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Analysis of the bus traffic volume on highest classes roads

Abstract: The paper presents the results of analyzes concerning the variation in daily traffic volumes of buses during the year. Based on them, typical groups of seasonal and weekly variation of buses were identified, along with the way in which they were assigned to a particular section of A-class or S-class roads. For the homogeneous traffic groups obtained in this way, representative traffic volume variation profiles were determined enabling direct calculation of volumes from daily measurements into AADT buses, which is a departure from the present approach (profiles determined for all vehicles). Additionally, the most favorable period for conducting measurements at random, that allows for a reliable estimation of AADT (the smallest AADT estimation error and lowest traffic variation), was determined. The results obtained can help to better estimate the traffic volume of buses and thus better design the road infrastructure.

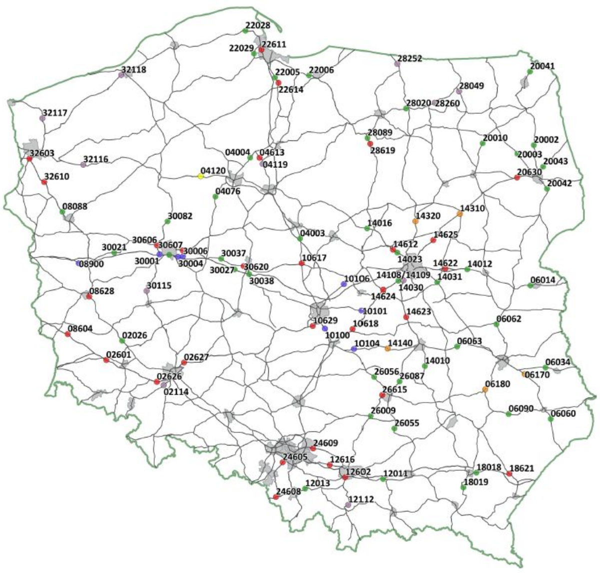
Keywords: Rural roads; Traffic flow variability; Annual Average Daily Traffic (AADT) of buses

Introduction

One of the foundations of European Union transport policy is the construction of the TEN-T network (trans-European transport network), which obliges Member States to build a core network by 2030 and a comprehensive network by 2050 [3, 14]. The total length of the TEN-T road network in Poland is approximately 7,400 km, which means that over 4,200 km of highways and expressways must be built. Rest and Service Areas (RSA) are an integral part of a properly functioning and coherent network of highways. According to current national regulations, the number of parking spaces for particular types of vehicles should be determined individually, taking into account in particular the annual average daily traffic (AADT) and the frequency of RSA [7]. From the point of view of potential interest in the use of RSA, one of the important elements of the generic structure are buses. However, there is no indication in the technical literature on how to determine the AADT value directly for buses. In addition, there is no research on their daily traffic volume variation and, as a consequence, it is unknown when to perform traffic measurements. It should also be noted that the volume of bus traffic on national roads is close to 1% of the total traffic so is small but not negligible [5, 10]. There is therefore a need to identify typical patterns of seasonal and weekly traffic variation of buses and to indicate the period in a year that is favorable for short-term traffic measurements (day and month of the year in which repetitive traffic volume is observed). This paper will present the results of the study on the above issues, including the verification of the AADT evaluation method for buses based on daily measurements and the developed conversion factors (related to the characteristics of the roads and their surroundings).

The database and the choice of research methods

The analyzes used data from the automatic traffic recorder (ATRs) equipped with a Sick counter, located on the Polish national road network (marked in red in figure **1**). Data from other stations (PAT, RPP, Golden River), due to errors in automatic vehicle classification (determined based on 16-hour supplemental manual measurements, performed twice a year) were not suitable for the analysis. In order to complete the database, data from the toll collection system viaTOLL (ttps://www.viatoll.pl/upload/images/mapy/pl_mapa_2016_viatoll. jpg) was used. Since 2011 in Poland, cars or combinations of vehicles with a maximum weight exceeding 3.5 tones and buses, regardless of their permissible maximum weight, have been subject to toll. A full list of road sections covered by the viaTOLL system is contained in the Regulation of the Council of Ministers [9]. Finally, data from 18 ATRs and 489 toll stations (TSs) located on the roads of technical classes A and S (highways and expressways) were selected for analysis, according to Table 1. For ATRs, the data completeness index is, on average, 98% (it ranges from 93% to 99%) and, for TSs, 100% has been assumed. Due to the possibility of referring to all vehicles, despite a smaller number of samples, the data from ATRs were considered as basic data (in the case of TSs, there was no identification of light vehicles).



1. Map of ATRs in Poland (source: Department of Traffic Analysis, GDDKiA, Jakub Maśkiewicz)

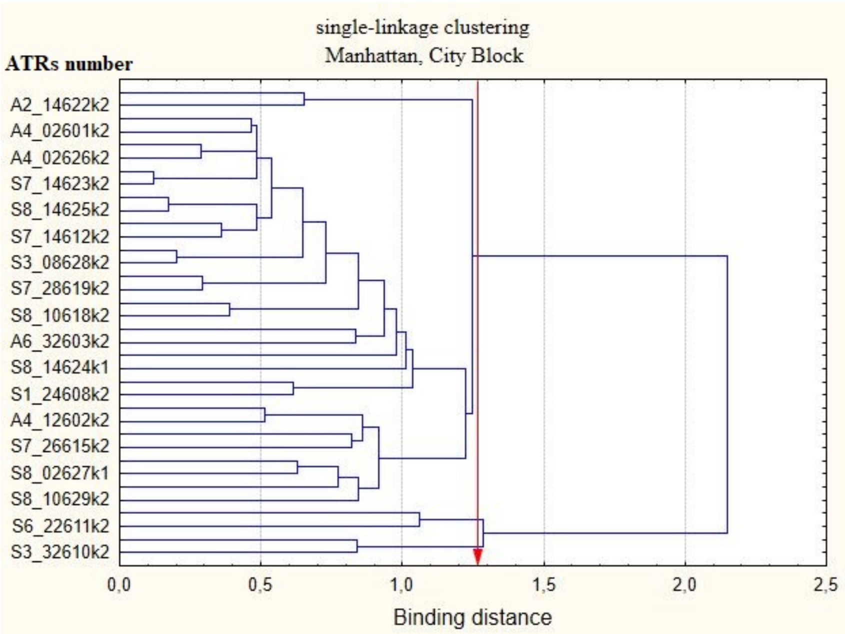
Tab. 1. Road number and number of TSs / ARTs within it

Year 2015			
Road number	number	Road number	number
A4/3	157/3	S2	7/-
S8	70/5	A6	6/1
S7	47/4	S22	6/-
A2	42/1	A8	5/-
A1	41/-	S10	3/-
S1	24/-	S19	3/-
S3	21/2	S69	3/-
S12	14/-	S14	2/-
S5	12/-	S79	2/-
S11	11/-	A18	1/-
S6	11/1	S61	1/-
S52	-/1		

Due to the fact that the most efficient way of exploring traffic data, shown in papers [1, 2, 8, 12, 13] (including grouping road sections into homogeneous traffic clusters), was the combined use of quantitative and qualitative methods, cluster analysis and expertise were used. In cluster analysis, the agglomeration algorithm was first applied (on the basis of which the required number of clusters was determined), and secondly, the k-means clustering algorithm (division into k clusters according to the agglomeration result). Once the division was established, functional-geographic features were identified, allowing for the assignment of a particular road section to the resulting cluster. The analyzes were carried out separately for the ATRs and TSs with regard to the daily traffic volumes of buses, for each traffic direction (in the case of TSs, due to the large sample, in the additional division of roads into classes A and S). In the case of weekly variation analyzes, due to divergent daily traffic volume values from average traffic volume values, statutory holidays and the days directly related to them were removed from the analysis. In order to standardize the data, the analyzes were carried out in relation to the day-of-week factor (the ratio of weekday average daily volume to the AADT) and monthly factor (the ratio of monthly average daily traffic to the AADT).

Seasonal variation

In the case of the TSs, in order to avoid the influence of extreme values, sections with the AADT value <25 buses per 24 hour (on average, one bus per hour) and those with values less than 0 in any month of the year were removed from further analyzes (in total, 218 cases were removed). Based on the hierarchical tree obtained as a result of the agglomeration, it was determined that for ATRs, the required cluster number was 3 (figure **2** – red arrow), and in the case of TSs, 3 for A-class roads and 5 for S-class roads. In the next stage, the roads were divided into k clusters, according to the results of the agglomeration. Tables 2 and 3 show descriptive statistics of the individual clusters (average value – av., number, and, in the case of ATRs, standard deviation).



2. Hierarchical tree diagram (ATRs)

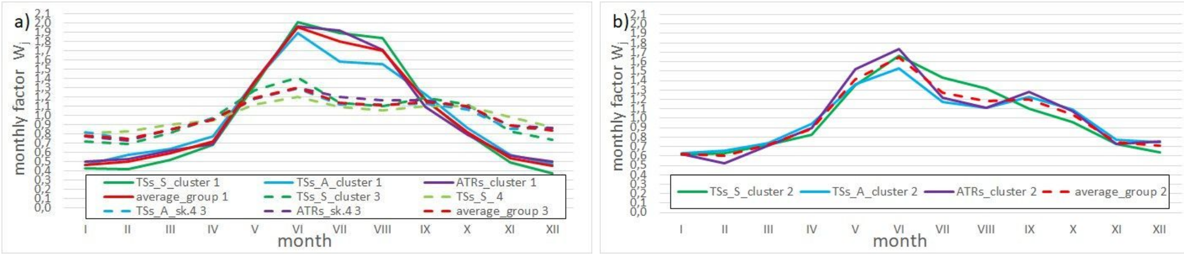
Tab. 2. Descriptive statistics of individual profiles – ATRs

month	cluster 1 – 4 elements		cluster 2 – 8 elements		cluster 3 – 23 elements	
	av. [-]	σ	av. [-]	σ	av. [-]	σ
I	0,497	0,07	0,619	0,09	0,77	0,07
II	0,527	0,06	0,524	0,15	0,728	0,12
III	0,617	0,07	0,709	0,10	0,847	0,07
IV	0,695	0,02	0,899	0,08	0,952	0,07
V	1,376	0,21	1,524	0,15	1,178	0,07
VI	1,959	0,08	1,733	0,09	1,297	0,10
VII	1,917	0,20	1,217	0,04	1,197	0,14
VIII	1,704	0,29	1,109	0,08	1,161	0,14
IX	1,093	0,14	1,282	0,05	1,164	0,12
X	0,795	0,03	1,077	0,11	1,092	0,12
XI	0,56	0,05	0,724	0,07	0,892	0,11
XII	0,506	0,02	0,753	0,10	0,86	0,12

Tab. 3. Descriptive statistics of individual profiles – TSs

month	S-class roads					A-class roads		
	cl. 1 (11 elem.)	cl. 2 (35 elem.)	cl. 3 (4 elem.)	cl. 4 (61 elem.)	cl. 5 (6 elem.)	cl. 1 (10 elem.)	cl. 2 (21 elem.)	cl. 3 (53 elem.)
	av.[-]	av. [-]	av. [-]	av. [-]	av. [-]	av.[-]	av. [-]	av. [-]
I	0,432	0,612	0,721	0,810	0,447	0,468	0,633	0,815
II	0,417	0,632	0,696	0,830	0,492	0,571	0,659	0,745
III	0,522	0,717	0,805	0,900	0,655	0,639	0,741	0,848
IV	0,685	0,824	0,973	0,945	0,750	0,771	0,938	0,963
V	1,329	1,354	1,271	1,118	1,095	1,375	1,356	1,178
VI	2,006	1,664	1,407	1,195	1,395	1,890	1,533	1,292
VII	1,892	1,428	1,134	1,086	1,187	1,578	1,175	1,114
VIII	1,831	1,313	1,102	1,053	1,163	1,552	1,113	1,117
IX	1,170	1,103	1,194	1,101	1,200	1,222	1,227	1,128
X	0,799	0,956	1,121	1,104	1,267	0,863	1,090	1,066
XI	0,494	0,731	0,825	0,978	1,207	0,570	0,774	0,852
XII	0,379	0,641	0,733	0,871	1,111	0,475	0,745	0,867

Because of the similar average variation profiles obtained in the ATRs and TSs analyzes (cluster 1 corresponds to cluster 1 obtained for S-class roads and for most of the year to cluster 1 obtained for A-class roads, clusters 2 and 3 correspond to clusters 2 and 3 obtained for A-class roads and for most of the year respectively to cluster 2 as well as 3 and 4 obtained for S-class roads), new groups were created by averaging similar values. Figure **3** shows the resulting mean values for the newly created groups (cluster 5 – S-class roads, was omitted due to a small sample).



3. Profile of seasonal bus traffic variation: a) groups 1 and 3, b) group 2

Finally, a division of the fast roads into three groups was obtained, which included road sections of different bus traffic patterns, that is:

- economic (traffic in VII and VIII is higher than AADT on average by maximum 20%) – group 3,
- economic-tourist (traffic at least in VII or VIII is higher than AADT on average by 20% to 45%) – group 2,
- tourist (traffic in VII and VIII is higher on average by minimum 55% than AADT) – group 1.

Table 4 shows the distinctive characteristics of the roads and their surroundings characteristic for a given group. Note: In some cases, no indication of the characteristics may be due to the lack of information on the location of the station that would enable its identification.

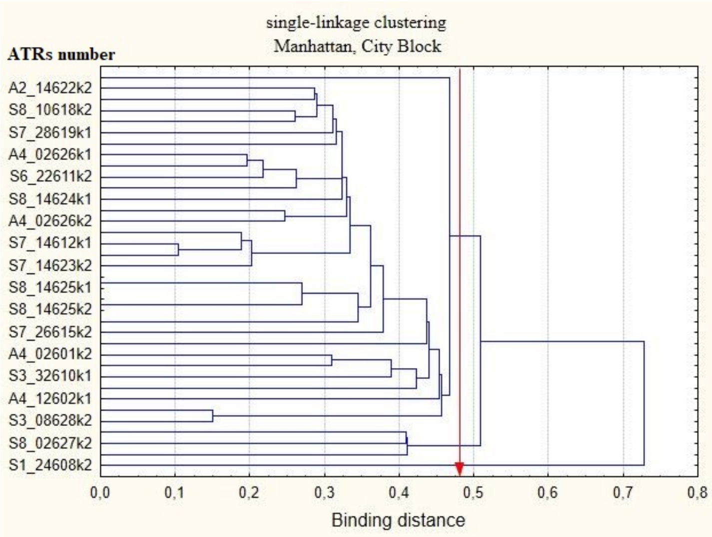
Tab. 4. Distinctive characteristics of the roads and their surroundings – seasonal variation groups

Profile symbol	Polish region	Spatial relationship
$DSRG_A$	1, 4	4 (without the main route connecting north to south of Poland - S3 from Szczecin, A6, A1), 3 (S3 from Baltic sea to Szczecin)
	2, 3, 5	1 (bypass of Rzeszow, passing through Katowice - no stations in the area of influence of the city of Opole, Lublin, Bialystok)
$DSRGT_A$	2, 3, 5	1 (bypass of the city of Cracow, Kielce, Wroclaw)
	6	4 (without A1)
$DSRT_A$	1, 4, 6	4 - main route connecting north to south of Poland (S3 from Szczecin, A1, A6)

Key: Polish region: 1 – central, 2 – south, 3 – east, 4 – northwest, 5 – southwest, 6 – north, 7 – without significance.
Spatial relationship: 1 – impact of cities at a distance of <25 km, 2 – impact of cities at a distance of >25 km, 3 – outside the impact of urban agglomerations, 4 – without significance.

Weekly variation

Similarly as in the case of seasonal variation, on the basis of the hierarchical tree, the required number of clusters was first determined, that is: ATRs – 2 (red arrow in figure **4**), TSs of A-class and S-class roads – 3 for each class. In the next step, the sections of roads were divided into k clusters, according to the results of the agglomeration. Tables 5 and 6 show descriptive statistics of the individual clusters (average value – av., number and, in the case of CMSs, standard deviation).



4. Hierarchical tree diagram (ATRs)

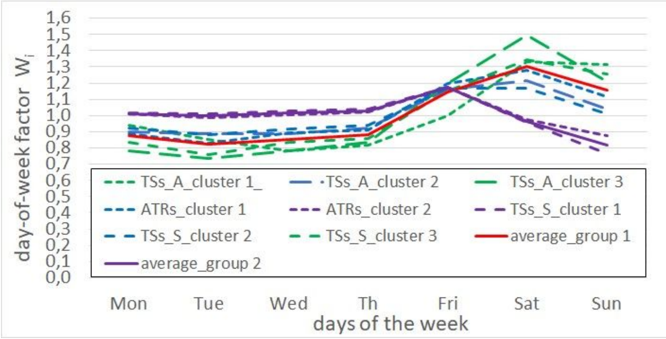
Tab. 5. Descriptive statistics of individual profiles – ATRs

Day	cluster 1 – 23 elements		cluster 2 – 12 elements	
	av. [-]	σ	av. [-]	σ
Mon	0,886	0,10	1,010	0,05
Tue	0,830	0,06	0,987	0,05
Wed	0,896	0,08	1,005	0,05
Th	0,910	0,05	1,022	0,04
Fri	1,196	0,10	1,172	0,04
Sat	1,279	0,13	0,973	0,10
Sun	1,118	0,13	0,874	0,11

Tab. 6. Descriptive statistics of individual profiles – TSs

Day	S-class roads			A-class roads		
	cl. 1 (104 elem.)	cl. 2 (193 elem.)	cl. 3 (81 elem.)	cl. 1 (35 elem.)	cl. 2 (78 elem.)	cl. 3 (56 elem.)
	av. [-]	av. [-]	av. [-]	av. [-]	av. [-]	av. [-]
Mon	0,993	0,912	0,817	0,940	0,901	0,785
Tue	0,979	0,874	0,753	0,851	0,885	0,737
Wed	1,002	0,914	0,809	0,781	0,889	0,781
Th	1,013	0,935	0,842	0,817	0,923	0,838
Fri	1,161	1,157	1,141	1,001	1,164	1,197
Sat	1,001	1,162	1,406	1,333	1,213	1,493
Sun	0,848	1,062	1,272	1,315	1,042	1,212

Because of the similar average variation profiles obtained in the ATRs and TSs analyzes (cluster 1 corresponds to cluster 2 obtained for S-class and A-class roads and, in the case of workdays, to clusters 1 and 3 obtained for A-class roads and cluster 3 obtained for S-class roads, cluster 2 corresponds to cluster 1 obtained for S-class roads), new groups were created by averaging similar values. Figure **5** shows the resulting mean values for the newly created groups. In all cases, there is no influence of traffic direction (both traffic directions in a given section belong to the same group).



5. Profile of weekly bus traffic variation - groups 1 and 2

Finally, the division of fast roads into two clusters was obtained, unrelated to the nature of traffic patterns, resulting from the seasonal variation of buses, characterized by:

- group 2 (about 20% of all cases) – road sections located throughout the country, mainly in the direct zone of influence of large cities, including their passageways and their bypasses (apart from bypasses located at some distance from the center, as in Krakow, Kielce, Wroclaw),
- group 1 (over 80% of all analyzed cases) – road sections located throughout the country apart from sections located in the direct zone of influence of large cities, including their passageways and their bypasses (in close proximity to the city center).

Table 7 shows the distinctive characteristics of the roads and their surroundings characteristic for a given group.

Tab. 7. Distinctive characteristics of the roads and their surroundings - weekly variation groups

Group number	Polish region	Spatial relationship
1	7	2, 3
2	7	1 (including passage through the cities, in the case of bypasses only in close proximity to the city center)

Key: Polish region: 7 – without significance. Spatial relationship: 1 – impact of cities at a distance of <25 km, 2 – impact of cities at a distance of >25 km, 3 – outside the impact of urban agglomerations.

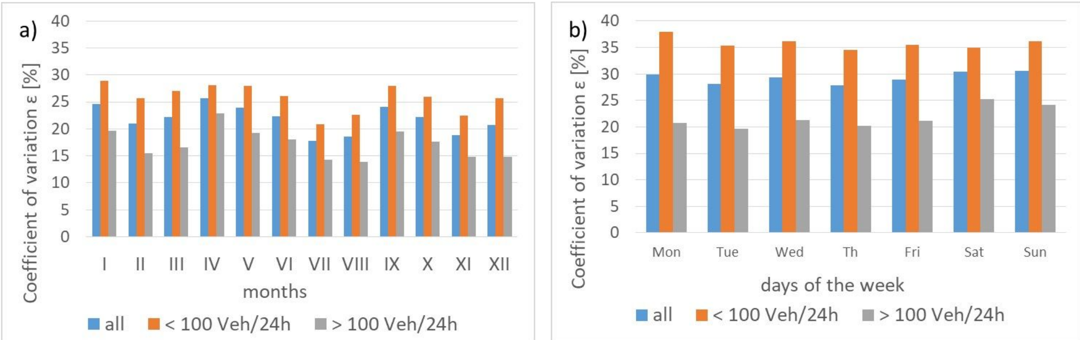
Annual average daily traffic volume variation

In order to determine the traffic variation of buses within a year, the daily traffic volume variation coefficients were calculated in the months of the year and days of the week according to formula 1 [4] (the entire period related to the holidays was removed from the analyzes).

$$\varepsilon = \left(\frac{\sigma}{\hat{y}}\right) \times 100[\%] \qquad (1)$$

where:
ε – daily traffic volume variation coefficient,
σ – standard deviation of the examined feature,
$\hat{y}$ – average value of the examined traffic feature.

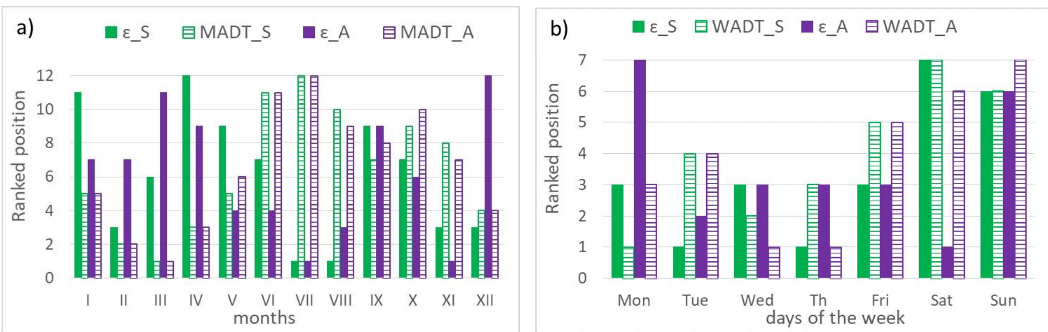
In case of annual variation, the analysis was first performed separately for each of the days of the week in each month and then for all days of the week in a given month (this allowed for the attenuation of outliers). Due to the supposed influence of the values of traffic volumes on their variation, an additional data division: from 25 to 100 Veh/24h and over 100 Veh/24h, was introduced. Exemplary results are shown in figure **6**.



6. Value of the coefficient of variation ε: a) months a year, b) days a week – S-class roads

In all cases, a reduction in the value of the variation coefficient was obtained for data with traffic volume above 100 Veh/24h compared to the data from the entire year. In the case of S-class roads, the difference is, on average, 4.6 percentage points for months of the year and 7.5 percentage points for days of the week. For A-class roads, the difference is, on average, 6.2 percentage points. In all cases, the increase in the value of the variation coefficient was obtained for data with traffic volume less than 100 Veh/24h compared to the data from the entire year. For S-class roads, the difference is, on average, 3.9 percentage points for months of the year and 6.5 percentage points for days of the week. In the case of A-class roads, the difference in both cases is, on average, 6.1 percentage points. For the most favorable variant, that is volumes above 100 Veh/24h (S-class roads – 169 cases, A-class roads – 82), the highest values of ε were obtained for: S-class road – April (>20%), Saturday and Sunday (>24%), and A-class road – December (>25%), Sunday and Monday (>24%). The smallest values of ε were obtained for: S-class road – August (<14%), Tuesday (<20%), and A-class road – July and November (<18%), Tuesday and Saturday (<22%).

In addition, in order to supplement the characteristics, a ranking was made, in which numbers 7 and 12 correspond respectively to the day and month with the highest value of ε and 1 to the day and month with the lowest value. In order to examine how the volume of traffic affects its variation, a ranking of the average daily traffic was made analogically as for the variation coefficient (for months – MADT and for the days of the week – WADT). The obtained results for the most favorable case (volume above 100 Veh/24h) were presented in figure **7**. The highest traffic volume in July coincides with the period of the smallest variation (the lowest value of ε) and, in the case of highways, the lowest value obtained in March corresponds to the period with the highest variation (the highest value of ε). Moreover, in the case of Sunday and Saturday, as well as S-class roads, the period with the highest volume corresponds to the period with the highest variation. In other cases, there was no relationship between the traffic volume and its variation.

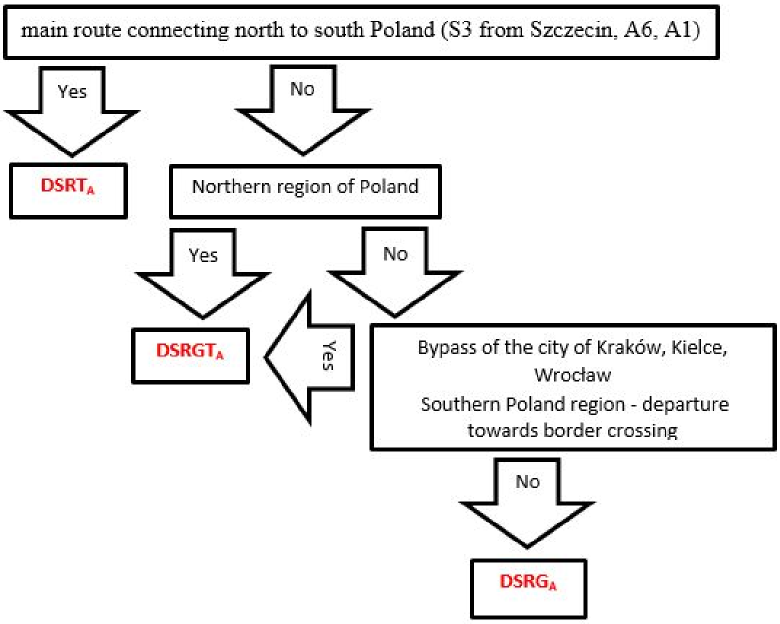


7. Ranking ε and ℑ: a) months a year, b) days a week

Development of a way of classification of a given section of the A-class or S-class road to the appropriate group of seasonal and weekly variation of buses

Due to the poor correlation between seasonal and weekly variation, the seasonal variation group (the nature of traffic patterns) should be determined first on the basis of figure **8**. Subsequently, the weekly variation group should be determined as follows:

- group 2 – sections of roads located in the direct zone of influence of the urban agglomeration (including their bypasses and their passageways),
- group 1 – other cases.



8. Scheme of assignment of a section of the road to the appropriate group of seasonal variation

In order to verify the developed procedure, the daily traffic volume (Q_d) calculations derived from short-term measurements on AADT (formula 2 [6]) were made and the result was compared to the AADT value determined on the basis of all days of the year (Mean Absolute Percentage Error – MAPE - was used as an accuracy measure). The coefficients W_i and W_j were adopted according to the scheme outlined above.

$$\text{AADT} = \frac{Q_d}{W_i \times W_j} \quad [Veh/24h] \tag{2}$$

For this purpose, data from the ATRs from 2015 were used for which the AADT value for buses was over 100 Veh/24. Tables 8 and 9 show the results obtained (mean value obtained for all ATRs). The results were grouped according to the day of the week in which the traffic measurements were conducted and measurement length, that is one-day measurement: Monday, Tuesday, Wednesday, Thursday, Friday – Wednesday, Thursday (according to table 8, the lowest value of MAPE and at the same time, according to [6, 11], favorable time of traffic measurement, also in groups of other types of vehicles), three-day measurement (consecutive days): Tuesday–Thursday and five-day measurement (consecutive days): Monday–Friday. In the tables, the color gray indicates an error value of less than 10% (this corresponds to an average of 15 buses a day, that is about one bus per hour during daytime, namely between 6:00 and 22:00), whereas the bold indicates favorable time, according to [11], for conducting traffic measurements for all vehicles and heavy vehicles (the lowest traffic variation and highest accuracy of AADT). As traffic measurement must fall within a favorable period for all generic groups (measurement on the same day), in the further part of the text, the reference is made to all the results, excluding the months XI – IV and the days Saturday – Sunday (because the high value of ε on Monday was obtained only in the case of buses on highways, this day was not rejected from the analysis at this stage). The biggest error (the highest value of MAPE) and the highest variation of results in consecutive days of the month (the highest value of σ) were obtained in June. It may be related to the end of the school year and the long weekend related to day off work. The highest accuracy and lowest variation in results (the lowest value of MAPE and σ, respectively) were obtained in July and October. In the case of both one-day and three-day measurements, MAPE values below 10% are obtained in months VII, VIII, and X (reduction of average MAPE at three-day measurements relative to one-day measurements by approximately 1 percentage point). In the case of five-day measurements, MAPE values below 10% are obtained in months V, VII – X (reduction of average MAPE relative to one-day measurements by approximately 2 percentage points). Given the low traffic volumes of buses on A-class and S-class roads (according to the GPR2015, on average 149 Veh/24h), the accuracy obtained can be considered acceptable. With the proposed approach, the accuracy of the AADT estimate (on the basis of one-day measurement) is nearly doubled with regard to determining the number of buses as a share in the group of heavy vehicles.

Tab. 8. Descriptive statistics on the accuracy of bus AADT estimates (without months I and XII) – 2015

	MON	TUE	WED	TH	FRI	SAT	SUN
MAPE [%]	9,4	12,1	10,3	10,1	10,7	12,0	19,3
σ [%]	5,7	6,1	6,3	5,8	6,4	8,6	9,1

Tab. 9. Descriptive statistics on the accuracy of bus AADT estimates – 2015

month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
	one day measurements (Monday, Tuesday, Wednesday, Thursday or Friday)											
MAPE [%]	10,6	13,9	10,0	9,3	**11,3**	**13,4**	**7,4**	**9,6**	**11,1**	**6,6**	12,7	19,1
σ [%]	6,4	5,9	6,3	5,4	**7,3**	**7,5**	**4,2**	**5,8**	**6,3**	**5,4**	6,4	9,7
	one day measurements (Wednesday or Thursday)											
MAPE [%]	9,1	13,5	8,7	8,7	**11,1**	**13,4**	**6,2**	**9,9**	**11,0**	**6,5**	13,3	20,2
σ [%]	6,4	6,1	5,7	5,2	**6,8**	**7,5**	**4,2**	**5,5**	**7,2**	**6,0**	5,8	9,4
	three-day measurements (Tuesday - Thursday)											
MAPE [%]	8,8	14,3	8,3	6,7	**10,4**	**12,6**	**5,4**	**9,0**	**10,3**	**4,7**	13,9	20,7
σ [%]	2,7	3,8	5,5	4,6	**5,7**	**7,8**	**2,9**	**4,9**	**4,9**	**3,5**	5,7	11,4
	five-day measurements (Monday - Friday)											
MAPE [%]	8,9	13,5	7,9	5,4	**9,5**	**13,2**	**5,2**	**8,5**	**8,4**	**3,9**	10,0	18,4
σ [%]	3,0	3,8	5,7	3,8	**4,3**	**7,9**	**2,8**	**6,1**	**3,4**	**3,2**	5,7	11,8

Conclusions

The paper presents the results of analyzes concerning the variation in daily traffic volumes of buses during the year. Based on them, typical groups of seasonal and weekly variation of buses were identified, along with the way in which they were assigned to a particular section of A-class or S-class roads. For the homogeneous groups obtained in this way, representative traffic volume variation profiles were determined enabling quick calculation of volumes from daily measurements into AADT. This method is very useful because of its simplicity. At the same time, this approach gives a sufficient accuracy of AADT (average MAPE value below 10% apart from winter months). In addition, studies have shown that the analysis period influences the accuracy of the AADT estimation. On the basis of the variation coefficient of daily volumes (in months of the year and days of the week) as well as the highest accuracy of the AADT estimation based on different measurement periods, the most favorable period of measurement was determined. In the case of one-day measurements (working days of the week, and, in the case of highways, without Monday) or three-day measurements (from Tuesday to Thursday), they are: months III, VII – VIII and X, and in the case of five-day measurements, also months V and IX. For data from this period, not only the highest accuracy of the estimated AADT was obtained, but also the lowest variation of subsequent daily traffic volumes. It should be emphasized that, according to the current recommendations [6], the AADT of buses can be estimated only on the basis of daily measurements as their share in the total number of vehicles in the cross-section of the road. The measurement (national rural roads) should be carried out on working days – from Tuesday to Thursday, from 1 April to 15 June or from 10 September to 31 October. This period only partially coincides with the results. The months April and June were also not confirmed as a favorable period of traffic volume measurement, and the months July and August proved to be favorable.

The results obtained can help to better estimate the traffic volume of buses and thus better design the road infrastructure.

Acknowledgement
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Source materials

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