COEFFICIENTS OF TRAFIC DENSITY FLUCTUATIONS ON THE URBAN ROADS NETWORK

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Abstract

The scope of the paper includes methods of designating the calculation coefficients for estimating Average Daily Traffic (SDR) based on short-term, random measurements of traffic density depending on:
– a month (W_M seasonal- annual fluctuations coefficients),
– a day of the week (W_T weekly fluctuations coefficients),
– time of measurements and their duration (W_{ZD} daily traffic density fluctuations coefficients).
The coefficients were designated for roads in urban areas on the grounds of the definitions of traffic fluctuations coefficients according to the General Directorate for National Roads and Motorways (GDDKiA – the Polish acronym) and the time series models. Furthermore, essential differences between the characteristics of urban and non-urban traffic were indicated. The coefficients supplement the current procedure of estimating the Average Daily Traffic on roads in urban areas, outgoing roads, and roads located on the outskirts of cities on the basis of random measurements taken at recommended intervals, as well as at any other time.
The author of the paper intends to continue the measurements extended to a complete structure of traffic taken in the cross sections of the segments between the junctions on roads of low, medium and high functionality in urban areas.

Streszczenie

W pracy przedstawiono sposoby wyznaczenia współczynników przeliczeniowych szacowania średniego dobowego ruchu w roku (SDR) z krótkotrwałych, wyrywkowych pomiarów natężenia ruchu w zależności od:
– miesiąca (współczynniki W_M sezonowej-rocznej zmienności ruchu),
– dnia tygodnia (współczynniki W_T tygodniowej zmienności ruchu),
– godzin prowadzenia pomiaru i czasu jego trwania (współczynniki W_{ZD} dobowej zmienności natężenia ruchu).
Współczynniki wyznaczono dla dróg w obszarach miejskich na podstawie definicji wskaźników zmienności ruchu wg GDDKiA oraz na podstawie modeli szeregów czasowych. Ponadto wykazano istotne różnice między charakterystykami ruchu zamiejskiego i miejskiego.
Wyznaczone wskaźniki uzupełniają procedurę, która umożliwia na bazie wyrywkowych pomiarów natężenia ruchu wykonywanych w okresach zalecanych i innych niż zalecane, szacowanie średniego dobowego ruchu (SDR) dla dróg w obszarach miejskich w centralnych i pośrednich częściach miast oraz na drogach wylotowych z miast. Zamierzeniem autorki jest kontynuacja pomiarów rozbudowanych o pełną strukturę rodzajową ruchu prowadzonych w przekrojach międzywęzłowych na drogach o wysokim, średnim i o niskim znaczeniu funkcjonalnym, na sieci dróg miejskich.

Keywords: **Average annual daily vehicle traffic (SDR – ADT); Seasonal fluctuations coefficient (W_M); Weekly traffic density fluctuations coefficient W_T; Daily fluctuations coefficients W_{ZD}; Time series.**

1. INTRODUCTION

Average Daily Traffic Density (SDR) provides the grounds for: planning urban and non-urban transportation networks, managing, maintaining and determining transportation work, designing roads and junctions, constructing road pavements, planning traffic organization, estimating roads throughput and their technical conditions, assessing the impact of roads on the environment, economic analyses, analyses of accident rates, etc [1], [3].

From the results of systematic analyses it is possible to obtain typical monthly, weekly and daily profiles of traffic density fluctuations, which facilitate the designation of the calculation coefficients of seasonal, weekly and daily traffic fluctuations (W_M), (W_T) and W_{ZD}, respectively, depending on the nature of traffic and the location of a given road in the transportation network.

The traffic fluctuations coefficients for roads in urban areas were calculated on the grounds of continuous measurements taken in 2003, 2004, 2005 and 2006. In the following 4 cities: Łódź, Bytom, Zabrze, Zawiercie, 14 junctions controlled by traffic lights were monitored by means of Remote Control and Data Collection System SNS/ASR, the controllers of which register the passage of vehicles (without sorting out their type) at 5 minute intervals. Thus, continuous measurements of traffic density on 47 junction inlets were obtained in the cross-sections of the roads at the distance of about 40-70 m from the conditional give way line, recorded by the passage loops (short loops – 1.5 m long). By designating the traffic fluctuation coefficients the hourly and daily traffic intensities were analysed, respectively.

The traffic fluctuations coefficients for roads in urban areas were derived with the use of classic, simplified methods of designating calculation coefficients (in accordance with GDDKiA's definition) and on the basis of models of time series.

2. DEFINITIONS OF TRAFFIC FLUCTUATIONS COEFFICIENTS (ACCORDING TO GDDKIA)

The average annual daily vehicle traffic (SDR) is a basic parameter of traffic. SDR denotes number of vehicles that go through an examined cross-section of the road in the successive 24 hours, during one year on average. The average annual traffic is determined from the analyses made each month, by designating SDR for particular days of the week in a month, and by designating SDR for all months [1], [2], [

The seasonal fluctuations coefficient (W_M) is a quotient of the average daily traffic in one month and the average daily traffic in one year, the weekly traffic density fluctuations coefficient (W_T) is a quotient of the average daily traffic during one day of the week and the average daily traffic during one year.

The daily fluctuations coefficients W_{ZD} are the sum ($\overline{u}_i$) of average percentage fractions of traffic density from Δh hours in the daily traffic density.

3. APPLICATION OF MODELS OF TIME SERIES [6], [7], [8]

Theory of time series facilitates modelling of various, very specific processes and their forecasting.

The adjustment trend models included:

- moving average model:
  - – centred moving average model for designating weekly traffic fluctuations coefficients – W_T)
  - – centred moving average model for designating seasonal coefficients W_M and percentage fraction of traffic density during the *i-th* hour in daily traffic $\bar{U}i$, constituting the grounds for determining the daily traffic fluctuations coefficients W_{ZD},
- Winters multiplicative method – (weekly traffic fluctuations coefficients – W_T)

By means of classic trend models (analytic methods) – the multiple-activity method of designating seasonal coefficients and adjustment of the trend function in consideration of the least squares approach, the traffic density fluctuations coefficients: W_M, W_T were derived, as well as the percentage fraction of traffic density during the i-th hour in daily traffic $\overline{u}_i$. Thanks to the use of different methods, theoretical series model was adjusted to the empirical one with minimal errors.

The model of moving average with an uneven number of the neighbouring terms assumes the following form:

$$\hat{y}_t = \frac{1}{2q+1} \sum_{r=-q+1}^{q-1} y_{t+r} \qquad (t = q+1, q+2, ..., n-q) \qquad (1)$$

where:

$\hat{y}_t$ – theoretical value of the variable in series y_t derived for moment or time period t,

y_t – real value of variable in the series in moment or time period t,

q – fixed natural number.

The centred moving average model with an even number of sub-periods is expressed as:

$$\hat{y}_t = \frac{1}{2q}\left[\frac{1}{2} y_{t-q} + \sum_{r=-q+1}^{q-1} y_{t+r} + \frac{1}{2} y_{t+q}\right] \quad (t = q+1, q+2, ..., n-q) \quad (2)$$

where:

q = d/2,

d – number of sub-periods in the fluctuations cycle

$\hat{y}_t$ – theoretical value of the variable in series y_t derived for moment or time period t,

y_t – real value of the variable in the series in moment or time period t,

Classic method of trend identification involves adjustment of a specific mathematical function to a given time series. Parameters of the trend function are derived on the grounds of the least squares method, and the corresponding curve is adjusted to the observation set $\{y_t ; t = 1, 2, ..., n\}$ [6], [8].

The multiplicative model renders relative – percentage seasonal coefficients W_M and W_T, which assume values close to the values of coefficients determined in accordance with the definition.

The seasonal fluctuations coefficients are derived by means of method which involves designation of seasonal coefficients or absolute seasonal fluctuations for particular phases of the cycle.

Designation of seasonal coefficients involves several stages:

1. identification of trend f – the least squares method,
2. elimination of trend from the series– derivation of u_{tli} values containing seasonal and accidental fluctuations:

$$u_{tli} = \frac{y_{tli}}{\hat{y}_{tli}} \qquad (t_{li} = 1, 2, \ldots, n). \quad (3)$$

3. determination of raw seasonality coefficients:

$$w_{0i} = \frac{1}{N}\sum_{l=1}^{N} u_{tli} = \frac{1}{N}\left(u_{t1i} + u_{t2i} + \ldots + u_{tNi}\right) \quad (4)$$

where:

N – number of periods (cycles),

m – number of phases in the cycle (number of seasons).

4. designation of pure seasonality coefficients (the sum of raw seasonality coefficients should be approaching or equal to

$$w_i = \frac{w_{0i}}{\bar{w}_0} \quad (5)$$

Coefficients wi correspond to coefficients W_T, W_M, and to percentage fraction of traffic density during the *i-th* hour in the daily traffic $\bar{U}$.

The third method of describing annual traffic fluctuations by means of the time series model is so called "Winters method", which is flexible and adjustable for irregular changes of the trend direction or for disturbances and displacements of periodic fluctuations (for example: the seasonal ones) – variables have a labile graph curve in time, e.g. the annual daily traffic density fluctuations.

Winters' method consists in exponential smoothing and is used for the time series, components which include: linear trend, periodic fluctuations and random fluctuations.

The multiplicative version assumes that each value of the time series is a quotient of the value with excluded seasonality and the seasonality index specific for a given period, whereas relative increments of values of the trend variable Y_t are approximately constant, or vary in a regular manner.

Winters model in the multiplicative version assumes the following form:

$$\begin{cases} F_r = \frac{1}{r}\sum_{t=1}^{r} y_t \\ F_t = \pm\left(\frac{y_t}{C_{t-r}}\right) + (1-\pm)\cdot(F_{t-1} + S_{t-1}) \end{cases} \quad \begin{cases} S_r = \frac{1}{r}(y_r - y_1) \\ S_t = {}^{2}\,(F_t - F_{t-1}) + (1-{}^{2})\cdot S_{t-1} \end{cases} \quad \begin{cases} C_t = 1, \quad t \in \overline{1, r} \\ C_t = {}^{3}\left(\frac{y_t}{F_t}\right) + (1-{}^{3})\cdot C_{t-r} \end{cases} \quad (6)$$

where:

F_t – assessment of mean value of variable Y in time t,

S_t – assessment of change in the trend of variable Y in time t,

C_t – assessment of seasonality effect of variable Y in time t,

r – number of phases of a given seasonal cycle,

α, β, γ – smoothing parameters, values of which are in the range [0;1].

Comparison between theoretical values with empirical ones is done by calculating accuracy measures of adjusting the smoothed series to the empirical series, including, among others, percentage error at time *t*, mean error – ME, mean percentage error – MPE and remainders relative coefficient v_e, standard deviation σ and randomness coefficient v.

The weakness of measures discussed above is the fact that positive deviations of empirical values from theoretical ones are offset by negative deviations. The measures that eliminate such disadvantage those of the absolute errors: mean absolute error – MAE, and mean absolute percentage error – MAPE.

If absolute values from measurements of errors ME and MAE are equal, theoretical values are systematically lower or higher than the real ones. If, on the other hand, the values of ME and MPE are definitely lower than MA and MAPE, the smoothing errors are anisotropic. The method that highlights particularly big errors is the mean square error – MSE.

4. RESULTS OF ANALYSES

On the grounds of the analyses of the time series models and definitions the following traffic fluctuations coefficients were designated for road networks in urban areas:

4.1. Monthly traffic fluctuations

The analyses of seasonal fluctuations at examined points made it possible to distinguish between 2 data groups, depending on the character of fluctuations distribution and location of points in the urban network. The first group comprises seasonal fluctuations at points located in the central and midway parts of cities.

The nature of traffic fluctuations in urban areas is different from that on national non-urban roads (Fig. 1). On national roads, significantly bigger average daily traffic is recorded during holiday time in comparison with the annual average daily traffic. Distributions of seasonal traffic fluctuations on the urban road networks are characterized by reduced density during holiday time, whereas, in the spring and autumn times, at the turn of October and November, by significantly increased density.

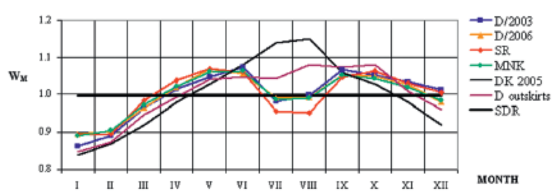

Figure 1.
Comparison between the values of traffic fluctuations seasonal coefficients W_M designated in accordance with the moving average (SR), the adjustment of the trend function by means of the least squares method (MNK) and GDDKiA's definition as of 2003 (D/2003) and 2005 (D/2006); as well as traffic fluctuations on non-urban roads (DK 2005)

The second group comprises of seasonal fluctuations on the outgoing roads. Seasonal fluctuations lie in-between the traffic fluctuations for national roads of economic importance and traffic fluctuations in city centres and midway parts of cities. The number of sections from the second group was not sufficient, and, accordingly, it was not possible to obtain reliable results. Therefore, the sections from the first group, concerning city centres and midway parts of cities were examined in the following analyses.

The nature of fluctuations of traffic density in urban areas differs from that on non-urban roads. The average daily traffic on national roads is bigger during summer time than the average daily traffic throughout the year. The seasonal fluctuations in

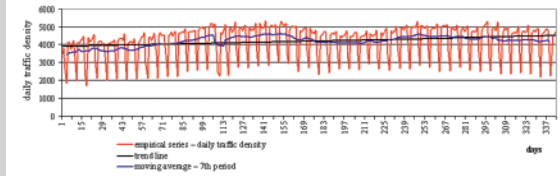

Figure 2.
Daily traffic density fluctuations in a selected cross-section of the road with the series smoothened by 7-period moving average and the linear trend

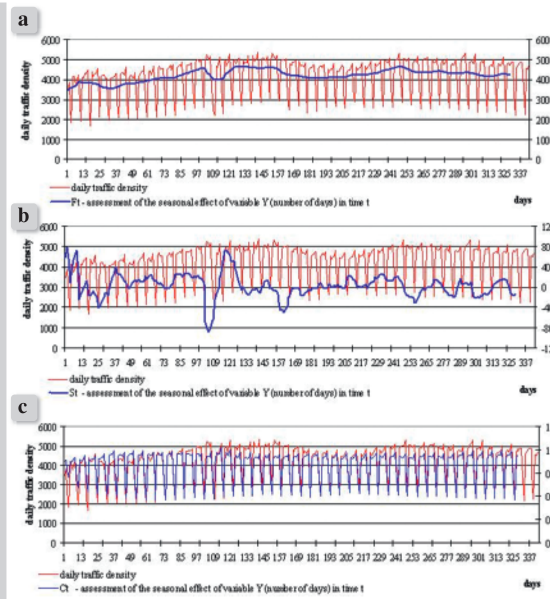

Figure 3.
Values of empirical series and theoretical one smoothed in accordance with Winters multiplicative method at exemplary point TB 0; a) estimation of the mean value of variable Y in time t; b) estimation of change in the trend of variable Y in time t; c) estimation of seasonal effect of variable Y in time t

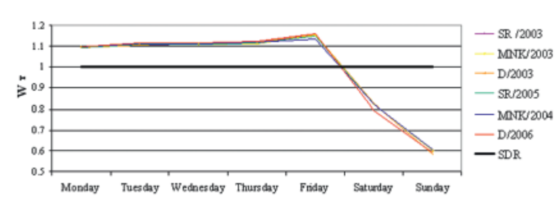

Figure 4.
Comparison between the values of weekly traffic fluctuations coefficient W_T designated by means of the least squares method (MNK), Winters method (W) and definition (D) as of 2003, 2004, 2005 and 2006

urban areas are characterized by reduced density during holiday time, whilst during spring and autumn time, at the turn of May, June, October and November by significantly greater traffic.

The results of calculations indicate that very low values of the remains relative ratio ve and the randomness ratio v, derived on the grounds of the least squares method (MNK), certify a good adjustment of the model to the real data; whereas the coefficients W_M have middle values, those determined in accordance with the said definitions set forth for 2003, 2004, 2005 and 2006.

4.2. Weekly traffic fluctuations

As far as the roads running in urban areas are concerned, SDR on working days from Monday to Thursday has similar values. On national roads, approximate values are rendered by the average daily traffic from Tuesday to Thursday, whereas the average daily traffic on Mondays is similar to SDR. On Fridays, the average daily traffic both on urban and non-urban roads reaches the highest values.

Application of the assumed models facilitated derivation of values of weekly traffic fluctuations coefficients W_T that are very similar to those determined in accordance with the definition. The best adjustment to the real data was achieved with the use of moving average model of the 7th period – i.e. lower v_e coefficients. Likewise, the values of Theil's ratios approaching zero testify to a good adjustment of theoretical values to empirical values of the series.

4.3. Daily traffic fluctuations

The basic characteristics of traffic variability within 24 hours in the cross-section of the road is variability graph of daily traffic densities, also referred to as the daily traffic density profile or the daily traffic distribution. To obtain graph of average daily traffic fluctuations, percentage fraction of hourly traffic densities is calculated for each day of the year. The standard graph characterized by low sensitivity to chance variations of traffic, specific for a given measurement day, enables comparison of distributions in different years.

On the grounds of continuous measurements of traffic it is possible to plot standard graphs of daily traffic density profiles for each day of the year, in the following division:

– all working days (Mondays to Fridays),

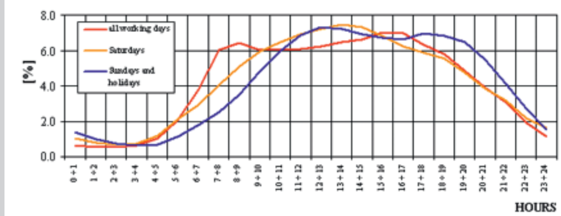

Figure 5.
Average daily traffic fluctuations at cross-section No 1

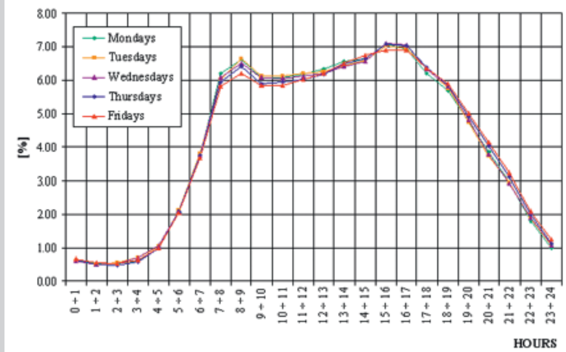

Figure 6.
Average daily traffic fluctuations for particular working days

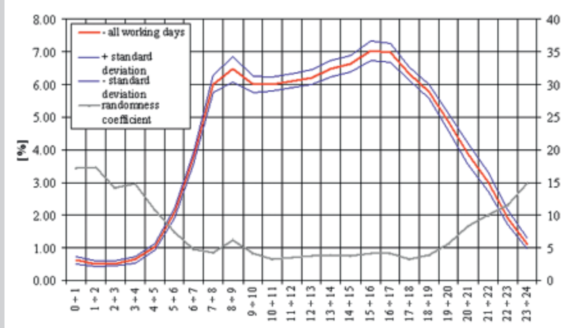

Figure 7.
Average daily traffic fluctuations – the distribution for all working days for Point

– Saturdays (plus days preceding holidays),

– Sundays and holidays.

Scatter results of the hourly values of traffic density during the i-th hour in the daily traffic density profile for particular working days and for a definite cross-section of the road was estimated by calculating standard deviation σ and variability coefficient ν. At all measurement points the variability coefficients had the lowest values (about 5%) in the daytime, from 8 am to 6 pm, and the highest at the night time (up to 100%).

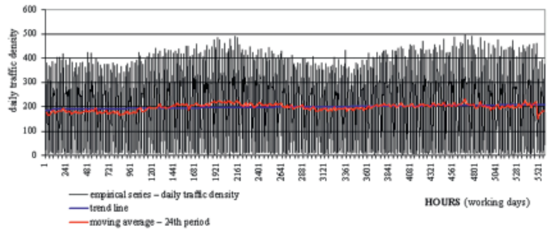

Figure 8.
Hourly traffic density fluctuations with the linear trend and the series smoothed by 24-period moving average

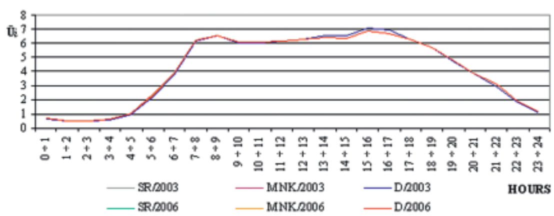

Figure 9.
Comparison between the values of the percentage fraction of traffic density during the *i-th* hour in the daily traffic $\bar{U}_i$, derived by means of the moving average (SR), the adjustment of the trend function by the least squares method (MNK) and the definition (D) at a selected measurement point

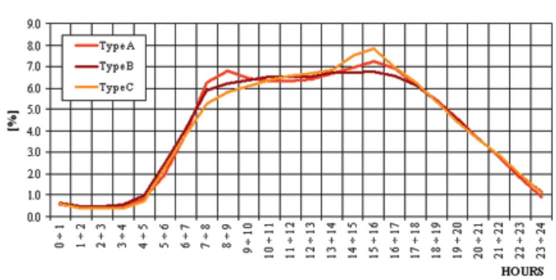

Figure 10.
Types of daily traffic fluctuations distribution curves

The analysis of the graphs of daily variability of traffic density in particular working days indicates that, for all measurement points, the daily distributions of traffic density on Mondays and Fridays are almost identical (convergent) with the distributions on the recommended [6] measurement days, that is: Tuesdays, Wednesdays and Thursdays. This convergence results from the similarity of shapes, as well as the percentage values of traffic density during the i-th hour in the daily traffic.

The percentage fraction of traffic intensity during the i-th hour in daily traffic $\bar{U}_i$ was determined on the basis of hourly traffic densities during all working days of the year, with the exclusion of days preceding holidays, on the bases of two time series models:

a) Model of 24-period centred moving average,

b) Adjustment of the trend function by means of the least squares method.

The values of $\bar{U}_i$ for some selected points were designated separately for the years of: 2003, 2004 and 2005.

On the grounds of the assumed models, the obtained values of the percentage fraction of traffic density during the *i–th* hour in the daily traffic $\bar{U}_i$, are very close to those determined by definition. The best adjustment to the real data was obtained with the use of the model of 24-period centred moving average – the lowest values of coefficients v_e, σ and v.

Among all average daily distributions of traffic fluctuations obtained for the analyzed roads inlets, significant similarities in graph distributions were observed, depending on the shape of distribution curves (number of peaks) and the role and location of analyzed street in the urban transportation system. On the basis of derived values of the average daily traffic fluctuations in all tested inlets, the results distributions were categorized into 3 typical traffic density distribution curves.

The types have different curses of traffic density variations during peak hours (morning and afternoon) and variations between peak hours (relation between the density level in the hours between the peaks and the peak hours).

Type A – characterized by two peaks.

Type B – absence of distinct peaks, traffic density at daytime (8 am – 4 pm) is, more or less, on constant level.

Type C – the daily traffic fluctuations curve has a distinct late afternoon peak.

5. THE PROPOSED PROCEDURE OF ESTIMATING SDR IN URBAN AREAS

It is recommended that the existing procedure of estimating average daily traffic (SDR) was supplemented with coefficients of annual W_M and weekly W_T traffic fluctuations for the roads in urban areas and also with 3 typical curves of daily traffic density and daily variability coefficients W_{ZD}.

The procedure of the estimation is as follows:

1. Plotting hourly traffic fluctuation density chart for the sum of all passing vehicles on the basis of the measured traffic density from n hours.
2. Selecting the appropriate curve by comparison between the traffic fluctuation density chart with 3 typical annual traffic density curves. (Fig. 9)

3. Adopting the annual traffic fluctuation coefficient W_{ZD} depending on the type of daily curve and time of testing traffic intensity (Table 1)
4. Transposing n-hour density $N_{\Delta h}$ into the daily traffic density fluctuation coefficient W_{ZD} in accordance with the following formula:

$$N_{dob} = \frac{N_{\Delta h}}{W_{ZD}} \cdot 100\% \quad \text{[vehicles/24 hours]} \qquad (7)$$

5. Selecting the value of annual traffic fluctuation coefficient W_M and weekly traffic fluctuation coefficient depending on the location of measurement point on urban road network and on the month and the day of the week of traffic measurement. (according to Tab. 2 and Tab. 3)
6. Transposing daily density N_{dob} from a specific day into the average daily density in the year (SDR), taking into account weekly traffic density fluctuations coefficient W_T weekly variability W_T and annual variability W_M using the following formula:

$$SDR = \frac{N_{dob}}{W_T \cdot W_M} \quad \text{[vehicles/24 hours]} \qquad (8)$$

On the basis of 24-hour independent checks of traffic intensity in Jastrzębie-Zdrój and Piekary Śląskie relative errors of the estimated daily traffic intensity were calculated. The relative errors for 4 and 8 hour measurements were in the range from 0 to about 10%, at the same time, the errors were bigger in case of 4-hour measurement.

Table 1.
Combination of daily traffic fluctuation coefficients W_{ZD} on urban roads

Number of hours of measurements	Time of measurements	Type of daily traffic fluctuation curve		
		A	B	C
3 hours	6.00 ÷ 9.00	16.2	16.4	13.2
4 hours	7.00 ÷ 11.00	25.4	25.1	23.5
	14.00 ÷ 18.00	27.1	26.1	29.1
8 hours	8.00 ÷ 16.00	52.6	52.4	54.0
	13.00 ÷ 21.00	47.7	46.3	49.6
8 hours	7.00 ÷ 11.00 14.00 ÷ 18.00	46.2	46.1	47.7

Table 2.
Compilation of seasonal fluctuation coefficients W_M on roads in urban areas

Location of the examined road section	months											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Central part of the city and midway parts	0.890	0.919	0.985	1.021	1.053	1.059	0.939	0.937	1.040	1.082	1.056	1.020
the outskirts of cities	0846	0.875	0.948	0.994	1.042	1.048	1.042	1.081	1.073	1.080	1.009	0.962

Table 3.
Compilation of weekly fluctuations coefficients W_T on roads in urban areas

Location of the examined road section	Day of the week						
	Monady	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Central part of the city and the midway parts	1.093	1.103	1.100	1.110	1.142	0.835	0.618
the outskirts of cities	1.090	1.059	1.067	1.083	1.121	0.870	0.711

6. CONCLUSIONS

Models of times series may be used for describing fluctuations of traffic density in the course of the year. The models facilitate designation of not only development trends, but also of traffic fluctuations coefficients, including: the seasonal traffic fluctuations (W_M), percentage fraction of traffic density during the i-th hour in the daily traffic $\overline{u}_i$, as well as any random fluctuations.

Daily, weekly and seasonal fluctuations coefficients provide the grounds for estimating the annual average daily traffic (SDR) from short-term, random measurements of traffic density taken at recommended intervals, as well as at any other time. Currently the calculation coefficients specified in *Road Traffic* refer only to the seasonal and weekly traffic fluctuations on extra-urban national roads.

The nature of traffic fluctuations in urban areas is different from that on national non-urban roads. On the national roads, significantly bigger average daily traffic is recorded during holiday time in comparison with the annual average daily traffic, whereas the roads in urban areas (located in the centre or midway parts) exhibit lower annual traffic in holiday seasons.

The results of the analyses of average daily traffic fluctuations run for several years may be used for the assessment of the development trend for vehicle traffic in urban areas and for traffic density forecasts.

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