



Prediction of Design Hourly Volumes on Roads with a Dominantly Local Character of Traffic Flows

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ABSTRACT

The analysis of design hourly volumes is one of the fundamental preconditions for the procedures of designing and evaluating road design solutions. In most cases, on road sections with a predominantly local character of traffic flows, there is an absence of automatic traffic counters, and determining the design hourly volumes is very difficult. In this regard, defining the design hour and developing a model for predicting design hourly volumes based on short-term traffic counts are the primary goals of this paper. Based on data from road sections with an automatic traffic counting system, the design hour is within the range of the 8th to the 16th hour of ordered hourly volumes. After further analysis, the 10th hour was adopted as the proposed value for determining design hourly volumes in local conditions. The prediction model is based on linear regression, i.e. modelling the relationships between the dependent variable, design hourly volume and independent variables, peak traffic volumes during design days. The model was tested for 10th and 30th hours in order to verify the model in local conditions as well as in accordance with the recommendations of the Highway Capacity Manual. The research results indicate that the average percentage deviation of the model-estimated design hourly volumes based on short-term traffic counts compared to the actual realised volumes ranges from 8% to 9%, depending on the analysed design hour.

KEYWORDS

traffic demand forecasting; traffic flow analysis; urban traffic modelling; DHV.

1. INTRODUCTION

In the process of managing the development and operation of the road network, a key role is to define plans and programs for the development of the road network according to the functional demands of traffic, ecological constraints and the economic justification of investments. In the procedures of creating road project solutions, the primary role of evaluating project solutions is reflected in defining arguments regarding the justification of investments. The basis for conducting functional evaluation is based on the investigation of design hourly volumes under local conditions and for each specific case.

The analysis of existing and future traffic demands, i.e. the problem of correctly determining design volumes, predominantly influences many strategic decisions in the entire process of optimising the road network (dimensioning the cross-section, new construction or reconstruction, functional, economic and ecological evaluation). The analysis of design volume is of great importance because determining the value on which the entire system is dimensioned is highly sensitive [1].

With the development of new technologies, modern traffic counting systems have been developed, enabling the permanent monitoring of traffic volumes. This has made it possible to define design volumes based on diagrams of ordered hourly volumes by size throughout the year. One of the characteristics of this diagram is

the “knee of the curve”, which is the point where there is a sudden change in the value of the volume expressed as a percentage of the average annual daily traffic (AADT), and in the traditional approach, the number of hours corresponding to the knee of the curve has been taken as the design number of hours for planning, design, operation, evaluation and other analyses where the value of the design volume is involved. In other words, when selecting the design volume, the aim is to choose a design volume that will best meet the required level of service (LOS), but not at the cost of satisfying maximum values, as this would lead to irrational investments in road infrastructure that would remain underutilised for most of the year.

The selection of the design volume based on the “knee of the curve” was first proposed by Peabody and Normann [2], and this approach has been supported to this day in the Highway Capacity Manual (HCM – 2022) [3] as well as by the American Association of State Transportation Officials (AASHTO) [4].

To reduce construction costs while maintaining efficiency, the initial assumptions were that the design hours should be sought within the range of the 30th to the 50th hour of ordered hourly volumes for sections with standard and seasonal variations in traffic volumes. The general guidelines in the two most commonly used manuals for capacity and LOS analysis provide different recommendations for selecting the design hourly volume: HCM suggests the 30th hour, while HBS (The German Highway Capacity Manual) [5] recommends the 50th hour. When it comes to the use of design volumes in the planning and design of road solutions within urban networks and on parts of the road network that pass through populated areas, the recommendations were directed toward the use of peak volumes, given that in urban networks, the differences between the 1st and 200th hour are significantly reduced compared to rural networks, making it very difficult to define the “knee of the curve”.

On sections that pass through populated areas and are located on entry-exit routes near cities, which are the focus of this study, there is a significant mixing of flows of different character. Local movements become dominant, but long-distance, intercity and often transit movements also appear on the network.

In this regard, the use of peak volumes as design values of volume is not rational, so the definition of the design hour on sections with a predominantly local character of movement is the first goal of this paper. Additionally, it is often the case that due to their position in the network, these sections are not equipped with automatic traffic counting systems, which poses a problem in determining the design hourly volumes. Therefore, the second goal of this paper is to define a model for predicting design hourly volumes in places where traffic counting systems are not installed.

The determination of the design hour was conducted through a detailed analysis of relevant data, analysing the trend of volume changes by hour at the analysed locations. On the other hand, the prediction model, presented in this paper, is based on the correlation between design hourly volumes and traffic volumes during peak hours on design days.

The primary contribution of this paper lies in the potential application of the given model for defining design volumes at locations with a predominantly local character of movement where automatic traffic counting systems are not implemented, or where there are problems with incomplete or inaccurate data.

The entire paper is structured so that, after the introduction, a review of relevant literature in the field of defining and predicting design hourly volumes is presented. After that, the third chapter presents the methodology of the conducted research. The fourth chapter presents and discusses the results obtained from the research, while the fifth chapter presents conclusions and provides recommendations for further research.

2. LITERATURE REVIEW

The data initially analysed by Peabody and Normann were later combined with additional data from 167 traffic counters in 48 states across the USA, forming the basis for defining design volumes in the Highway Capacity Manual (HCM) from 1950 [6]. Research presented in the recommendations of the first editions of the HCM indicates that the data collected were primarily from rural roads, and thus, such results cannot be generally applied to all road types, as the position of the knee in the diagram varies depending on the type of road. The first step in resolving this issue was the recommendation to use the design hour within the range of the 30th to the 100th hour, as it was believed that the curve’s inflexion point was located within this range. These values were established as criterion values, providing a standardised framework for the design process, but not accounting for variations in road characteristics.

The coming research, primarily by Werner and Willis [7], suggests that the proposed range up to the 100th hour is appropriate for roads with lower traffic volumes, and that as the traffic volume increases, the curve’s inflexion point shifts to the range between the 200th and 600th hour. Another significant issue from the past

was the consideration of only the first 100 or 250 hours by managers and decision-makers, with the goal of finding the curve's inflexion point. This approach led to subjective and somewhat unclear decisions when selecting design volumes.

In support of that, the study by Crabtree and Deacon [8] confirms that objectively determining design volume values that would lead to rational decisions is only possible by considering all 8,760 hours in a year.

Despite all this, the rationality of the traditional method of selecting the design volume has often been questioned. Designers and experts in this field have in the past raised serious concerns regarding the validity of the traditional approach to determining design volumes [9, 10]. One of these criticisms relates to the concept of determining design values strictly depending on the object (the road) without considering the user's perspective. For this reason, Sharma [9] conducted a study that re-examined the traditional 30th-hour factor as a design value from the user's perspective.

The main conclusion of this study further confirms the previously mentioned view that the nature of traffic flows, i.e. the different functions of the road, undoubtedly represents a very significant factor that should be considered in the process of determining design hourly volumes for road design and evaluation. The results also indicate the justified application of different values of design hourly volumes in the process of creating road project solutions, depending on the different characteristics of the flows they accommodate, to achieve a uniform (required) LOS.

Supporting the above, research in predicting design volumes in recent years has been conducted specifically for different types of roads and various dominant traffic flow characteristics [11, 12].

Sharma and Oh [13] proposed three models for predicting design volumes. The first model used a traditional linear relationship between design volumes and AADT, while the second model accounted for different road types, and the third model focused on traffic volumes during the peak months (July or August). The third model performed the best by eliminating the need for road classification and incorporating traffic volumes on design weekdays and weekends.

To determine design volumes more precisely, Liu and Sharma [14] directed their research toward analysing maximum volumes during significant holidays throughout the year. Generally, based on their research, it was found that 86% of the maximum hourly volumes over a 50-year period were recorded during holiday periods. The developed models were based on linear regression for different road categories. The results indicated that the average errors between calculated and actual design volumes ranged from 1% to 4%.

Capparuccini et al. [15] developed methods to estimate design volumes at locations without automatic traffic counters, using short-term traffic counts. They applied three methods: counting traffic during peak periods, using an average K-factor for counters in the same category, and using the K-factor from the nearest counter. Their research showed more accurate volume estimates for roads with smaller traffic variations, with errors of about 5% for urban areas and highways, and 8–9% for roads with greater fluctuations in traffic volume.

In addition to the aforementioned methods of predicting design volumes and defining missing data due to malfunctions of automatic traffic counting systems, the literature also presents models based on neural networks [16, 17]. The results of analyses conducted by Khan et al. [16] show that a model based on long-term memory can estimate the design volume with a mean absolute error of 2.10%. On the other hand, based on the results of Zhong et al. [17], it was found that the average errors in volume estimation for genetically designed regression models were less than 1% for counters with smaller traffic volume variations throughout the year and up to 3% for counters with greater traffic volume variations.

3. RESEARCH METHODOLOGY

Given the primary objectives of the study, the research methodology is divided into two parts. The first part pertains to determining the hour corresponding to the design hourly volume value throughout the year, while the second part focuses on defining a model for predicting the design volume (*Figure 1*).

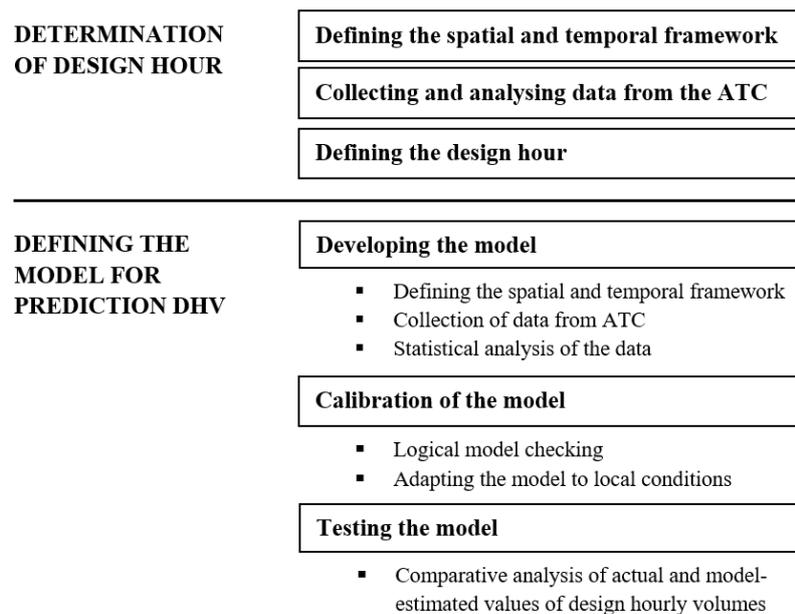


Figure 1 – Research methodology

The first step of the proposed methodology in both cases is determining the design hour and defining the prediction model, which involves defining the spatial and temporal scope. Given the considered problem, the analysis used data from automatic traffic counters (ATCs) on 32 sections in the Republic of Serbia characterised by predominantly local traffic flows. These sections are primarily entry-exit routes near large cities or sections that directly pass through populated areas, leading to an increased number of movements with a local character. At all the analysed locations, traffic is continuously counted over all 8,760 hours of the year. The study used data from 2015 to 2019 as the relevant time frame. This period was selected because it is characterised by a stable economic, social and financial situation in the country. The period from the onset to the end of the COVID-19 pandemic, which undoubtedly influenced changes and imbalances in traffic demands, was excluded from the analysis. For model testing, available official data from the last year from the Public Enterprise “Roads of Serbia” were used.

In the second step of the methodology, data from automatic traffic counters were collected. In the part related to determining the design hour, values of ordered hourly volumes from the first to the thirtieth hour were collected from all analysed ATCs over a five-year period. When it comes to defining the prediction model, in addition to the values of the design volumes, values of traffic volumes during design days necessary for the development, validation and testing of the model were also collected.

The final step in determining the design hour involved analysing the volumes sorted by size and defining the range of the “knee of the curve” diagram. In other words, the last step involved defining the range that excludes extreme (maximum) traffic volume values while providing a rational volume that can meet the required LOS.

To develop a model for predicting design hourly volumes on road network sections characterised by predominantly urban conditions and parts of the network characterised by predominantly local traffic, it was necessary to build a system that encompasses all direct and indirect factors that can influence the value of design hourly volume. As confirmed in the literature, linear regression has found extensive application in traffic engineering and is one of the most commonly used methods in predicting design hourly volumes. For this reason, a prediction model for design volumes based on linear regression was developed in this study. Specifically, in statistics, linear regression refers to an approach to modelling the relationships between one or more dependent variables, denoted as Y, and one or more independent variables, denoted as X, in such a way that the model linearly depends on unknown parameters estimated from the data [18].

The next step in the analysis involved defining the variables included in the model. The dependent variable is the value of the design hourly volume, i.e. the magnitude that the model needs to predict. However, defining the independent variables is a subject on which researchers have different opinions. A review of relevant literature from previous studies suggests that the temporal variation of volume plays a significant role in defining independent variables in prediction models. In the models, the independent variables were generally

the values of traffic volume at the daily level on design days [11, 19], traffic volume values during holidays [14], traffic volume values by direction [20] and similar factors. The most reliable models were those where the independent variables were the values of traffic volume during design weekdays and design weekends [11, 19]. In studies conducted by Sharma and Oh [11] and Petković et al. [19], the dependent variables were precisely the values of traffic volume during design weekdays and weekends. In the aforementioned studies, i.e. models, the values of independent variables were expressed in vehicles per day. However, considering the specific conditions prevailing on sections that pass through populated areas, which are closely related to the conditions on urban networks, the total traffic on a design day does not represent an adequate parameter. On the other hand, the volume during peak morning and afternoon periods on design weekdays and weekends is a significant indicator of changes in the traffic pattern over time. For this reason, in this study, the independent variables used were the values of traffic volume during the morning and afternoon peak periods on design weekdays and the design weekend day. Design weekdays are defined as Tuesday, Wednesday and Thursday, as these are the days with the least variation in traffic volume during the week. On the other hand, Saturday is the design day during the weekend, as Sunday, being a non-working day, is not a representative indicator (Figure 2a). The analysis of hourly traffic volumes on weekdays defined the periods from 7:00 AM to 9:00 AM as the design morning peak period, and from 4:00 PM to 6:00 PM as the afternoon peak period (Figure 2b). The figure shows that the traffic pattern during the weekend is different from that on weekdays, which is one of the reasons for including design weekdays and weekends in the model. Significantly lower traffic volume values in the morning analysed period indicate that this is a road with predominantly local movements, as traffic during the workweek is mainly for commuting, which changes during the weekend.

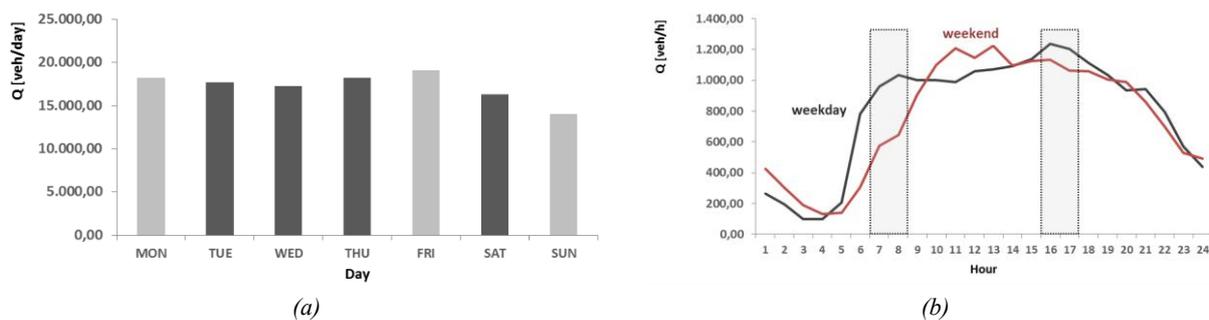


Figure 2 – (a) Distribution of traffic volume by days of the week; (b) Distribution of traffic volume by hours of the day

The characteristic of monthly traffic volume irregularity is the most reliable indicator for identifying the nature of traffic flows and the function of the observed road within the network. Continuous changes in traffic volume values throughout the year are primarily a result of seasonal socio-economic activities in certain areas. Significant fluctuations in volume are typically present during the summer months from June to September. For tourist and seasonal roads, the demand for movement is significantly higher during this period, while on the other hand, for suburban roads, traffic volume during the summer period is mostly below the level of average annual daily traffic.

Daily variations in traffic volume represent changes in traffic demand by day within a week and are also related to the type of road being analysed. Specifically, on predominantly urban roads, there is a slight decrease in traffic volume during weekends and holidays. Conversely, on rural roads, particularly those with dominant tourist flows, there is a significant increase in traffic volume during weekends, contrary to the previously mentioned trend.

Based on these principles of traffic volume variation and the specific characteristics of traffic on roads with predominantly local movements, the data used for developing and testing the proposed model in this study were collected for the period from April to October of each analysed year (Figure 3). This is the time of year with a relatively balanced trend in traffic volume by month at the analysed locations, as evidenced by the ratio of the average monthly daily traffic (AMDT) to the average annual daily traffic (AADT). In other words, for the purposes of developing and testing the model, traffic count data were collected for each design weekday (Tuesday, Wednesday and Thursday) and the design weekend day (Saturday) during morning and afternoon peak periods for each analysed year.

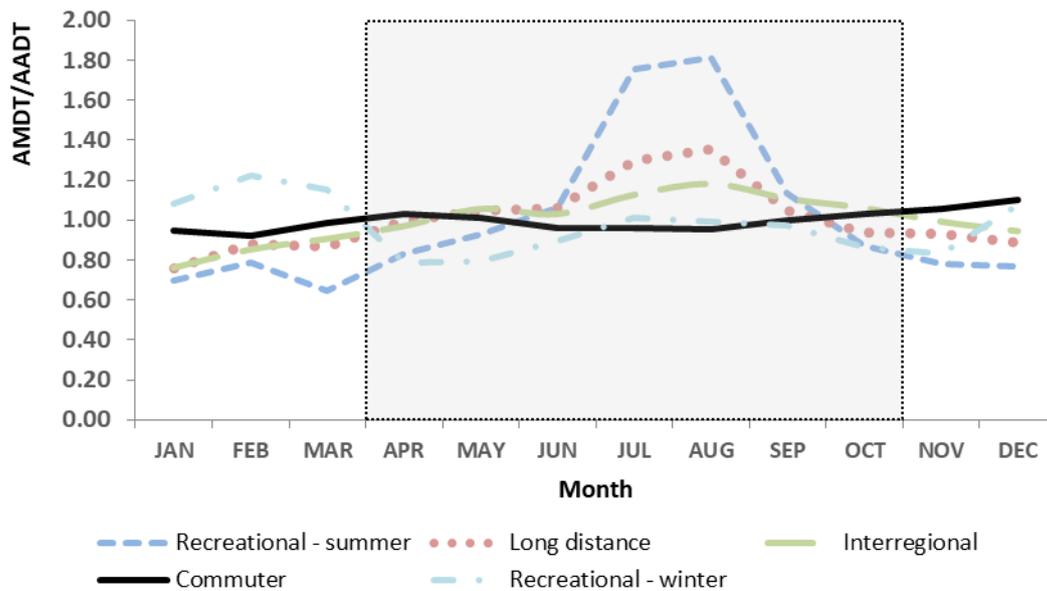


Figure 3 – Monthly traffic volume irregularity

The next step in the methodology involved calibrating the model. Calibration included a logical verification of the collected data and adjusting the model to local conditions. Data that were not representative or that displayed illogical information for any reason were excluded from the analysis. For example, data from periods of roadwork on the analysed sections, during which one or more traffic lanes were partially or completely closed, were excluded. Data on atypical periods of traffic operation on the network were collected by the authorities responsible for road maintenance.

Finally, after calibrating the model, the process moved on to validation and testing. The validation of the model was conducted using the data that were used for developing the model to determine the model's ability to predict the required magnitude. On the other hand, the testing of the model was conducted with data that were not used in the model development, with the goal of demonstrating the model's ability to predict traffic volumes.

The parameters necessary for applying the model to predict design volumes in real conditions include data from two days of traffic counts (one design weekday and one design weekend day) during the morning and afternoon peak periods on the observed section between April and October. Specifically, it is necessary to count traffic on one of the design weekdays (Tuesday, Wednesday or Thursday) and on Saturday during the periods from 7:00 AM to 9:00 AM and from 4:00 PM to 6:00 PM. This ensures that the parameters included in the traffic volume prediction models are obtained.

4. RESEARCH RESULTS

After defining the basic parameters and collecting data from automatic traffic counters, this chapter focuses on determining the design hour and defining the model for predicting design volume values. In accordance with the methodology, the first part of the analysis will focus on defining the design hour value, while the second part will concentrate on presenting the results of the design hourly volume prediction model.

4.1 Determining the design hour

To determine the design hour, an analysis was conducted of ordered hourly volumes (from the 1st to the 30th hour) at all subject locations over a five-year period. The determination of the design hour was carried out based on the differences between the ordered hours. Based on *Table 1* and *Figure 4*, it is clear that at most of the analysed locations, increased traffic volume is present during the first eight hours, which is a result of peak hours during holiday periods or certain sports or other events during the year. On the other hand, after the 16th hour, a decrease in volume is noticeable at almost all analysed locations, along with a balanced trend of the curve with a slight downward trend until the last hour. Although the differences between the hours in absolute values are not significant, the analysis of the relationships in volume size indicates that the range of the "knee

of the curve”, or the range of volume decline, is approximately between the 8th and 16th hour, and the design hour should be sought within this range. The design hourly volume is crucial for ensuring that the traffic infrastructure can adequately serve the expected traffic, minimising congestion and improving the overall efficiency of the system. Accordingly, and in line with the analysed graphical interpretation in Table 1, the point at each location where the period of maximum volumes is avoided and the curve trend stabilises corresponds to the 10th hour of ordered hourly volumes. In other words, based on a detailed analysis of hourly volumes on roads with predominantly local traffic, it was determined that the design volume corresponds to the volume value at the 10th hour, and this value was used as the design value in the further course of the study. By defining the 10th hour as the design hour, the first nine hours with maximum traffic volumes were excluded from further analysis.

Table 1 – Average values of arranged design hourly volumes by locations (from the 1st to the 30th hour)

	ATC 1022	ATC 1023	ATC 1051	ATC 1061	ATC 1066	ATC 1068	ATC 1070	ATC 1072	ATC 1073	ATC 1074	ATC 1104	ATC 1110	ATC 1135	ATC 1145	ATC 1189	ATC 1268_69	ATC 1270	ATC 2003	ATC 2009	ATC 2016	ATC 2028	ATC 2046	ATC 2048	ATC 2049	ATC 2054	ATC 2055	ATC 2058	ATC 2061	ATC 2064	ATC 2067	ATC 2070	ATC 2077_78
1st	755	1.485	922	610	1.053	662	1.039	966	938	1.124	581	606	479	764	674	5.058	1.776	777	713	452	393	634	1.088	1.720	736	638	493	733	403	550	893	1.270
2nd	779	1.471	883	591	1.014	641	1.007	921	907	1.097	567	566	462	753	654	5.034	1.723	762	644	438	384	603	1.051	1.671	675	620	476	697	391	543	869	1.224
3th	767	1.459	873	579	992	626	998	876	889	1.086	564	541	456	747	647	4.993	1.708	739	600	432	379	586	1.037	1.649	653	614	464	689	380	525	857	1.158
4th	756	1.443	867	569	989	620	989	852	884	1.081	561	536	451	739	642	4.945	1.700	729	574	429	368	584	1.023	1.637	648	607	459	681	376	520	854	1.181
5th	745	1.435	854	559	986	603	986	846	879	1.070	559	533	447	735	639	4.913	1.684	727	538	427	345	582	1.020	1.628	643	603	455	675	369	516	844	1.171
6th	742	1.428	840	553	981	592	978	839	876	1.064	557	524	446	731	637	4.879	1.678	725	526	417	344	576	1.006	1.618	640	600	451	672	365	510	839	1.158
7th	736	1.417	833	546	975	586	974	829	868	1.061	556	520	443	729	634	4.850	1.664	724	515	414	343	573	1.000	1.610	631	599	447	666	362	507	834	1.153
8th	734	1.407	830	543	965	584	969	816	865	1.056	554	518	439	727	633	4.833	1.651	718	501	412	341	569	992	1.604	628	594	443	662	358	504	829	1.149
9th	732	1.397	824	539	961	583	967	814	861	1.053	552	517	437	724	629	4.812	1.646	716	492	411	339	567	990	1.600	626	592	439	661	356	501	826	1.147
10th	730	1.392	819	535	959	581	963	812	857	1.049	549	516	431	720	627	4.793	1.636	714	486	409	338	563	988	1.592	622	591	438	658	353	501	824	1.145
11th	728	1.388	815	533	954	577	962	810	856	1.045	547	513	429	718	626	4.779	1.633	712	482	408	338	562	985	1.589	619	590	437	656	349	499	818	1.139
12th	725	1.385	810	529	951	576	958	804	851	1.041	546	512	427	716	624	4.763	1.630	711	480	408	337	556	983	1.584	616	589	435	655	346	498	816	1.136
13th	723	1.383	809	527	949	570	955	803	849	1.037	545	511	425	715	622	4.744	1.624	710	477	406	336	554	979	1.582	614	588	434	654	345	498	813	1.134
14th	721	1.375	807	526	944	569	953	802	847	1.035	543	510	423	714	621	4.735	1.619	708	476	405	335	552	977	1.581	612	586	433	652	344	496	810	1.132
15th	719	1.371	805	524	941	568	952	801	845	1.030	542	507	420	710	620	4.723	1.615	708	471	404	335	550	975	1.577	611	584	432	649	342	496	808	1.132
16th	718	1.370	801	520	938	565	950	800	843	1.028	541	506	419	708	619	4.705	1.609	706	470	402	333	550	974	1.570	609	583	430	648	342	495	807	1.130
17th	717	1.368	797	518	933	564	947	799	841	1.024	540	503	417	706	618	4.701	1.606	704	466	401	333	548	971	1.563	608	581	429	646	341	494	804	1.129
18th	716	1.364	795	517	930	564	947	797	840	1.021	540	501	415	705	617	4.679	1.602	701	464	401	332	547	969	1.558	607	579	428	644	338	492	802	1.127
19th	715	1.362	793	514	926	563	945	796	839	1.017	539	500	413	703	616	4.667	1.598	700	463	399	332	546	966	1.554	605	578	427	643	337	492	800	1.125
20th	714	1.360	790	513	923	562	944	795	838	1.015	538	498	411	701	615	4.654	1.596	700	461	397	330	545	963	1.552	604	577	427	642	336	491	799	1.122
21th	713	1.357	788	511	921	559	943	793	838	1.014	537	498	410	700	612	4.644	1.591	698	458	397	330	545	962	1.550	602	575	424	640	335	491	796	1.121
22th	712	1.355	786	509	918	558	941	791	835	1.013	536	496	409	699	612	4.635	1.588	697	458	396	329	543	960	1.547	601	574	423	638	334	490	795	1.117
23th	710	1.353	785	508	917	557	940	790	835	1.010	535	495	407	698	611	4.623	1.586	695	456	395	329	542	960	1.545	600	573	423	637	333	489	794	1.116
24th	709	1.351	782	508	915	556	938	789	832	1.008	535	493	406	697	610	4.608	1.584	694	455	393	329	541	958	1.543	598	573	421	636	332	488	793	1.114
25th	708	1.350	780	507	913	555	936	787	831	1.006	533	492	406	696	609	4.601	1.580	692	454	392	328	541	957	1.542	597	572	420	635	332	488	791	1.114
26th	706	1.349	778	506	912	554	935	786	831	1.005	533	491	405	695	608	4.589	1.577	691	454	392	328	540	956	1.540	595	571	419	634	330	487	790	1.111
27th	705	1.347	776	503	908	553	934	785	829	1.003	533	490	404	693	607	4.583	1.575	690	453	391	327	539	956	1.536	594	570	418	634	330	487	789	1.110
28th	704	1.345	774	501	907	552	934	783	828	1.002	532	489	403	691	606	4.576	1.574	689	453	390	327	539	954	1.533	593	569	417	633	329	486	788	1.109
29th	703	1.344	773	499	904	551	933	783	827	1.001	531	489	402	691	606	4.566	1.572	688	453	389	326	538	954	1.531	592	568	416	632	329	486	786	1.107
30th	702	1.343	772	498	901	551	932	782	826	1.000	531	487	402	690	605	4.559	1.570	687	452	388	326	537	953	1.530	590	567	415	631	328	485	785	1.106

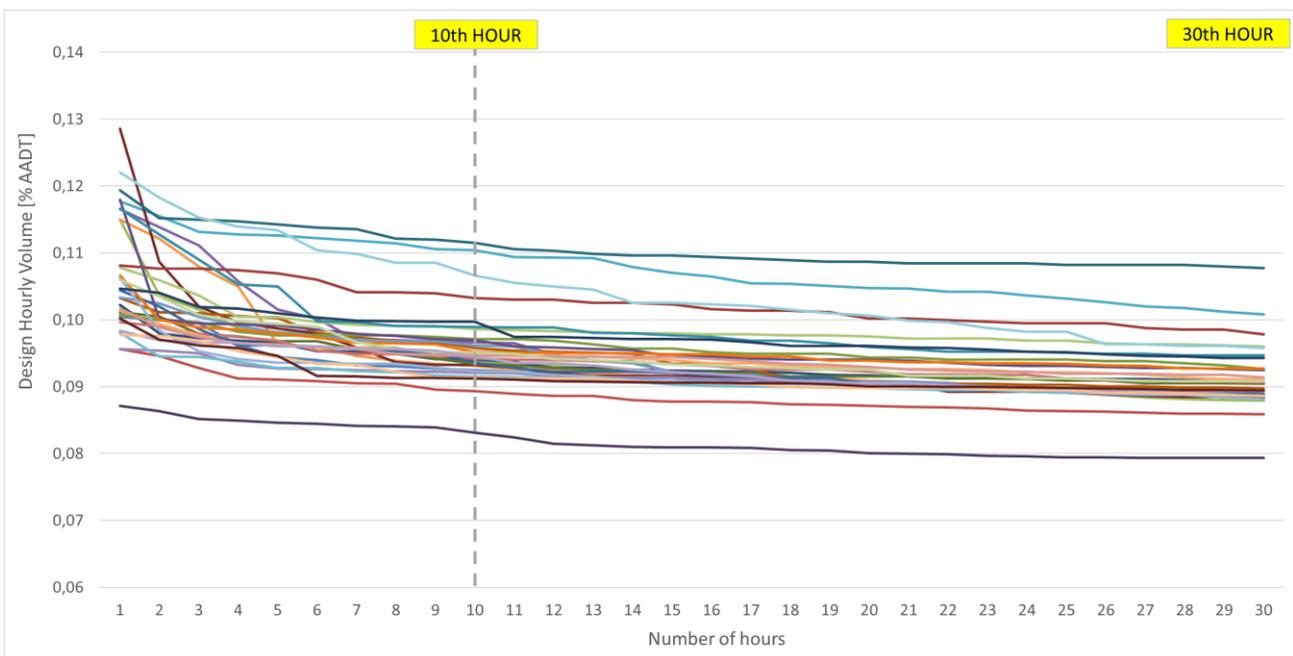


Figure 4 – Graphic display of arranged design hourly volumes by locations (from the 1st to the 30th hour)

4.2 Defining the model for predicting design volumes

As previously mentioned, in the proposed model, the dependent variable is the value of the design hourly volume, while the independent variables are the traffic volumes during the morning and afternoon peak periods on design weekdays and design weekends. The total sample consisted of 32 traffic sections (each with one automatic traffic counter). Data from the period 2015 to 2019 were used for model development. During this process, a total of 58,144 hourly traffic volumes were analysed on design weekdays and 19,424 hourly traffic volumes on the design weekend day, corresponding to 36,084,454 and 9,442,600 vehicles, respectively. On the other hand, model validation was conducted for the year 2021. In this process, a total of 9,268 hourly traffic volumes were analysed on design weekdays and 2,424 hourly traffic volumes on the design weekend day, corresponding to 7,237,862 and 1,490,719 vehicles, respectively.

Accordingly, the model can be adjusted to calculate design volumes as a function of different hours. The adjustment of the model is based on adjusting the coefficients of the independent variables and the constant term, while the traffic volumes during peak periods remain unchanged. In this study, the model was adjusted to define the design volume as a function of the 10th hour, which is defined in this study as the design hour. The 30th-hour factor, the use of which is recommended by the HCM, is still frequently applied when defining design hourly volumes. For this reason, in addition to the model based on the proposed 10th hour, this study also develops a model for predicting traffic flow as a function of the 30th hour, categorised by hourly traffic volumes throughout the year.

The formulations of both models are presented below (*Formulas 1 and 2*):

$$DHV_{10th} = 14.556 - 0.070 * a_1 + 0.652 * a_2 + 0.099 * b_1 - 0.026 * b_2 \quad (1)$$

$$DHV_{30th} = 13.171 - 0.033 * a_1 + 0.617 * a_2 + 0.064 * b_1 - 0.029 * b_2 \quad (2)$$

where:

- DHV_{n-th} - Design hourly volume according to the criterion of the n-th (10th and 30th) hour, expressed in [vehicles/hour],
- a_1 - Number of vehicles during the morning peak period on the design weekday [vehicles],
- a_2 - Number of vehicles during the afternoon peak period on the design weekday [vehicles],
- b_1 - Number of vehicles during the morning peak period on the design weekend day [vehicles],
- b_2 - Number of vehicles during the afternoon peak period on the design weekend day [vehicles].

For the analysis, specifically to check the relationship between the design volumes calculated by the models and the actual realised values, the Pearson correlation coefficient (r) was used.

Additionally, the coefficient of determination (R^2) was calculated, representing the total variation in the dependent variable y (design hourly volume calculated by the models) that is explained or attributed to the variation in the independent variable x (the actual realised design hourly volume).

Based on the obtained results, it can be concluded that the applied model demonstrated a strong ability to predict design volumes based on input data. *Figure 5a* provides a graphical interpretation of the model validation results, showing the average values of the predicted and realised design volumes for the dataset used to develop the model. The values of the Pearson correlation coefficient and the coefficient of determination for both models ($r = 0.9963$ and $r = 0.9972$, $R^2 = 0.9927$ and $R^2 = 0.9945$) indicate a strong positive relationship between the analysed variables.

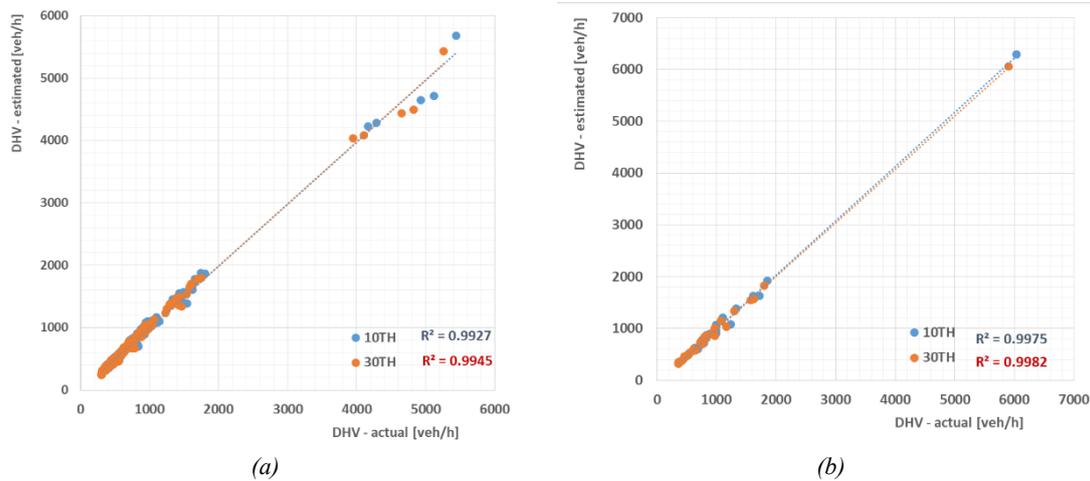


Figure 5 – Dependence of estimated and actual design volume values: a) model development and b) model testing

The diagram in Figure 5b shows the relationship between the predicted and actual average values of design hourly volumes for the dataset used to test the model, which was not included in the model development. What can be concluded from the diagram is that both models (for the 10th and 30th hour) exhibit a very strong positive correlation between the actual realised and the model-predicted design hourly volumes. This is confirmed by the Pearson correlation coefficient (r), which is approximately 0.995 for both models. The coefficient of determination for the model calculating the design volume as a function of the 10th hour is $R^2 = 0.9975$, while for the model as a function of the 30th hour, it is $R^2 = 0.9982$. The coefficients of determination indicate that over 99% of the variance in the predicted design volumes is explained by the actual realised values for both models.

To assess the percentage deviation of the obtained design volume values from the actual realised design volume values, an additional analysis was conducted. Specifically, for each analysed segment, the percentage deviation, or the difference between the calculated design volumes and the design hourly volumes recorded by the ATCs, was calculated. The deviation values are presented in Table 2, and the results are graphically depicted in Figure 6.

Table 2 – Percentage deviation of estimated from actual design volume values

% deviation	≤ 5%	5%-10%	10%-15%	15%-20%	20%-25%	≥ 25%	Total
10th hour							
No of deviations	875.00	620.00	373.00	276.00	165.00	8.00	2,317.00
% deviations	38%	27%	16%	12%	7%	0%	
30th hour							
No of deviations	913.00	610.00	372.00	259.00	141.00	22.00	2,317.00
% deviations	39%	26%	16%	11%	6%	1%	

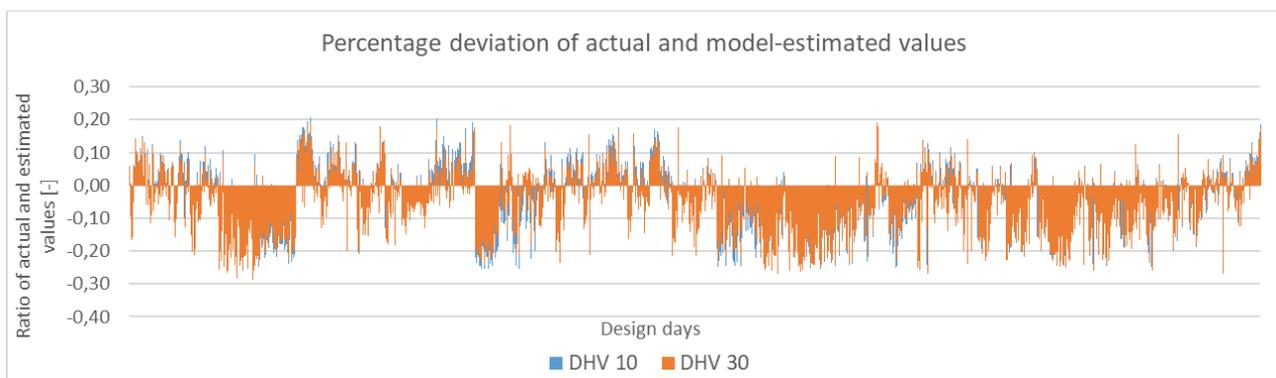


Figure 6 – Deviation of the estimated from the actual values of the design hourly volumes

Figure 6 shows the percentage deviation between the estimated and actual values of the design hourly volumes. Positive values indicate that the design hourly volume obtained by the model is lower than the actual realised values, while negative values indicate the opposite. The maximum value of the percentage deviation for the DHV 10th model is 25%, while the maximum deviation for the DHV 30th model is 29%. The average percentage deviation of the calculated design volumes compared to the realised values is 9% for the DHV 10th model and 8% for the DHV 30th model. Further observation of the deviation percentage shows that 65% of the calculated volumes from the total number of analysed cases, in both proposed models, fall within a 10% deviation from the actual values, confirming the significant accuracy of the proposed models.

In addition to these analyses, a descriptive statistical analysis was conducted for the design volumes obtained by the models and the realised volumes recorded by the ATCs. The results of this analysis are presented in Table 3.

Table 3 – Descriptive statistics of analysed parameters

		Mean	Median	Min	Max	Standard deviation	Standard error
DHV 10th	Estimated [veh/h]	1,090.14	842.23	300	7,349	1,129.10	23.46
	Actual [veh/h]	1,104.26	838.00	376	6,041	1,070.69	
DHV 30th	Estimated [veh/h]	1,043.27	803.58	286	7,067	1,087.20	22.59
	Actual [veh/h]	1,104.26	814.00	361	5,907	1,048.75	

What can be observed from the table is that the average values of the design hourly volumes in both models are close to the average values of the actual realised design volumes. For the DHV 10th model, these values are 1,090 vehicles/hour and 1,104 vehicles/hour, respectively, while for the DHV 30th model, they are 1,043 vehicles/hour and 1,104 vehicles/hour, respectively. The median values of the calculated values in both proposed models also do not deviate significantly from the median values of the realised values. For the DHV 10th model, this difference is smaller, amounting to approximately 4.23 (~4) vehicles per hour, while the difference for the DHV 30th model is slightly larger, at 10.42 (~10) vehicles per hour. Based on the results shown in the table, it is observed that the minimum and maximum calculated values in both models are somewhat lower compared to the actual realised values. The differences in standard deviation between the models, i.e. between the calculated and realised values, are 58.41 for the DHV 10th model and 38.45 for the DHV 30th model. The value of the standard error for the model predicting design volumes as a function of the 10th hour is 23.46, while for the model as a function of the 30th hour, it is 22.59.

5. CONCLUSIONS AND RECOMMENDATIONS

This study conducted research on the design hourly volumes on road sections with predominantly local nature of the flows. The primary goal of the study was to define the design hour and develop a model for predicting design hourly volumes as a function of the design hour.

Based on a detailed analysis of ordered maximum hourly volumes on 32 sections over a five-year period, it was determined that the design hour on sections with a predominantly local nature of the flows is within the range of the 8th to the 16th hour. This result is particularly significant because the literature and guidelines for feasibility studies related to design volumes mainly focus on conditions applicable to the rural road network, while urban network conditions have been insufficiently analysed. By defining an appropriate design hour, a prerequisite for correctly determining design volumes was established.

Determining design hourly volumes predominantly influences a number of strategic decisions in the entire process of optimising the road and street network. Accordingly, this study presents a model for predicting design volumes on sections with predominantly local traffic where automatic traffic counters have not been implemented. Unlike traditional models for defining design hourly volumes, the model developed in this study is based on linear regression, specifically modelling the relationships between the dependent variable, design volume and the independent variables, peak traffic volumes during design days.

Given the specificity of the analysed sections, which are mostly located on entry-exit routes near cities, the independent variables used in the traffic prediction model were the traffic volumes during the morning (from 7:00 AM to 9:00 AM) and afternoon peak hours (from 4:00 PM to 6:00 PM) on design weekdays and weekends. The main advantage of the proposed model is that it only includes the values of traffic volumes

during peak hours on the design weekday and weekend. In other words, the model does not include the average annual daily traffic (AADT) value or factors related to the temporal variability of traffic volumes.

The proposed model in this study was applied to predict design hourly volumes as a function of the 10th and 30th hours. The results obtained from the analysis indicate that it is possible to predict the design volume using the model, as confirmed by the Pearson correlation coefficient and the coefficients of determination. The Pearson correlation coefficient for both models is approximately $r = 0.995$, while the coefficient of determination for the model calculating the design volume as a function of the 10th hour is $R^2 = 0.9975$, and as a function of the 30th hour, it is $R^2 = 0.9982$. The coefficients of determination indicate that for both models, over 99% of the variance in the predicted design volumes is explained by the actual realised design hourly volumes.

Additionally, the results of the conducted analyses indicate that the average error of the predicted design volume values compared to the actual realised values is 8% for the 30th hour and 9% for the 10th hour, which is consistent with the results of previous research.

Based on the complete analysis of design volumes on sections with predominantly local traffic, the main advantages of this study can be summarised as follows:

- The analysis of hourly volumes determined that the range of design hourly volumes on sections with predominantly local nature of the traffic flows is between the 8th and 16th hour of ordered hourly volumes.
- A prediction model for design hourly volumes was developed that does not include AADT values or factors related to traffic volume variability, but only the volume values during peak hours on design weekdays and weekends.
- A prediction model for design hourly volumes was developed that is applicable to sections passing through populated areas, sections located on entry-exit routes near cities, and urban sections where predominantly urban traffic conditions prevail.

The primary contribution of this study should be utilised in the future for the practical application of the obtained results to define design volume values in cases where, for various reasons, automatic traffic counters are not installed on sections with local traffic.

The main limitation of this study lies in the sample, which consisted of 32 analysed sections with characteristic conditions corresponding to those on the urban road network. In this regard, a recommendation for future research is the need to analyse design volumes on a larger sample, which would include sections in urban areas, particularly those on major arteries of larger urban regions.

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