ENVIRONMENTAL ENGINEERING

The 8th International Conference
May 19–20, 2011, Vilnius, Lithuania
Selected papers

ISSN 2029-7106 print / ISSN 2029-7092 online
ISBN 978-9955-28-829-9 (3 Volume)
ISBN 978-9955-28-827-5 (3 Volumes)
http://enviro.vgtu.lt

RESEARCH ON TRAFFIC FLOW SPEED OF ARTERIAL STREETS IN URBAN AREAS

Ziedonis Lazda[1], Juris Smirnovs[2]

Faculty of Civil Engineering, Riga Technical University, 16, Āzenes Street, LV 1048, Riga, Latvia.
E-mails: [1]ziedonis.lazda@csdd.gov.lv; [2]smirnovs@latnet.lv

Abstract. Road traffic flow intensity is growing up in Latvia. To address increasing traffic intensity, there is a need for new arterials in urban areas, but then, of course, require additional infrastructure space. However it is known that the construction of arterials in urban areas, compared to a lower category of street construction, is very expensive. The high costs include not only the construction of arterials, but also the land redemption, demolition of buildings, businesses moving to other areas issues. In order to reduce the above costs, there is a need to evaluate all possible ways to reduce the total costs of construction of arterials that first of all can be achieved by reducing geometrical parameters of arterials. The street design parameter reduction, such as travel longitudinal profile of the radius of curvature, plane curve radius of carriageway lane widths, etc., is a compromise resolution. The arterial streets' parameters can be reduced first of all by changing the design speed. The study makes the correlations between the momentary speed of the continuity of service orientated city conditions and the maximum permitted speed, design speed, traffic flow density and loading ratio. Authors have found the relationship between design speed and momentary speed for different traffic densities on arterial streets. Further efforts are needed in developing recommendations for the design speed of numerical values.

Key words: local speed, momentary speed, traffic flow density, traffic loading level, permitted speed, road design speed.

1. Introduction

Construction of arterial streets in the conditions of dense housing in urban territories requires significant financial investments that are connected not only to the construction of arterials itself. In conditions when the financing available for the construction of interchanges is limited, it becomes more and more important to evaluate every possible way to reduce the costs for the construction of arterial streets, and this primarily may be achieved by reducing the geometrical parameters for arterial streets. The mentioned parametres may be changed by changing design speeds, of course, with respect to appropriate level of traffic safety. Within this study the necessity to review normative documents in relation to functions and categories of city streets was evaluated. The analysis of the influence of traffic speed on the designing of city streets, as well as, on traffic conditions was carried out.

2. Methodology and initial data

2.1. Recording of speed measurements

The methodology used in research provided that the recording of speed was carried out with traffic counters that continuously recorded local speeds on all bridges in the Riga city that in their essence were the only arterial streets with free traffic flow. Local driving speed was measured on arterial streets with free traffic flow with different speed limits, different design speeds and different road parametres. Data recording was done automatically and continuously for a number of years, and daily traffic intensity was counted per every day hour in the period of 2007 - 2009. The recording of traffic intensity and road accidents was done simultaneously with the measurements of actual speed.

Automatic recording of traffic data is done with two methods of counting. The first method is counting with the help of induction loops embedded in roadway pavement, and the second is the recording of traffic data with the system of laser beams that is installed on a special gantry above driving lanes.

2.2. Adjustment of data from traffic flow measurements

In general to describe the traffic, the data acquired in local measurements and the data acquired in momentary measurements are used.

In case of local measurements the counting of vehicles is performed at a specified cross-section x, where the vehicles that cross the specified cross-section within time period T are counted. Traffic flow intensity may be determined basing on these observations:

$$q = M/T, \quad (1)$$

where q – traffic flow intensity, vehicles per hour;
M – number of counted vehicles, vehicles;
T – time period, when measurements were taken, h.

In case of momentary measurements the counting of vehicles is performed within specified time period t in a specified road section S, and the number of vehicles N is observed within the specified time t in the mentioned section S. The parameter used to describe traffic loading is the density of traffic flow k:

$$k = N/S \quad (2),$$

where k – density of traffic flow, vehicles per km;
N – number of observed vehicles, vehicles;
S – length of road section where counting was performed, km.

The speed of each vehicle at a certain moment of time is called the momentary speed. Existing speed measurements on city arterial streets were performed according to local measurement method. In our case for further research of traffic flow such speed measurement data is necessary that is acquired according to the method of momentary observations. As the relation between the values acquired in momentary and local measurements exist, therefore it is possible to calculate the average momentary speed of traffic flow according to the following formula (Smirnovs 2008):

$$V_{mom} = M/SUM\ (1/v_{lok}) \quad (3),$$

where V_{mom}- average momentary speed of traffic flow, km per hour;
V_{lok}- local speed of traffic flow, km per hour.

Thus the speed data acquired with automatic counting may be transformed into average momentary speeds in all arterial streets with free traffic flow.

Further calculation of flow density will be done according to the following formula:

$$k = q/V_{mom} \quad (4),$$

where k – density of traffic flow, vehicles per km;
q – traffic flow intensity, vehicles per hour;
V_{mom}- average momentary speed of traffic flow, km per hour.

2.3. Determination of road capacity

The capacity of a single lane of street carriageway is the maximum number of vehicles that may be accommodated on the cross-section of single lane per one hour in one direction with the condition that traffic safety is ensured.

By imagining a row of vehicles that moves along a single driving lane it is possible to conclude that theoretical capacity of this lane is inversely proportional to the distances between the moving vehicles in this row.

The practical road capacity P_{max} is assumed basing on the number of driving lanes in the whole road section. For two-lane roads the practical capacity is assumed to be 2000 vehicles per hour, and for three-lane roads - 4000 vehicles per hour accordingly.

Road capacity is generally calculated in order to identify road sections where congestions may occur, as well as, to determine economical benefits and traffic comfort and to choose methods and measures to improve traffic conditions. Road capacity is not constant in the whole road section all year around. Maximum road capacity value may be observed at favourable conditions for traffic flow and maximum share of cars. Minimum road capacity value may be observed in complicated road sections with poor parametres of horizontal and vertical curvature, with mixed traffic content (large share of trucks, buses, suburban traffic) and at adverse climatic conditions (black ice, blizzard, fog, etc.).

According to the source of reference (Министерство автомобильных дорог РСФСР 1988) the maximum road capacities (cars per hour) are the following:

- two-lane roads - 2000 cars in both directions of traffic flow;
- three-lane roads - 4000 cars in both directions of traffic flow;
- four-lane highways - 2000 cars in one lane;
- six-lane highways - 2200 cars in one lane;
- eight-lane highways - 2300 cars in one lane.

For roadways with several driving lanes the capacity of a single lane may serve as a basis for the calculation of total road capacity (Самойлов and Юдин 1972). In theory to calculate the total road capacity, the capacity of a single lane has to be multiplied by the number of lanes. In real conditions of free traffic flow on arterial streets, however, several serious obstacles exist that may significantly reduce the total road capacity. Continuous changing of lanes, overtaking manoeuvres, etc. have to be considered. The above mentioned conditions reduce the total road capacity of arterial street with several driving lanes, and the level of reduction that will be designated by factor α, is increasing together with the increase of the total number of driving lanes. Numerical values of factor α are given below:

- carriageway with one lane (in one direction) - 1.00;
- carriageway with two lanes (in one direction) - 0.90;
- carriageway with three lanes (in one direction) - 0.82;
- carriageway with four lanes (in one direction) - 0.74.

In addition to that, total road capacity may be calculated according to another method that may be found in the source of reference (Полукаров 1968). In this case the total road capacity is calculated by multiplying the capacity of a single lane with respective factor γ:

- one lane (in one direction) - 1.00;
- two lanes (in one direction) - 1.80;
- three lanes (in one direction) - 2.45;
- four lanes (in one direction) - 2.95;
- five lanes (in one direction) - 3.35.

2.4. Calculation of loading factor

Road loading factor is calculated by considering the relation of traffic intensity and potential road capacity. When performing the analysis of free traffic flow on arterial streets in this study, the actual intensity recorded automatically and the road capacity calculated according to the methodology described in the previous chapter were taken into consideration. Road loading factor for normal traffic flow conditions is considered to be within the values of 0.75 – 0.80 that characterises the reserve of traffic flow capacity of 20-25%. When the capacity and traffic intensity in a specific section is low, the loading factor may be calculated according to the following formula:

$$Z = N_{st} / P \qquad (5)$$

where Z – road loading factor;
N_{st} - calculated traffic intensity per one hour, vehicles per hour;
P – potential road capacity, vehicles per hour.

The available data of traffic flow intensity does not show different vehicle types, therefore it is necessary to adjust the data. In accordance with different sources of reference (Самойлов and Юдин 1972) and (Brilon 1993) the factor ε with the value 1.2 was chosen by the authors. Therefore the average hourly intensity used in this study is multiplied with the adjusting factor ε=1.2.

3. Results

Considering that peak hours in the street network approximately amount up to 12 to 14 hours, this study proves that approximately in a half of the day the actual driving speed in the street network does not exceed the design speed. Speed measurements in the street network show that high design speed has no influence on the increase of driving speed of traffic flow and the time savings in driving, and this may be especially observed in the most active hours. As the study shows, the main factors that influence the actual speed of traffic flow are the traffic density and the level of loading.

Measurements during night time (1.00 – 5.00) show that traffic intensity in the street network is the lowest in comparison with the whole day. Therefore arterial streets in this time period are used with the loading factor of 0.2. In the time period of 23.00 to 1.00 the loading factor is around 0.2...0.3. Traffic intensity on city streets increases sharply in the morning (6.00 – 8.00), when the loading factor reaches 0.5 - 0.6 and the actual driving speed decreases. Practically during the whole day (8.00 - 20.00) the loading factor amounts up to 0.7 - 0.8.

The relations identified in this study describe such traffic flow condition that was observed in the time and place when and where the measurements were performed. The results of this study may be practically used in other locations, as well, with appropriate adjustments in relation to road, traffic and climatic conditions. The primary condition has to be the principle that road geometrical dimensions, traffic intensity and content, as well as, climatic conditions in specific road section where the relations of traffic flow identified in another location are to be applied are similar to those observed in the locations where measurements were performed.

Relations that interconnect the traffic flow intensity q, density k and average momentary speed (with stripe above v) are called the mathematical flow models. Traffic flow models are based on the following relations:

$$v_m = \text{function}(q)$$
or
$$v_m = \text{function}(k)$$

When analysing the data acquired in this study the relation of traffic flow intensity and average momentary speed will be described first. Linear equation may be chosen as an example for initial conditions of traffic flow mathematical model.

$$v = c - aq \qquad (6)$$

where v – traffic flow speed, km per hour;
q – traffic flow intensity, vehicles per hour;
constants „a" and „c" may be calculated with the help of linear regression.

This relation describes the flow condition in the linear section of the ascending branch of fundamental diagram that may not be widely used in practical work.

3.1. Identified relations between traffic flow intensity and momentary speed

Traffic flow intensity is one of the properties that characterise the traffic flow. In accordance with the theory of traffic flow the actual driving speed decreases with the increase of traffic intensity, as it is connected with the limitations of road or street capacity. The analysis of interrelated speed and intensity data performed in this study proves the above mentioned general relations of traffic flow. Figure 1. shows the relations between traffic flow intensity and speed on arterial streets with free traffic flow at different speed limits, as well as, with different numbers of lanes in different time periods (data from 2007 and partially from 2009).

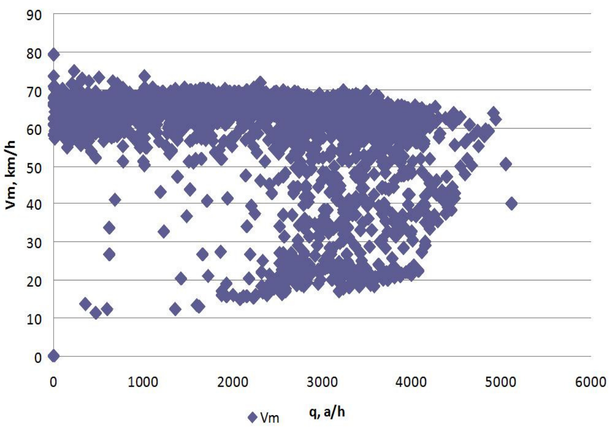

Fig 1. Relation of traffic flow intensity and speed at speed limit of 50 km/h, 2 lanes in each direction

The identified relation between traffic intensity and speed allows to forecast certain traffic conditions, for example, by knowing the actual traffic intensity it is possible to calculate the momentary driving speed according to the following formulas:

- At speed limit of 50 km/h with 2 lanes:

$$V_m = 45.243 - 1E\text{-}12q^4 + 6E\text{-}09q^3 - 8E\text{-}06q^2 - 0.0008q \quad (7)$$

- At speed limit of 70 km/h with 3 lanes:

$$V_m = 56.15 - 4E\text{-}13q^4 + 5E\text{-}09q^3 - 2E\text{-}05q^2 + 0.023q \quad (8)$$

- At speed limit of 70 km/h with 2 lanes:

$$V_m = 58.511 + 5E\text{-}09q^3 - 2E\text{-}05q^2 + 0.0153q \quad (9)$$

3.2. Identified relations between traffic flow density (Vm) and momentary speed (k)

The relation between traffic flow density and momentary speed is also used to describe the conditions of traffic flow. Similarly to the relation between intensity and speed the actual driving speed in traffic low greatly depends on traffic density. The greater the number of vehicles in traffic, the lower is the actual driving speed. Figure 2. shows the relations between traffic flow density and momentary speed on arterial streets with free traffic flow at different speed limits, as well as, with different numbers of lanes in different time periods (data from 2007 and partially from 2009).

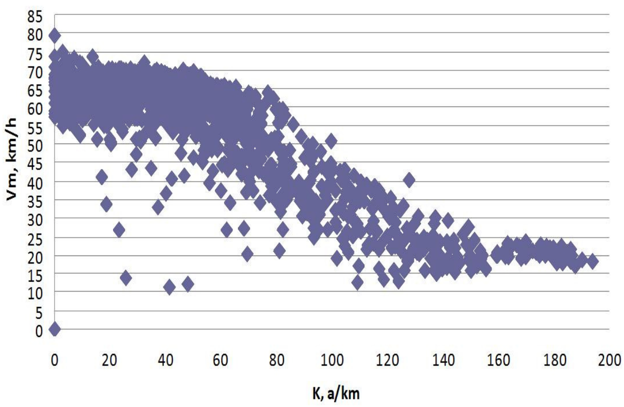

Fig 2. Relation of traffic flow density and speed at speed limit of 70 km/h, 3 lanes in each direction

The identified relation between traffic density and speed allows to forecast the momentary driving speed on arterial streets with free traffic flow according to the following formulas:

- At speed limit of 50 km/h with 2 lanes:

$$V_m = 48.194 + 0.0008k^2 - 0.3434k \quad (10)$$

- At speed limit of 70 km/h with 3 lanes:

$$V_m = 63.275 - 0.0023k^2 + 0.078k \quad (11)$$

- At speed limit of 70 km/h with 2 lanes:

$$V_m = 62.789 - 0.1982k \quad (12)$$

3.3. Identified relations between traffic flow intensity (q) and density (k)

The interrelation between traffic flow intensity and density is another property used to describe the conditions of traffic flow. Traffic flow theory shows that with the increase of traffic intensity the traffic density or the traffic flow loading increases, as well. Figure 3. shows the relations between traffic flow intensity and density on arterial streets with free traffic flow at different speed limits, as well as, with different numbers of lanes in different time periods (data from 2007 and partially from 2009).

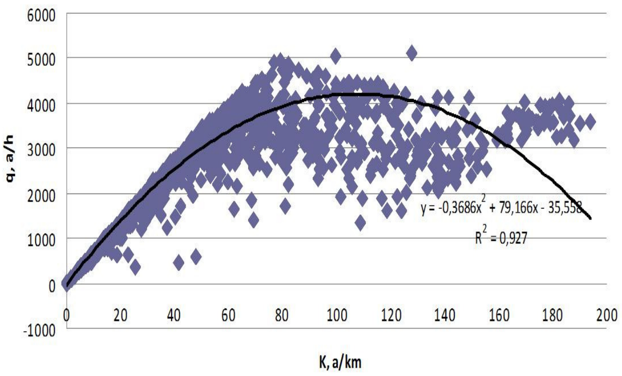

Fig 3. Relation of traffic flow intensity and density at permitted speed of 70 km/h, 3 lanes in each direction

The identified relation between traffic intensity and density allows to forecast traffic intensity on arterial streets with free traffic flow according to the following formulas:

- At speed limit of 50 km/h with 2 lanes:

$$q = 81.176 - 0.1277k^2 + 37.857k \qquad (13)$$

- At speed limit of 70 km/h with 3 lanes:

$$q = 35.558 - 0.3686\,k^2 + 79.166k \qquad (14)$$

- At speed limit of 70 km/h with 2 lanes:

$$q = 16.35 - 0.3693\,k^2 + 63.814k \qquad (15)$$

3.4. Identified relations between traffic flow loading (k) and momentary speed (Vm)

When weather conditions change, or when traffic accident has occurred or vehicle is standing on carriageway due to any reasons, congestion situations occur when driving speed decreases down to 5...10 km/h and traffic intensity decreases, as well. The particular traffic conditions apply to maximum density of traffic and level of loading which is close to 1.0 (Figure 4.).

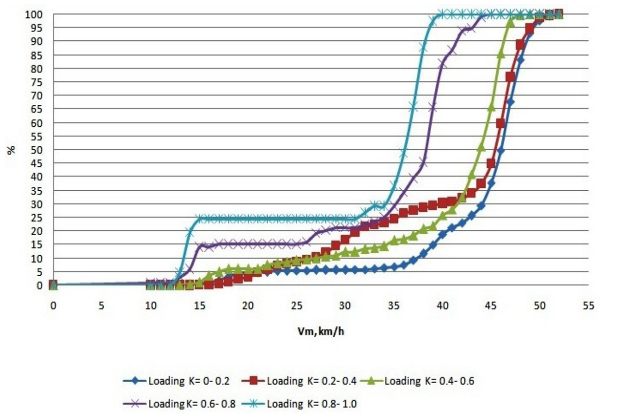

Fig 4. Levels of loading of traffic flow at speed limit of 50 km/h

3.5. Identified relations between momentary speed of traffic flow (Vm) and design speed (Vpr)

To evaluate the influence of design speed on the actual driving speed the study included the measurements of driving speed on arterial streets with free traffic flow with different speed limits, numbers of lanes, geometrical dimensions and design speeds.

Traffic flow measurements performed within this study show that the main factor that influences the choice of driving speed is the road capacity. When looking at 95% of average momentary sped and design speed at different levels of loading on arterial streets with free traffic flow, it was concluded that the increase of design speed above 80 km/h will not result in any influence on the actual driving speed (Figure 5.).

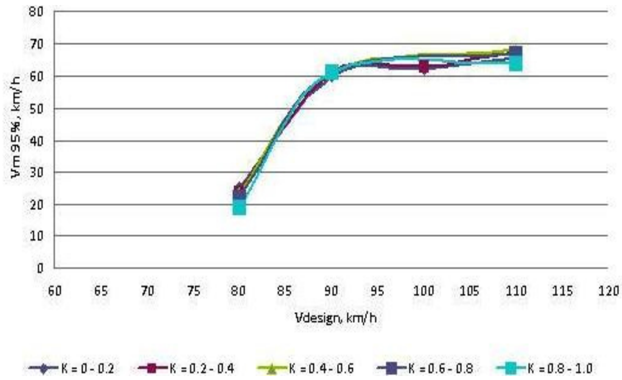

Fig 5. 95% momentary speed in relation to design speed in the direction out of the office

3.6. Identified relations between traffic flow intensity (q) and momentary speed (Vm)

Traffic intensity on arterial streets with free traffic flow changes during the day (Figure 6.). However, if in the past the densest traffic could be observed in specific morning and evening hours then the present situation has changed. The results show that the greatest traffic flows may be observed starting from 7.00 in the morning and up to 20.00 in the evening. It has to be concluded that dense traffic may be observed for more than half of the day (from 12 to 14 hours).

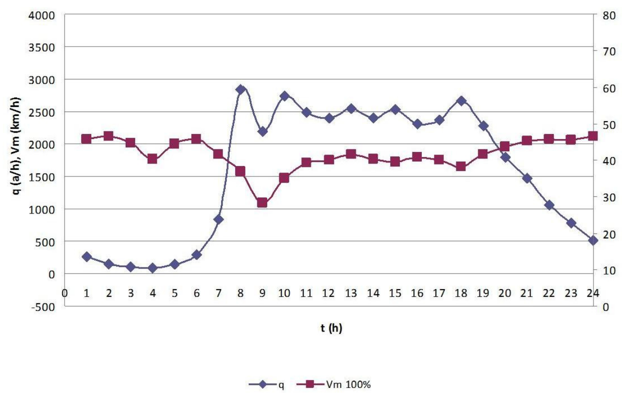

Fig 6. Relation of traffic intensity and average momentary speed at speed limit of 50 km/h in the direction towards city centre

The study also identified the share of the momentary driving speed at different speed limits, shown in Figure 7.

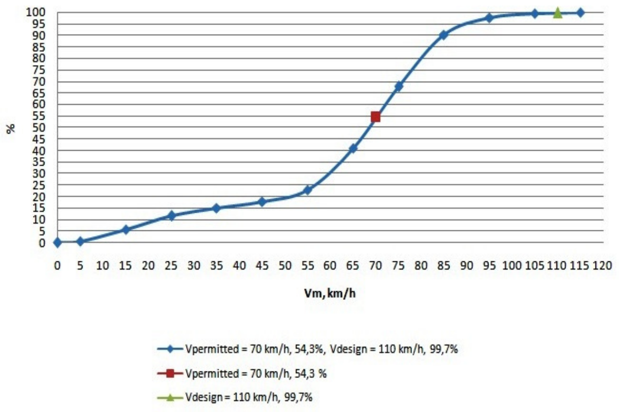

Fig 7. Share of momentary driving speed at speed limit of 70 km/h, per cent

When analysing the data acquired on average momentary speeds it was concluded that the actual speeds on arterial streets with free traffic flow rarely exceeded the design speeds for arterial streets. Such situations were observed only in 2% of all hours per day at the speed limit of 50 km/h. However, at the speed limit of 70 km/h the situations when driving speed exceeded the design speed occurred even much more rarely – only in 0.03%.

Considering the above mentioned it may be stated that significant capital investments needed to comply with the requirements set in normative documents for geometrical dimensions of arterial streets are inadequately high, as they would provide traffic safety only for 2% of all drivers that in their essence brutally violate the established maximum speed limit on roads for more than 40 km/h.

4. Conclusion

This study shows that traffic flow loading at the level of 0.2 to 0.4 does not provide any significant impact on the actual driving speed. With the increase of traffic intensity the average momentary speed decreases. With dense traffic flow when the loading factor exceeds 0.8, the average momentary speed decreases and the density of traffic flow increases. More constant relation between driving speed and traffic flow density was observed during this study.

The results of this study may serve as the basis for determination of design speed and permitted driving speed in urban areas on arterial streets with free traffic flow. This means that road parameters as radius of travel longitudinal profile, radius of plane curves, lane widths can be reduced. Furthermore, the general road costs can be reduced, while ensuring an adequate level of safety.

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