PERIODICA POLYTECHNICA SER. CIV. ENG. VOL. 46, NO. 1, PP. 83–94 (2002)

MEASUREMENTS TO DEFINE RELATIONSHIP BETWEEN TRAFFIC VOLUME AND TRAFFIC CONDITIONS IN HUNGARY

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Received: Oct. 5, 2001

Abstract

The traffic volume (expressed either in Vehicle/hour or in Passenger Car Unit/hour) resulting from traditional traffic counts is only an approximation to reflect the quality of the traffic flow. The drivers appreciate traffic conditions considering and evaluating the situation in their immediate neighbourhood. These conditions can be more accurately represented by a fictive traffic volume calculated on the base of five minutes long intervals, the average speed and the active driving speed as well as that of the instantaneous traffic density. The level of services associated to different traffic conditions can be defined using these parameters.

Keywords: traffic, traffic condition, level of service.

1. Introduction

For the description of the characteristics and the quality of the road traffic several methods can be found in the international literature, evaluating a wide range of measurements' data processed by mathematical and statistical methods. In the early years of motorization's progress it was apparently enough to learn and accept these foreign results in Hungary. Results of the first Hungarian measurements corresponded quite appropriately to the international trends of progress of methodology. The design standards, technical conditions and quality of the Hungarian main road network were improved significantly during the past decades and were approached to that of the average European level. There are, however, significant differences between conditions of the traffic in Hungary and in other countries with high motorization (number of vehicles/1000 inhabitants) rates, which could not be explained by the relatively low level of the motorization alone. In Hungary the average and specific power of the road vehicles is generally lower, the rate of heavy good vehicles in the traffic is higher than in several countries with high motorization level. Moreover, a now questionable speed limit of 80 km/h is enforced in rural areas since the energy-crisis of the seventies. After a correction to be introduced in 2000, this speed limit will be raised to 90 km/h, which remains under the 100 km/h limit effective in most European developed countries. In Hungary there is a quite dense network of urbanised areas, while the density of the main road network lags behind the demand. A considerable part of this main road network crosses these urban areas, where the local speed limit is 50 km/h. This is exactly the same as in the developed European countries.

Table 1. The maximum allowed traffic volumes associated to a given level of service for different road categories, according to the Road Design Standard ME-07-3713:1994

	Suitable (Vm) PCU/h	Affordable (Ve) PCU/h
Rural roads:		
Motorways per lanes	1000	1500
Roads with two or more lanes in one direction per lanes	900	1400
Two lanes roads (in both directions)	900	1400
Urban roads:		
Urban motorways per lanes	1300	1800
Roads with two or more lanes in one direction, per lanes	1100	1500
Two lanes roads (in both directions)	1200	1600

As a standard for road engineers, the Highway Capacity Manual [1] provides a methodology and basic values to estimate the traffic conditions on a two lane road. Ever since the first publication of this Manual, several measurements and researches have been made in the countries with high traffic volumes, either to validate and adopt the procedure described in the Manual, to establish reliable relationships between the measured or observed traffic data on one hand and the traffic conditions on the other, or to modify the methodology and determine the appropriate set of input parameters needed to apply the procedure [2].

In function of the category of the road, the Hungarian road design standard – Road Design ME-07-3713:1994 [3] – designates different traffic volumes as criteria for the two basic types of 'level of service' on road sections (see *Table 1*).

In the new Hungarian 'Road Design' standard in preparation [4] these criteria will be replaced by new values (see *Tables 2* and *3*).

Table 2. The maximum allowed traffic volumes according to the Road Design Standard in preparation

		Traffic volume (PCU/h) up to	
		Suitable	Affordable
		Level of service	
		(Vm)	(Ve)
Rural area			
Motorways per lane		1200	1700
Expressway	in case of 2 × 2 lanes, per lanes	1100	1600
	in case of 2 × 1 lanes with two direction traffic	1200	1700
Roads with two or more lanes in one direction, per lanes		1000	1400
Two lane roads with bidirectional traffic		1200	1700
Urban area*			
Motorways per lane		1400	1800
Expressway	in case of 2 × 2 lanes, per lanes	1200	1600
	in case of 2 × 1 lanes with two direction traffic	1300	1700
Roads with two or more lanes in one direction, per lanes		1200	1600
Two lane roads with bidirectional traffic		1400	1800

*These values are reduced according to the *Table 3* in function of the 'network rule'

2. The Measurements

The Department of Highway and Railway Engineering carried out detailed studies [5] aiming to define the parameters influencing the quality of the traffic conditions. The findings were expressed using mathematical functions derived from appropriate statistics.

The measurements were made using two different methodologies:

- distance–time function and speed measurements with a test-vehicle running on the section under different traffic conditions
- headway and speed measurements executed at a given cross-section.

3. The Parameters Measured

3.1. Measurements with a Test-Vehicle

The average speed and the active driving speed values were determined in function of the fictive hourly traffic volume, defined from the measurements executed by a

Table 3. The maximum allowed traffic volumes in urban areas according to the Road Design Standard in preparation

Design class, 'network rule[1]'	Traffic volume (PCU/h) to	
	Suitable	Affordable
	Level of service	
Roads with two or more lanes, in one direction per lanes, '**a**' rule	1200	1600
Roads with two lanes in one direction per lanes, '**b**' rule	900	1300
Two lanes roads in both directions, '**a**' rule	1400	1800
Two lanes roads in both directions, '**b**' rule	1000	1200
Two lanes roads in both directions, '**c**' rule	800	1000
At signalised junctions the sum of the crossing traffic, depending on the number of phases[2]	1100	1300

[1]The 'network rule' on the urban roads:

- The '**a**' network rule: very important element to the settlement structure; for their design must be preferred the connections rule (demands of transit traffic) oppose the opening and attending rule.
- The '**b**' network rule: an important element to the settlement structure; for their design the connections rule must be preferred (demands of transit traffic) but must be given the opening and attending rule.
- The '**c**' network rule: important local elements of the settlement structure, for their design must be given right rate between the opening and the attending rule with restriction of connections rule.
- The '**d**'" network rule: not important local elements of the settlement structure, for their design must be preferred the attending rule with giving the opening rule and not allowing the connections rule.

[2]The crossing traffic is the sum of the design traffic volume of each phase at signalised junctions. The capacity of the whole junction depends on the number of lanes per directions.

test-vehicle running in the traffic. The traffic flow's direction and the type of the vehicle followed were taken into consideration too. It was also considered, whether the followed vehicles run freely or in a platoon of vehicles.

The results related to the whole test section and its parts were examined separately, while the speed data were taken from the followed vehicle.

The average speed on the test section was determined in the following ways:

- separately in both directions (from Budapest and towards Budapest) and then as a weighted average.

- in function of the vehicle type and considering, whether it runs freely or in a platoon:
  - freely running car
  - light truck + heavy truck running free
  - all kinds of vehicles running, free
  - all kinds of vehicles running in platoon
  - all vehicles running free and in platoon.

The calculated average speed values were grouped in function of the traffic volume (see *Table 4*).

Table 4. The traffic volume limits used to determine the average speed values (fictive hourly traffic in PCU/h)

From Budapest V_1 PCU/h	Towards Budapest V_2 PCU/h	Both directions $V*$ PCU/h
$V_1 < 216$	$V_2 < 216$	$V* < 216$
$217 < V_1 < 360$	$217 < V_2 < 360$	$217 < V* < 360$
$361 < V_1 < 504$	$361 < V_2 < 504$	$361 < V* < 504$
$505 < V_1 < 648$	$505 < V_2 < 648$	$505 < V* < 648$
$649 < V_1 < 792$	$649 < V_2 < 792$	$649 < V* < 792$
$793 < V_1$	$793 < V_2$	$794 < V* < 936$
		$937 < V* < 1080$
		$1081 < V* < 1224$
		$1225 < V* < 1368$
		$1369 < V* < 1512$
		$1513 < V* < 1656$
		$1657 < V* < 1800$
		$1801 < V*$

The following conclusions can be drawn as a summary of the computerised data processing:

- The average speed values and their statistics in both directions (from Budapest and towards Budapest) are appropriately similar (see *Table 5*).
- The speed values (either for all kinds of vehicles or for those (running freely and in platoon) decreased in function of the growth of the $V*$ PCU/h (fictive hourly traffic volume, summing up both directions), (*Fig. 1*).
- Until around 800 PCU/h traffic volume value, there was no significant difference between the speed of freely running vehicles or those running in platoon. Above 800 PCU/h hourly traffic volume, however, that difference becomes significant.

Table 5. The average speeds and their statistics

	v km/h	σ km/h	Standard deviation %
From Budapest	61.8	12.5	20.2
To Budapest	62.2	11.0	17.7
Driving free	65.2	12.2	18.7
Driving in column	56.2	8.1	14.5

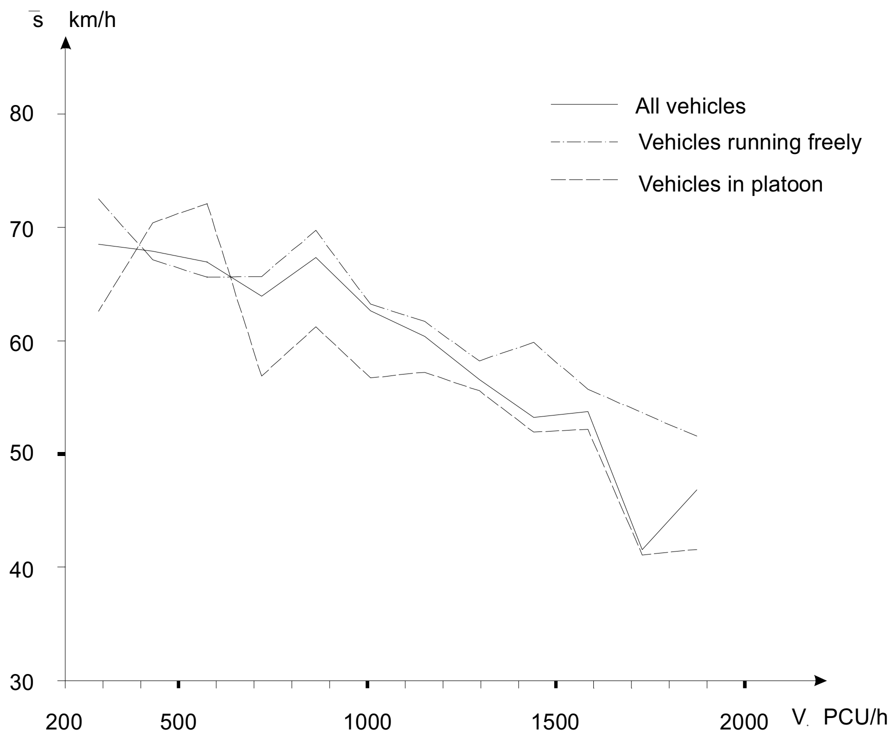

Fig. 1. Average speed values in function of $V*$ PCU/h fictive traffic volume

3.2. Measurements at a Given Cross-Section

On the base of headway and speed measured at a given cross-section simultaneously, the following data were determined:

- the vehicles' instantaneous speed,
- distribution of headways in one direction,
- distribution of headways in both directions,

- parameters of platooning,
- distribution of instantaneous vehicle density.

The data measured at different cross-sections were processed together in function of the information on road and traffic conditions. Parameters taken into account to define the latter were the following:

- horizontal road geometry
- vertical road geometry
- speed limits
- overtaking possibilities
- type of section (urban crossing or rural)
- data and time of measurements.

The instantaneous speed was calculated on the base of time needed to travel on the 100 m long test section. Cases of free flow and platooning traffic conditions and vehicles of different vehicle categories were distinguished, respectively.

For determination of instantaneous vehicle density, on the base of measured headway and speed data, the distance between the bumpers of two vehicles following each other was calculated using the following formula:

$$\Delta l = \Delta t \cdot s,$$

where

Δt is the headway between the two vehicles
s the speed of the vehicle following the other.

Thus, the $\underline{D}$ instantaneous vehicle density (expressed in vehicle/km) can be determined as:

$$D = 1000/\Delta l.$$

The evaluation of instantaneous vehicle density has been made using the statistics of $\underline{D}$ values.

For studying the phenomenon of platooning it was considered as starting when at least three vehicles followed each other with smaller headways than 7.2 s. The following parameters were taken into account for the studies:

- headways between vehicles running in a platoon
- length of the platoon (number of vehicles running in it)
- statistics of the platoons
- the type of the two leading vehicles in the platoon.

4. Results

4.1. Relationship between Traffic Volume and Speed, the Active Driving Speed

Taking into consideration the actual position of vehicles in the traffic flow, the $\overline{s} = f(V*)$ relationship was determined, using *Fig. 1* where curves were fitted onto the points representing the measured data, using the least squares method. The constants of these curves were weighted according to the frequency of the average values.

The following cases were examined:

1. For all vehicles
   - Considering all data
     1.1. Fitting $\overline{s} = a + b \cdot V * + c \cdot V*^2$ parabola
   - Considering only the values below 1656 PCU/h
     1.2. Fitting $\overline{s} = a + b \cdot V * + c \cdot V*^2$ parabola
2. For vehicles running freely
   - Considering only the values below 1512 PCU/h (there was no measured traffic volume exceeding that value)
     2.1. Fitting $\overline{s} = a + b \cdot V * + c \cdot V*^2$ parabola
3. For vehicles in platoons
   - Considering all data
     3.1. Fitting $\overline{s} = a + b \cdot V * + c \cdot V*^2$ parabola

The parameters of regression functions are shown in *Table 6*, using the same symbols as in the formulae above.

Table 6. The parameters of regression functions

	Number	A	b	c	m
All vehicles	1.1.	67.2	0.00568	−0.00001	
All vehicles below 1656 PCU/h	1.2.	66.5	0.0075	−0.000011	
Vehicles running freely	2.1.	67.2	0.00759	−0.0000103	
Vehicles in platoon	3.1.	63.5	0.0038	−0.0000084	

The functions are shown in *Fig. 2*.

The active driving speed values were studied on similar basis. More than 85% of vehicles is running on that, or on lower speed. Assuming normal distribution, this can be determined as the speed value at $\overline{s} + 1.04 \cdot \sigma$.

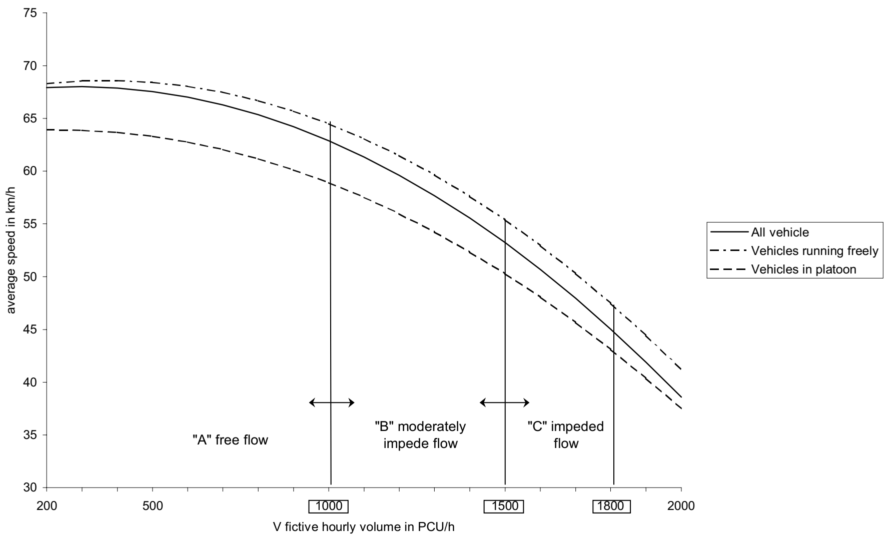

Fig. 2. The functions fitted to the measurements' results according to the proposed traffic condition categories

4.2. Proposed Level of Services in Function of Traffic Conditions

Based on the speed values, the following traffic condition categories were proposed:

'A' level of service: free flow up to 1000 PCU/h total traffic volume

'B' level of service: moderately impeded flow between 1000 PCU/h and 1500 PCU/h total traffic volumes

'C' level of service: impeded flow above 1500 PCU/h total traffic volume

Based on the results of speed measurements made on main roads with high traffic volumes, the values shown in *Fig. 3* were suggested for the evaluation of traffic conditions.

In *Fig. 3* the $\bar{s} = f(V*)$ functions are presented, showing the $V*$ PCU/h fictive bidirectional traffic volumes delimiting the proposed three grades of level of services. *Table 7* summarizes the same data, where:

- $V*$ is a fictive bi-directional traffic volume (PCU/h),
- $\bar{s}$ is the average speed,
- $s_{85\%}$ is the active driving speed.

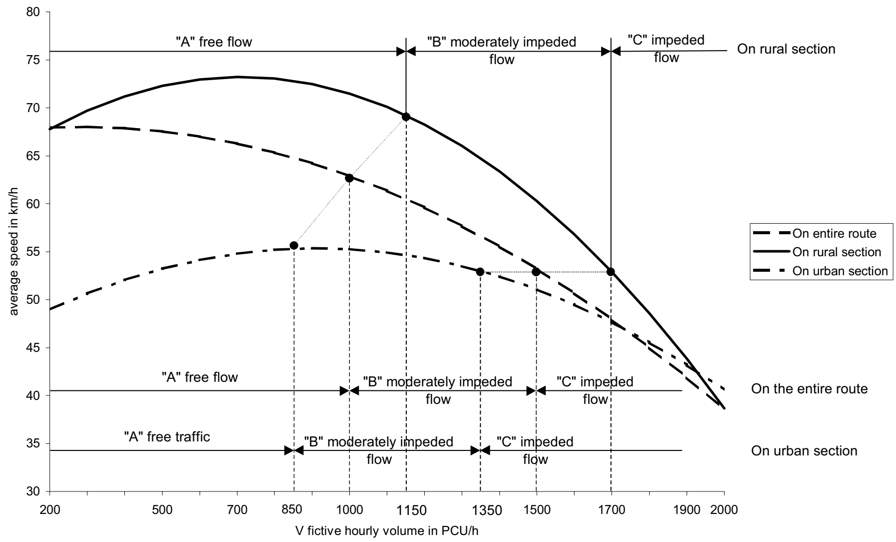

Fig. 3. Traffic volume and average speed values belonging to different traffic conditions

Table 7. Traffic volume and average speed values characterising different traffic conditions

	On rural sections between settlements,	On the entire route	On urban crossing sections
Free flow	$V* \leq 1150$ PCU/h $\bar{s} \geq 69$ km/h	$V* \leq 1000$ PCU/h $\bar{s} \geq 63$ km/h $s_{85\%} \geq 74$ km/h	$V* \leq 850$ PCU/h $\bar{s} \geq 55$ km/h
Moderately impeded flow	$1150 < V* < 1700$ PCU/H $69 > \bar{s} > 53$ km/h	$1000 < V* < 1500$ PCU/h $63 > \bar{s} > 53$ km/h $74 > s_{85\%} > 59$ km/h	$850 < V* < 1350$ PCU/h $55 > \bar{s} > 53$ km/h
Impeded flow	$V* > 1700$ PCU/h $\bar{s} < 53$ km/h	$V* > 1500$ PCU/h $\bar{s} < 53$ km/h $s_{85\%} < 59$ km/h	$V* > 1350$ PCU/h $\bar{s} < 53$ km/h
Capacity	$V* \approx 2100$ PCU/h $\bar{s} \approx 33$ km/h	$V* \approx 1900$ PCU/h $\bar{s} \approx 42$ km/h $s_{85\%} \approx 42$ km/h	$V* \approx 1750$ PCU/h $\bar{s} \approx 47$ km/h

5. Summary and Conclusions

The hourly traffic volume calculated from traditional data of traffic counts (expressed either in PCU/h or vehicle/h) could be related only approximately to the quality of the traffic flow. According to our studies for example, the volumes of traffic measured in 5 minutes intervals within an hour are significantly different from each other: the highest value may be 2.5–3.0 times higher than that of the lowest one. The drivers appreciate the traffic situation on the base of their actual impressions on the situation experienced nearby. That traffic condition can be characterised much better by a traffic volume of 5 minute interval, than by the hourly traffic volume. This is the reason why measurements' data are usually related to the fictive hourly traffic volume. The fictive hourly traffic volume is twelve times more than the actual traffic volume of 5 minute interval.

In the study 'passenger car', 'light truck' and 'heavy truck' vehicle categories were distinguished.

The following conclusions can be drawn from the results:

1. The difference between the speed of vehicles running freely and those running in a platoon appears and increases beyond 800 PCU/h bidirectional total traffic volume.
2. To reflect the $\overline{s} = f(V*)$ relationship, a parabola determined by the method of the least squares can be fitted to the data representing the average traffic volume values weighted by their frequency: of $\overline{s} = a + b \cdot V * + c \cdot V*^2$. The proposed parameters for the studied relationships are the following:
   - For the entire road (urban crossings and rural sections together)
   - All vehicles

$$\overline{s} = 67.2 + 0.00568 \cdot V * -0.0001 \cdot V *^2 .$$

   - Vehicles running freely (below $V* = 1512$ PCU/h traffic volume)

$$\overline{s} = 67.2 + 0.00759 \cdot V * -0.0000103 \cdot V *^2 .$$

   - Vehicles in platoon

$$\overline{s} = 63.5 + 0.0038 \cdot V * -0.0000084 \cdot V *^2 .$$

   - Active driving speed (speed exceeded by less than 15% of vehicles)

$$\overline{s} = 78.55 + 0.0114 \cdot V * -0.00001625 \cdot V *^2 .$$

   - On rural section

$$\overline{s} = 62.7061 + 0.02959 \cdot V * -0.0000208 \cdot V *^2 .$$

   - On urban crossing section

$$\overline{s} = 44.9006 + 0.02287 \cdot V * -0.0000125 \cdot V *^2 .$$

3. Because of the current speed limits enforced in Hungary, high speed values could not be reached even at low traffic volumes. Thus, traffic volume has a weaker impact on the average speed value, especially when it is relatively lower than in other countries, where there are no speed limits. So, in Hungary at low traffic volumes, the average speed decreases less sensibly in function of traffic volume.
4. As a result of the recent revision of the Hungarian Highway Design Standard, the traffic volume limit values separating the two levels of service reflecting traffic conditions, have been increased. Urban roads' classification has been made more detailed, in line with network hierarchy. It means that for roads classified higher in the hierarchy, the criteria are even stricter.
5. The traffic volume limit values contained in the revised design standard and the traffic conditions' categories proposed show good correlation on road sections. The 'suitable' level of service (upper limit value 1200 PCU/h) of the standard matches well to the proposed 'A' free flow category (upper limit value 1150 PCU/h), while the 'affordable' level of service (upper limit value 1700 PCU/h) fits to the 'B' moderately impeded flow category (upper limit value 1700 PCU/h).
6. According to our studies, on urban crossing sections the traffic volumes accepted in the revised design standard allow more frequent and/or longer appearance of unfavourable traffic conditions. Due to the characteristics of the urban crossing sections, this is generally accepted by the drivers as well. Based on the parameters measured on the sections studied, the limit value for 'A' free flow category is 850 PCU/h, which approximately fits to the 800 PCU/h limit value of 'suitable' level of service of a road classified as being in the 'c' network hierarchy. The limit value of 'B' moderately impeded traffic flow category is 1350 PCU/h, which could match to the 1200 PCU/h limit value of 'bearable' level of service of a road within the 'b' network hierarchy class. This demonstrates, that the local traffic impacts significantly the traffic conditions of local roads. The higher the total traffic volume, the lesser the effect of the local traffic on the traffic conditions is.

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