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DEPENDENCE OF DESIGN HOURLY VOLUME ON THE FUNCTION AND NATURE OF TRAFFIC DEMAND OF RURAL ROADS

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Abstract

In the first phases of study and design documentation of rural roads, one of the key parameters to determine in the analyses is the Design Hourly Volume (DHV). The required level of service and the feasibility of the project depend to a large extent on a properly established DHV. Essentially, the problem is to determine the value of the K-factor for a certain nth highest hour of the year. This paper points to the need for additional analysis of existing databases of long-term automatic traffic counting, from which the necessary guidance for planners and designers can be derived, enabling them to understand and apply the K-factors in a clearer and more detailed way. Using specific data examples, characteristic sections of rural roads with different functions and types (seasonal variations) of traffic demand were selected to show significant differences in the values of the K-factors for the same selected nth highest hour of the year. Several guidelines (BiH, Slovenia, Croatia, Italy, Serbia) were analysed beforehand to get a better understanding of how the K-factor or DHV is explained and used in different countries. The main objective of the article is to show that, on the basis of the existing databases of continuous automatic counting in these countries, with additional analyses presented in this paper or in a similar form, significant regularities in determining the DHV can be achieved, eliminating difficulties of application in engineering practice. As all guidelines practically recommend the use of HCM in capacity analyses, specific examples are selected to show the difference between the definition of HCM for a route with dominant recreational traffic and our route with dominant tourist traffic (recreational versus tourist).

Keywords: K-factor, DHV, measure of seasonal variation

1 Introduction

In the capacity analysis of rural road sections, the first step is to determine the Design Hourly Volume (DHV). This analysis is also an integral part of the study documentation up to the level of the main project. An insufficient determination of the DHV can lead to considerable errors in choosing the most optimal solution. In the absence of more detailed guidelines, quite different approaches, as well as the lack of importance attached to this problem, can be observed in engineering practice.

1.1 Design Hourly Volume

Design Hourly Volume is defined as a proportion of AADT using the K-factor. It is determined at the n^{th} highest peak hour at the end of the planning period.

$$DHV = K\ AADT$$

DHV – design hourly volume (veh/h),
K – factor representing the proportion of annual average daily traffic occurring in the n^{th} highest hour,

AADT - the annual average daily traffic volume, corresponding to the average daily (24-hour) traffic volume on a given cross-section over the whole year. It is obtained by dividing the total number of vehicles that have passed through the cross-section during the year by 365 days. In cases where continuous automatic counting (Croatian for "permanent counting" is NAB) is available for 365 days or 8760 hours, the problem is determining the n^{th} highest hour. Figure 1 shows the descending curve of hourly volume as a percentage of the AADT in the year (8760 hours) from maximum to minimum. The shape of the curve shows that there are only very few (n) hours of the year when the road is extremely congested, and in the remaining hours of the year the volume is much lower. There is the "knee" on the curve, which is the boundary between the strongly descending and the slightly descending part of the curve. It is not possible to plan the road for a few hours and for a volume that on tourist roads can be up to 50 % higher than during the rest of the year. The n^{th} highest hour is defined differently in different countries (30^{th}, 50^{th}, 60^{th}, 100^{th}). Practically, the K-factor is the percentage ratio of the hourly volume in the n^{th} highest hour to the AADT.
Figure 1a shows the percentage ratio of all hourly volumes of the year to the AADT in the order from highest to lowest for two different roads (left and right). In this case, the range is from a maximum of 15.21 % (left) or 21.98 % (right) to values close to zero. It can also be seen that there is the above-mentioned "knee", which is more clearly recognizable with a lower number of peak hours (Figure 1 b, c, d). All countries carry out automatic traffic censuses to a greater or lesser extent, but the usual situation is that permanent censuses are carried out on about 50 % of the total number of sections. The remaining sections are usually subject to a temporary count, from which the AADT and other required parameters are estimated based on permanent count data on sections with similar traffic characteristics. Various methods for estimating AADT have been proposed, based on a combination of temporary and permanent counts [1], while research on K-factors has yielded significantly fewer results [2]. These are mostly manuals [3], [4], [5], [6]. The key question in this article is the estimation of the K-factor or DHV.

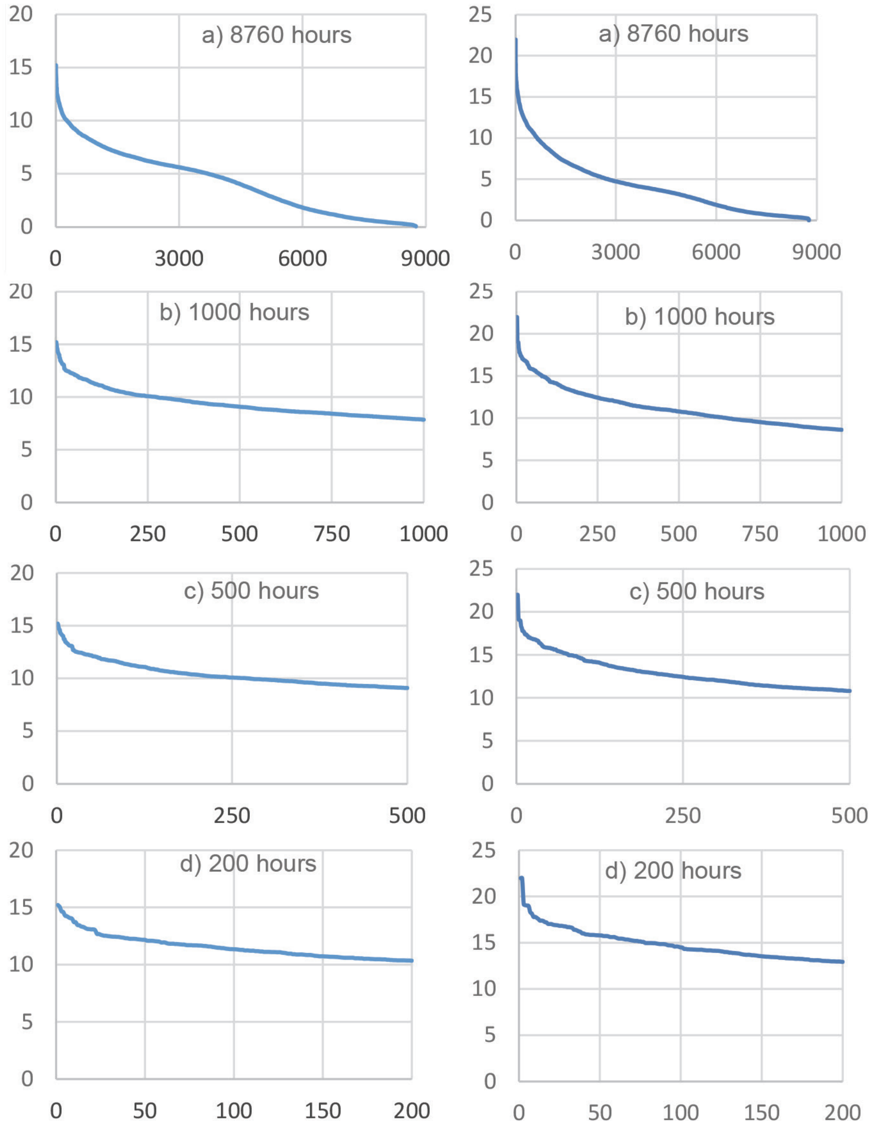


Figure 1 The percentage ratio of hourly volume to AADT for two different roads

1.2 Determination of DHV according to different guidelines

On road sections where there is no permanent counting, the K-factor must be estimated based on additional analyses that are not sufficiently specified in the guidelines. The following is a brief overview of how the guidelines in Bosnia and Herzegovina, Croatia, Slovenia, Serbia and Italy define it.
The guidelines in BiH [7] do not specify the n^{th} highest hour at all, but only give approximate values of the K-factor (Table 1).

Table 1 Indicative values of K-factor [7]

Type of road	K-factor [% AADT]
Roads for long-distance connection	12 - 16
Intercity roads (rural)	10 - 14
Suburban roads (and long - distance)	9 - 11
Urban roads (except local)	8 - 10

In addition, it is stated: "On roads with particularly heavy seasonal traffic (when seasonal traffic exceeds the average by more than 50 %), it is recommended that traffic data and flow calculation be provided separately for seasonal and non-seasonal traffic. In such a case, for reasons of construction rationality, it is recommended to consider a lower service level or a 10-20 km/h lower average speed than planned on a specific road of a certain category for the season. The above recommendation generally cannot be applied to multi-lane roads with separate lanes" [7]. The guidelines in Croatia [8] only specify that the 100th highest hour (Q100) of a year is relevant for the capacity analysis. The guidelines in Slovenia [9] specify that traffic loads should be determined on the basis of HCM methodology. In the absence of traffic load forecasts for peak hours (DHV), the following AADT percentages are used to calculate the level of service – LOS (Table 2).

Table 2 Indicative values of K-factor from Slovenian guidelines [9]

Type of road	K-factor [% AADT]
Roads for long-distance connection	12
Connecting road	10
Collector road	9
Access road	8

The guidelines in Serbia [10], take a closer look at this issue. First, they introduce specific classifications in the functional classification of roads, including the type of transport demand. On rural roads, relatively independent of the functional classification, there are different characteristics of the dominant traffic flows in terms of frequency of occurrence. There are three types of roads (Table 3).

Table 3 Road types in terms of traffic demand character [10]

Nature of traffic flow	Movement frequency	Characteristic day	b_s	K-factor (%)
Urban - suburban	every day	weekday	< 1.2	10 - 14
Intercity	temporary	weekday, weekend	$1.2 < b_s < 1.4$	13 - 17
Intercity - tourist	seasonal	weekend, season	> 1.4	15 - 30

It is further illustrated by the approximate coefficient of annual unevenness b_s, which is defined as the ratio between the average daily traffic volume (ADT) in the peak month (July, August) and the ADT in the average month (April, May, October, November). The months mentioned above refer to road sections that were counted temporarily.

As usual the DHV is defined by the K-factor for a given n^{th} highest hour. The Q_{30} is assumed for the highest categories of rural roads and the Q_{60} for the other roads. For the dominant character of traffic flow (Table 3), the approximate values of the K-factor are given for road sections on which no continuous automatic counting takes place.
The guidelines in Italy [11], are limited to providing only a few definitions and implement the contents of the HCM (Highway Capacity Manual published by the TRB, 1994) as regards the definition of Level of Service (LOS). In general, the roads are classified and divided as in the following table.

Table 4 Italian Road classification [11]

Network	Scope	Extra-urban area	Urban area
Primary	transit and sliding	extra-urban highway main suburban roads	urban highway extra-urban roads
Principal	distribution	main suburban roads	extra-urban roads
Secondary	penetration	secondary suburban roads	urban neighbourhood streets
Local	access/entry	urban local roads	extra-urban local roads

In the Italian guidelines, the service flow rate is the maximum value of the traffic flow that can be accommodated by the road at the assigned service level. It depends on the transverse characteristics of the section and plano-altimetric characteristics of the axis.
The Italian rules do not provide any K-value but there is a good practice of adopting some American values. In fact, in agreement with Florida Department of Transportation FDOT, K-values are considered to be between 0.095 and 0.10, for rural developed and rural undeveloped roads, respectively [12].
The two manuals most frequently used worldwide for capacity analysis to determine DHV use the Q_{30} (American HCM [3]) and the Q_{50} (German HBS [4]).
All countries carry out traffic counts on their road networks. In places where continuous automatic counting takes place in the year (8760 hours), it is possible to determine the change in hourly volume, expressed as a percentage of the AADT, in descending order from the highest to the lowest value (Figure 1a). Normally only 200 peak hours aredisplayed. On the other hand, road sections with temporary counting points require additional analyses.
From the above it is clear that the most frequently mentioned guidelines do not sufficiently define how the DHV is to be determined. Planners and designers are required to recognise this in the early design stages with additional analyses. Moreover, as will be shown below, the nature of traffic demand varies considerably from country to country, suggesting the need to derive additional specific characteristics from existing automatic counting databases.

1.3 Recreational versus tourist traffic

Due to the different nature of traffic demand on the one hand and the function of roads on the other hand, changes in the characteristics of traffic flows can vary significantly by seasons, months and weeks. Typically, a daily volume (veh/day) is used and the following characteristic quantities are available:

- Average annual daily traffic (AADT), as defined above
- Average summer daily traffic (ASDT) represents the average daily (24 hours) traffic volume on a given cross-section during the summer (here July and August). It is obtained by dividing by 62 days the total number of vehicles that have passed through the cross-section in July and August.

- Average daily traffic (ADT) represents the average daily (24 hours) traffic volume for a given cross-section over a period of less than one year (normally used for months). It is obtained by dividing the total number of vehicles that have passed through the cross-section in the given time interval by the number of days in that interval.
- Average annual weekday traffic (AAWDT) represents the average daily (24 hours) traffic volume on a given cross-section during the year, counted only on weekdays (Monday - Friday). It is obtained by dividing the total number of vehicles that have passed through the cross-section in weekdays during the year by the number of weekdays (usually 260 days).
- Average weekday daily traffic (AWDT) represents the average daily (24-hour) traffic volume on a given cross-section in weekdays over a period of less than one year (usually used for months). It is obtained by dividing the total number of vehicles that have passed through the cross-section in the given time interval by the number of weekdays in that interval.

AADT, ASDT and ADT are used in our prevailing traffic conditions. AAWDT and AWDT represent the average daily traffic from Monday to Friday and are not of great interest to us as the seasonal fluctuations in traffic demand are much more dominant.
Figure 2 shows a typical US classification of roads in terms of the type of traffic demand on roads with dominant recreational traffic and roads with dominant intercity traffic. The variation of monthly ADT and AWDT in the year is shown. “Monthly volume variations for routes with recreational traffic show much higher seasonal peaking than for routes with predominantly intercity traffic” [3]. Weekend traffic values range from about 100 % to 200 % of the AADT. For roads with dominant intercity traffic, this difference is insignificant (Figure 2b).

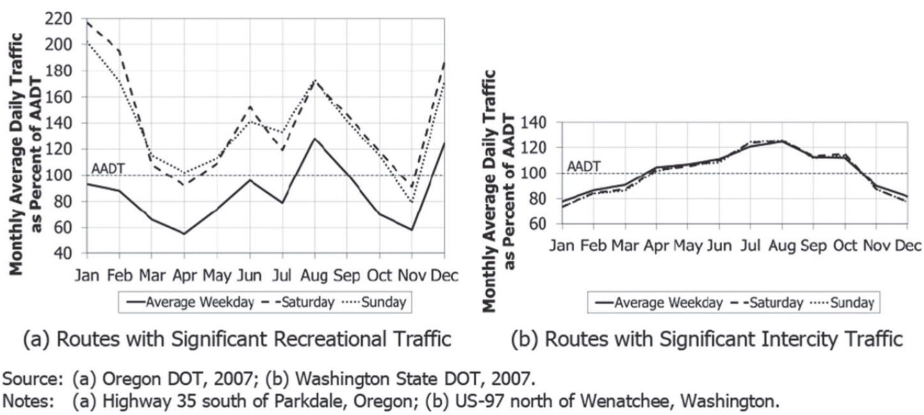


Figure 2 Examples of monthly ADT variation on highway [3]

Figure 3 shows a comparison of the annual variation of monthly ADT and AWDT as percent of AADT for:
- Road with dominant recreational traffic [5]
- Road M2 - section - Neum - Zaton Doli in BiH [13]
- Road M6.1 - section – Mostar - Široki Brijeg in BiH [13]

In contrast to the pattern of traffic demand on recreational roads in the US, which are used by drivers on weekends throughout the year and where the AADT is significantly higher than the AAWDT, it is obvious that the M2 road with the pattern of “tourist” traffic demand does not show this difference at all (Figure 3). In contrast, a significant difference in seasonal variation can be observed.

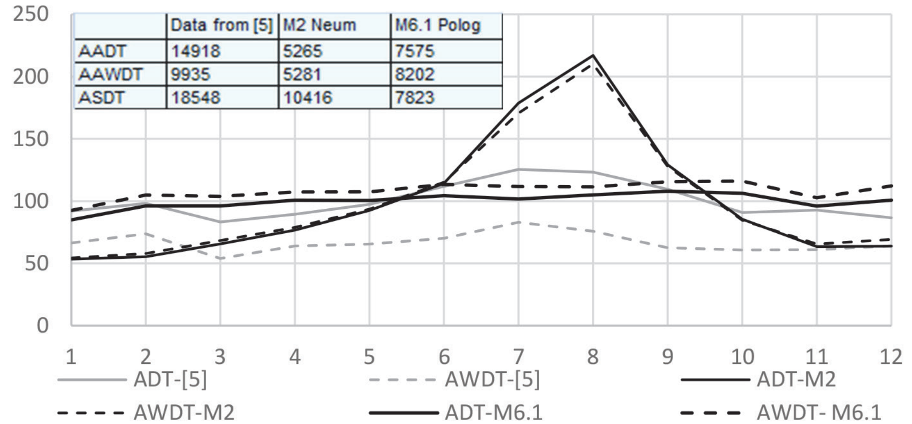


Figure 3 Variation of Monthly ADT and AWDT as Percent of AADT for USA road with recreational traffic and two types of roads in BiH

Although there is also a seasonal (summer) increase in traffic under the conditions of traffic demand in America, it is negligible in relation to the weekly changes, while under our conditions of traffic demand from "tourist" roads, the seasonal (in this case summer) increase has a dominant influence. For example, it is obvious that the average daily traffic during the summer peak exceeds 200 % of AADT, i.e. the ASDT/AADT ratio is almost twice as high. In contrast to the M2 section, the M6.1 road section is characterized by dominant intercity traffic. A slight difference between ADT and AWDT is also noticeable. If the function of the house-work connection is considered, it is logical in this case to obtain slightly higher AWDT values. There are no seasonal fluctuations.
Given the significant differences in the conditions of traffic demand in the USA and here described above, it is necessary to distinguish between a road with recreational (HCM) and a road with "tourist" traffic (here). A road with significant "recreational" traffic is a road that has a higher volume of traffic on weekends (Saturday and Sunday) than on weekdays throughout the year. The characteristic traffic parameters are AADT, AAWDT, ADT and AWDT. A road with significant "tourist" traffic is a road with dominant seasonal variations (summer and/or winter). The characteristic traffic parameters are AADT, ASDT and ADT.

2 K-factor in function of the character of traffic demands

It is clear from the above that the choice of the n^{th} highest hour of the year varies from one guideline to another between the 30^{th} and 100^{th} highest hour. Essentially, this question should be answered by the institutions responsible for overall road management, and it must be based on the results of multi-year traffic counting and research. The choice of the n^{th} highest hour and the determination of the K-factor is always a compromise between the satisfaction of traffic demand (desired level of service) on the one hand and investment possibilities on the other. Regardless of the choice of the n^{th} highest hour, the value of the K-factor depends primarily on the character of traffic demand, on its different occurrence. The four characteristic sections of BiH's main roads on which permanent traffic counting is carried out over several years were selected [13]:

a) Road M17, section: Jablanica - Mostar, counting station Salakovac, example of a rural section
b) Road M17, section: Mostar - Buna, counting station Ortiješ, example of a suburban section

c) Road M6.1, section: Mostar - Široki Brijeg, counting station Polog, example of a rural section
d) Road M2, section: the border of the Republic of Croatia - Neum, counting station Neum, example of a rural section

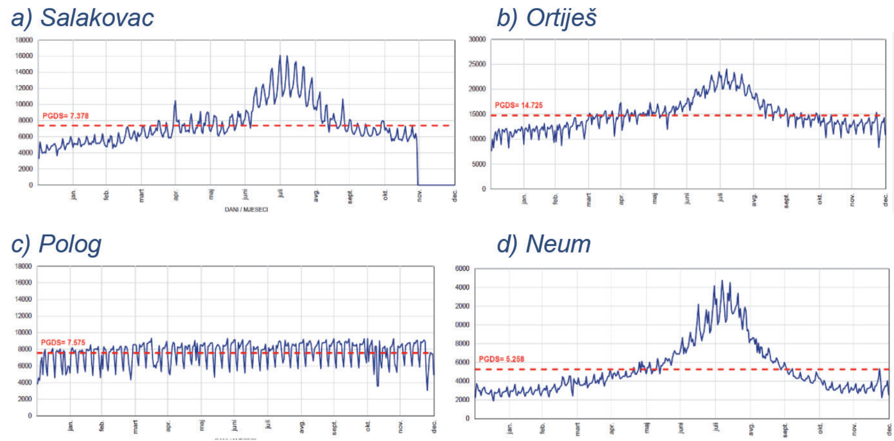


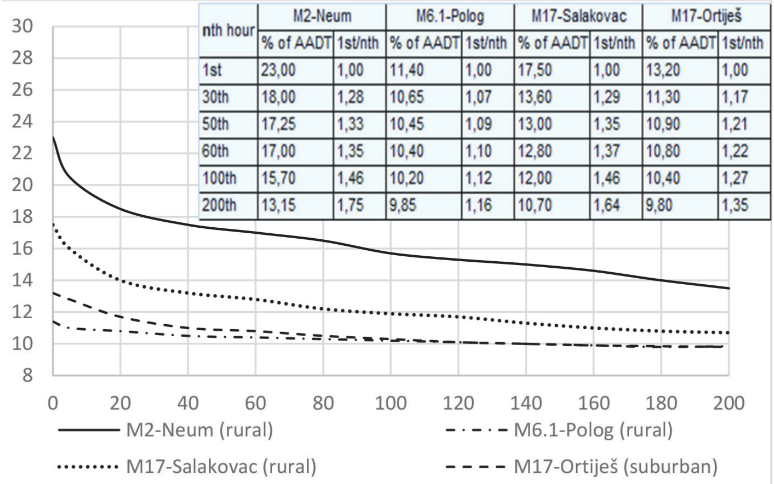
Figure 4 Variation of daily volume for 4 above selected roads in BiH

Annual variation of daily volume for these road sections is shown in Figure 4. The M17 (E-73) is a main road connecting the north and south of BiH. It is located along the Corridor Vc and, because the motorway is not built yet, it is still one of the main roads with the function of a long-distance connection. Two sections (rural and suburban areas) were selected to identify differences. Figures 4a and 4b also show considerable seasonal variations. The M6.1 (Figure 4c) represents the rural section of the main road without seasonal variations. The M2 (Figure 4d) represents the section of the main road (along the Adriatic Sea) in BiH, which has a dominant seasonal variation.

The graphs in Figure 5 show the decreases of the 200 highest hours of the year as a percentage of AADT for the listed sections based on actual permanent counting data. The following points can be highlighted:

- It is expected that a significant difference in the K-factor values will be observed, although all roads have the same classes and almost the dominant connection function. The value of the K-factor thus depends on the nature of the traffic flows in terms of their seasonal variation.
- Roads without seasonal variations (M6.1) have the lowest values of the K-factor as well as the smallest difference in percentage ratio in the 1^{st} and the indicated n^{th} highest hour. Roads with dominant seasonal variation (M2) have the highest K-factor values and the greatest difference in the characteristic n^{th} hour.
- The K-factor for rural roads with a certain degree of seasonal variation takes values between the lowest and the highest (M17-Salakovac). In the case of a suburban road section (M17 - Ortiješ), the value of the K-factor decreases and approaches the values of the sections without seasonal fluctuations due to the high proportion of local traffic in the AADT.
- The specific values of the K-factor for different n^{th} highest hours are shown in the table in Figure 5. They are not representative but are presented with the aim of showing significant differences.

It is obvious that it is necessary to introduce a measure of seasonal variations following a similar logic as the Serbian guideline.

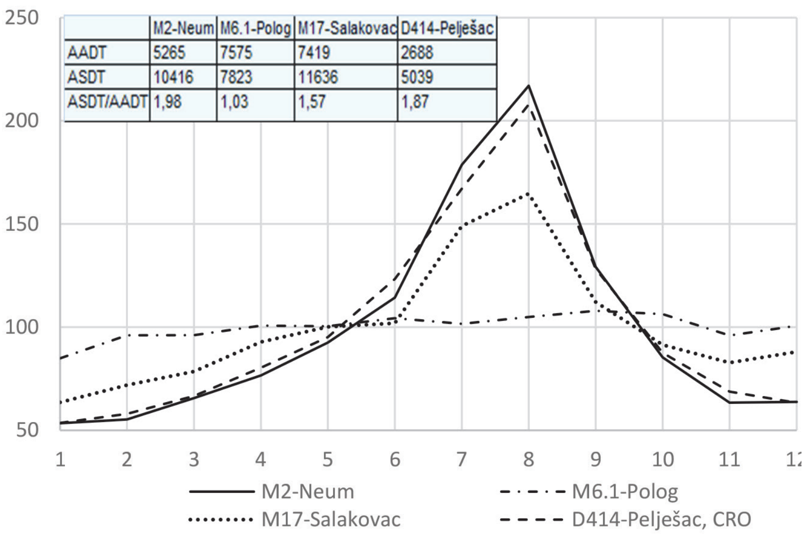


nth hour	M2-Neum		M6.1-Polog		M17-Salakovac		M17-Ortiješ	
	% of AADT	1st/nth	% of AADT	1st/nth	% of AADT	1st/nth	% of AADT	1st/nth
1st	23,00	1,00	11,40	1,00	17,50	1,00	13,20	1,00
30th	18,00	1,28	10,65	1,07	13,60	1,29	11,30	1,17
50th	17,25	1,33	10,45	1,09	13,00	1,35	10,90	1,21
60th	17,00	1,35	10,40	1,10	12,80	1,37	10,80	1,22
100th	15,70	1,46	10,20	1,12	12,00	1,46	10,40	1,27
200th	13,15	1,75	9,85	1,16	10,70	1,64	9,80	1,35

Figure 5 Volume of 200 highest hours as a percent of AADT for road sections with different seasonal variation

3 A measure of seasonal variation

From the above examples of seasonal variation, it is clear that the relationship between ASDT and AADT can be one measure. Unlike AADT, ASDT is defined differently in different countries. In this article, ASDT represents the average daily summer traffic in July and August.
Figure 6 shows the changes in monthly ADT over the year, the values of AADT and ASDT and their ratio for the listed sections. Instead of the suburban section (M17 Ortiješ), a section of the main road D414 in the Republic of Croatia (Peljesac) was inserted, the Zamaslina counting station [14], which, like the section M2 Neum, has a dominant seasonal variation.



	M2-Neum	M6.1-Polog	M17-Salakovac	D414-Pelješac
AADT	5265	7575	7419	2688
ASDT	10416	7823	11636	5039
ASDT/AADT	1,98	1,03	1,57	1,87

Figure 6 Annual variation of monthly ADT as percent of AADT for roads with different character of traffic demand

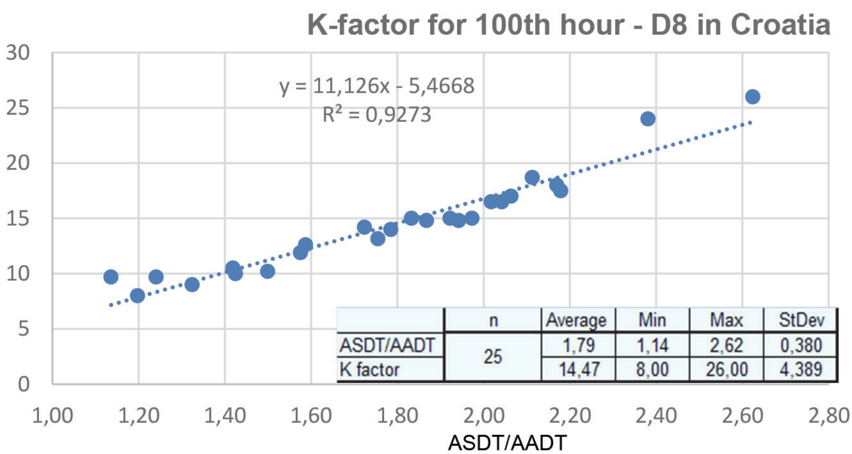
Seasonal variation (changes in monthly ADT and the ratio of ASDT/AADT values) shows three characteristic road types in relation to the type (character) of traffic demand:

- Roads without seasonal variations are those where the ASDT/AADT ratio is close to 1.0. In Figure 6 it is section M6.1.
- Roads with a dominant tourist function (seasonal variations) are those where the ASDT/AADT ratio is extremely high. In Figure 6 these are sections of M2 Neum in BiH and D414 in Peljesac, Croatia.
- Roads in the middle range of the ASDT/AADT ratio are those where there is significant but not dominant seasonal variation. An example is the section of the M17 road, data from the Salakovac counting station.

It can be observed that the differences in the values of the K-factor in Figure 5 and the differences in the ASDT/AADT ratio in Figure 6 show the same analogy in terms of the seasonal nature of traffic demand. The logical question is whether there is a functional relationship between this seasonal measure and the K-factor.

4 K-factor dependence on ASDT/AADT ratio as a measure of seasonal variation

To answer the above question, an example of two two-lane rural roads was taken. The first road is the D8 in the Republic of Croatia and the second is the M17 in BiH. Only data from permanent counting stations are analysed [13], [14]. As the Croatian guideline defines the 100th highest hour as relevant for the determination of the DHV, and the BiH guideline does not define the n^{th} highest hour at all, in this article the 100th highest hour was used for the determination of the K-factor.
There are 39 counting stations on the D8 road from Slovenia to Montenegro, and permanent counting is carried out at 27. The data from 2 counting stations (Solin and Stobrec) were left out, as these are suburban and four-lane sections. Figure 7 shows a very strong correlation between the measure of seasonality of ASDT/AADT and the value of the K-factor. This allows a more accurate determination of the K-factor on a road section with temporary counting.

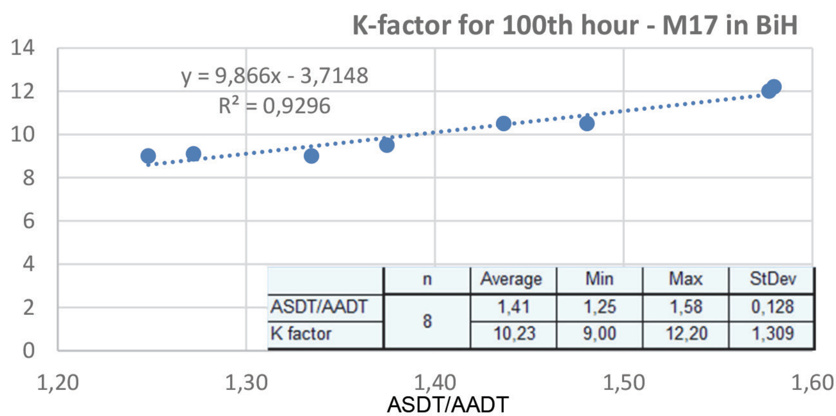


	n	Average	Min	Max	StDev
ASDT/AADT	25	1,79	1,14	2,62	0,380
K factor		14,47	8,00	26,00	4,389

Figure 7 Dependence of K-factor on ratio ASDT/AADT for two-lane state road D8 in Croatia

On the road M17 (E-73), there are a total of 18 counting stations, 9 of which are with permanent counting. At the Buna counting station, the data since 2010 are incomplete, so they are not taken into account.

As in the previous case, a high collinearity was achieved between the ASDT/AADT measure and the K-factor. It is important to note that the ASDT is not taken from the original publication, in which it was calculated as an average of the calendar summer days, but it was calculated as an average of the daily volumes in July and August, as in the case of the D8 road.



	n	Average	Min	Max	StDev
ASDT/AADT	8	1,41	1,25	1,58	0,128
K factor		10,23	9,00	12,20	1,309

Figure 8 Dependence of K-factor on ratio ASDT/AADT for 2-lane main road M17 in BiH

One must also note the difference in the value ranges of the K-factors of one road and the other, which is also shown in Figures 7 and 8. Differences are expected, but only by introducing a measure of seasonality can this difference be quantified. Apart from the fact that BiH and Croatia generally have different seasonal effects, the main difference lies in the function of these two roads. For most of the D8 road, there is a parallel A1 motorway, which significantly reduced its long-distance function, and its seasonal character increased, while the M17 still has a long-distance function due to the lack of construction of the Vc motorway. In order to obtain more accurate results and verify them, it is certainly necessary to extend this research to a much larger number of roads.

5 Conclusions

The results presented in the paper show the following:

- It is possible and necessary to introduce a measure of seasonality that defines more clearly the character (nature) of traffic demands. This paper shows that this can be an ASDT/AADT ratio.
- Examples of two roads with different functions in different states, which are significantly covered by permanent counting, show that there is a high collinearity between the seasonality measure of ASDT/AADT and K-factors. There are no precise guidelines on how to determine the K-factor and DHV on road sections with temporary counting. This approach would enable engineers in daily practice to identify more accurately and clearly the DHV, which is one of the key parameters in capacity analyses.

As most of the guidelines refer to HCM, the difference between the “recreational” and “tourist” character of traffic demand is explained. All countries have an “endless” data source (decades of automatic traffic counting systems) from which these and a number of other regularities can be derived, which contribute significantly to achieving a more sustainable road system.

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