffic changes by lane, vehicle set and day of the week. A mathematical model was proposed to describe changes in the relative traffic volume in the time period from 0:00 to the afternoon peak on Sundays for both directions of travel.

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