DISCRETE SIMULATION OF TRAFFIC FLOWS IN HIGHWAY TUNNELS

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Abstract

Tunnels are an element of roadway network characterized by their specific principles of operation. They must therefore be analyzed separately from the rest of the traffic system, especially when traffic safety is considered, which is influenced by numerous factors (technical, technological, organizational, psychological, sociological, etc.). These factors are not considered, or are considered to a lesser extent, in traffic safety studies of the road network.

In this paper, we have analyzed traffic flows in the wide area of the Slovene highway network A1 by using simulations. In this area there are four successive tunnels and the Jasovnik tunnel (left tube) was chosen to be studied according to different scenarios leading to congestion. In the analysis, the parameters (such as the number of vehicles, velocity, vehicle structure, system response time) varied and the response to these parameters was measured. Measures were suggested to reduce the consequences of congestion considering the results of micro-simulations of traffic flows, and suggestions were given for a possible enhancement of the traffic safety in the tunnels. The computer programme Vissim 4.10 was used for micro-simulations of traffic flows, using the car-following model. This paper is aimed at presenting the application of simulations when decisions have to be taken about improving the measures and when the tunnel is in the planning phase.

Keywords: car-following model, traffic flow simulations, highway tunnels, traffic safety.

Presenting Author's Biography

Matjaž Šraml is an assistant professor, holding a Ph.D degree of Mechanical Engineering, employed at the Faculty of Civil Engineering, University of Maribor. His specialization refers to the pedagogical topics of "Devices, systems and constructions for transport" and "Traffic technique". So far he has been included in several applicable and fundamental projects. He is a principal researcher of international bi-lateral projects and participates in other international projects as well. He is also a member of several professional associations and an author and a co-author of original scientific, scientific and technical articles in the field of his specialization, which refers to the simulation of material flow, logistics and transport analysis and the analysis of technical systems.

1 Introduction

This paper presents a micro-simulation analysis of traffic flows in the highway tunnel and an analysis of possible traffic congestions. This is fundamental for suggesting measures to raise the level of traffic safety, whereby taking into account professional requirements and the latest achievements in the field of assuring traffic safety in tunnels.

When providing a computer-based simulation of traffic flows, real input data for the left tube of the Jasovnik tunnel (A1 highway) were used. Ahead of the Jasovnik tunnel, in the discussed direction of driving, there is the Trojane tunnel, which is the longest tunnel with two tubes in the Slovene A1 roadway network. Followed by the Jasovnik tunnel is the Ločica tunnel. The traffic flow in the Jasovnik tunnel can influence the traffic flows in the Trojane and Ločica tunnels as well as traffic flows in the open highway section between the afore-mentioned tunnels.

Microscopic models of traffic flow simulation encompass every single motorized vehicle, i.e. car, lorry, motorcycle, with real characteristic (dimensions, acceleration, deceleration, velocity of movement, etc.). Microscopic models make possible a detailed study of intervals of traffic congestion and its reduction. Consequently, a detailed analysis of roadway traffic can be made. In certain cases roadway traffic can be marked as chaotic and non-linear. Such cases are easier to model on a microscopic level, by modelling individual vehicles on the highway in every time space, whereby vehicles move from the start to the end in real time.

Lately, the significance of simulation methods is increasing, with most credit going to increasingly capable computers and the numerous possibilities of creating complex mathematical models that enable a good comparability of results with actual circumstances. Several analytical and micro-simulation models offer variants of traffic flow analysis based on either the gap acceptance or empirical approaches. Yet further calibration work under various operating conditions is still required in order to confirm their reliability [1]. Examples of such codes are SIDRA, RODEL, VISSIM, SYNCHRO, PARAMICS etc. RODEL is an empirical model based on empirical studies [1]. SIDRA [2, 3] was developed primarily for Australian operating conditions, but has been expanded to include the United Kingdom (UK) regression equations as well as various gap acceptance models. One of the main advantages is also that it incorporates all Highway Capacity Manuel (HCM) [2, 3] standards/defaults and could be adopted for almost all traffic problems around the world. Traffic flow analyses in the VISSIM and SYNCHRO follow the HCM approach and are insensitive to the geometric features [1]. The analysis in PARAMICS is based on the gap acceptance approach and it takes into account some roundabout geometric features. In contrast to the abovementioned computer codes, for the present analysis the micro-simulation code Vissim 4.10 has been used (PTV-Vision) [4], which is based on the car-following model, proposed by Wiedemann [5, 6, 7]. Lately, the version 4.30 of Vissim code is already available. However, in the Eurosim 2007, we will present among this paper also a simulation model of pedestrians influence the roundabout capacity.

2 Problem description

With the realization of the National Programme of Building Highways (NPIA) Slovenia is gaining a new well-built infrastructure and some highway tunnels. Together with the existing highway tunnels, these new tunnels form a tunnel network in the Slovene roadway system (Fig 1 - inside the circle the sequence of four tunnels is marked, the Jasovnik tunnel is the third one in the direction from Ljubljana to Maribor), which should fulfil the conditions of a safe, comfortable and undisturbed traffic flow (adequate inner-state connections, connections with the roadway network of neighbouring countries, improved traffic safety, competitiveness of Slovene products, reduction of negative effects on the environment, etc.).

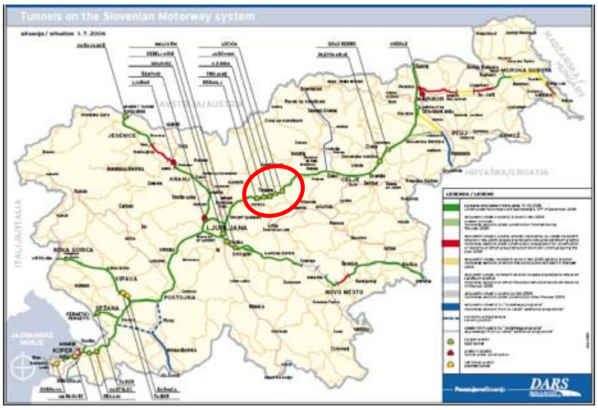

Fig. 1 Tunnels in the Slovene highway network

The basic problems that have been dealt with are traffic blocks in the tunnel, caused by a closed driving lane or closed driving and overtaking lanes. In the former case the influence of the reduced speed limit on the queue length was also researched, considering the possibility of an increase in the number of vehicles.

Before we started to design the simulation model, the data on the system processes were collected. The data was gathered with the help of the Motorway Company in the Republic of Slovenia (DARS) on the Vransko toll station, which covers the aforementioned section of the highway network (larger section of the Jasovnik tunnel), which was analysed with the simulation.

Data collection presents an important area in the simulation analysis, since the simulation role can be annulled on the basis of incorrect data. When collecting data, contacts were made with engineers, operators and technologists. The analysis of the appropriate existing documentation was of help, too. The objective of gathering data was to determine parameters of the model. After the data was collected, the simulation model of the existing situation was developed.

The model was designed with the application of the real data in the computer programme Vissim. With the help of links and connectors the adequate area was first drawn on the scale. Then all data was entered in the programme and we began with the simulation. After designing the model (the validity of the model had to be established because the model did not entirely follow the real action), the calibration of the model was performed. Then the model acted similarly to the real system.

The output data of the simulation experiments were used as a numerical evaluation of the measurements for every option, system variant, which were later on mutually compared. Beside the numerical values, graphic demonstrations of output data, which are clearer than numerical values, were also elaborated.

The details of documenting are of major importance. The simulation project was concluded with a presentation of results and video shots of simulations, with the emphasis put on the credibility of results.

3 Methodology

Different car-following models have been used in the past and recently, which can be classified into the following groups based on the concept behind the model (they are presented in detail in reference [8]): (i) *Stimulus response model* (Chandler model (1958), generalized GM model (1961)); (ii) *Safe distance model* (Gipps model (1981), Krauss model (1997)); (iii) *Psychophysical model* (Leutzbach-Wiedemann model (1986)), (iv) *Cell based model* (cellular automata model (Nagel (1992)); (v) Optimum velocity model (Bando et al (1995)); (vi) *Trajectory based model* (Newell model (2002)). Among all models, we will apply Leutzbach-Wiedemannov model (usually named Wiedemann model). It can be described with the equation [5]

$$a_n(t+T) = \frac{dv(t)^2}{2[S - dx(t)]} + a_{n-1}(t) \qquad (1)$$

The model considers psychophysical aspects of the driving behaviour (see Fig. 2– definition of basic psychophysical parameters in Vissim code). For the presented analysis the Wiedemann 74 [4, 9] model is used.

This model is well-known especially for simulation purposes. It differs from other models in that it considers the acceleration $a_{n-1}(t)$ of the vehicle ahead as a stimulus for the following vehicle, in addition to the difference between the current spacing and desired following distance *S*. Parameters to be optimized are the response time *T* and the desired following distance *S;* where *t* is the actual time, and *dv*(*t*) is the velocity divertive and *dx*(*t*) is the distance divertive.

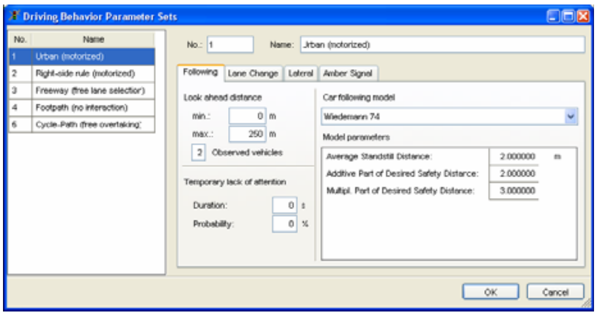

Fig. 2 Definition of basic psychophysical parameters

Vissim 4.10 [4] presents a discrete, time-oriented microscopic simulation model. It makes use of the robust psychophysical behaviour model (developed by Leutzbach and Wiedemann [5,6,9]) of car characteristics for longitudinal vehicle movement and algorithms based on vehicle driving rules. Mathematic model (Eq. 1) is based on Leutzbach-Wiedemann's theory, which presupposes that every driver can find himself in one of the following situations:

- driving in a free traffic flow – without the influence of other vehicles,
- access driving – the process of adjusting the speed to the vehicle ahead,
- pursuit driving – the driver keeps a constant distance from the vehicle ahead without accelerating and braking,
- braking – it applies when the safe distance is under the lowest limit.

As stated above, the simulation model has a psychophysical model of following the vehicle, with linear movement of vehicles and directions for lateral movement. The model takes into account various types of drivers (female, male, old, young) and their individual characteristics – see Fig. 2.

4 Simulation models

For the experiment procedure, the date 13. 06. 2006, was chosen, since it ensures actual values, with which the simulation can be continued. Fig. 3 shows the number of vehicles in the driving lane of the left tube of the Jasovnik tunnel on that day. With the help of Fig. 3 it can be established that there is a lower traffic density in the morning (from 00:00 a.m. to 06:00 a.m.), then the traffic increases and it reaches two peaks (at approximately 08:00 a.m. and 16:00 p.m.). After that the traffic slowly decreases until 22:00 p.m. and then the traffic flow is significantly lower.

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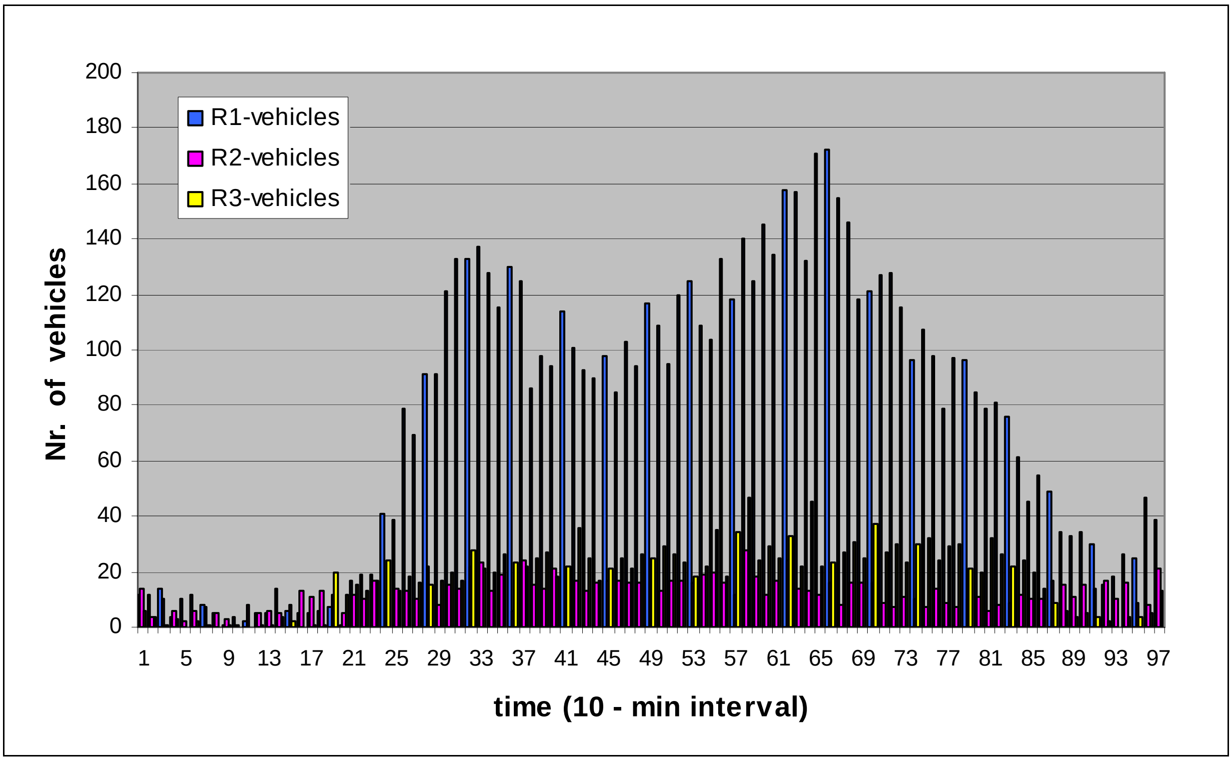


Fig. 3 Numerous data on 13. 06. 2006 in the driving lane of the left tube of the Jasovnik tunnel

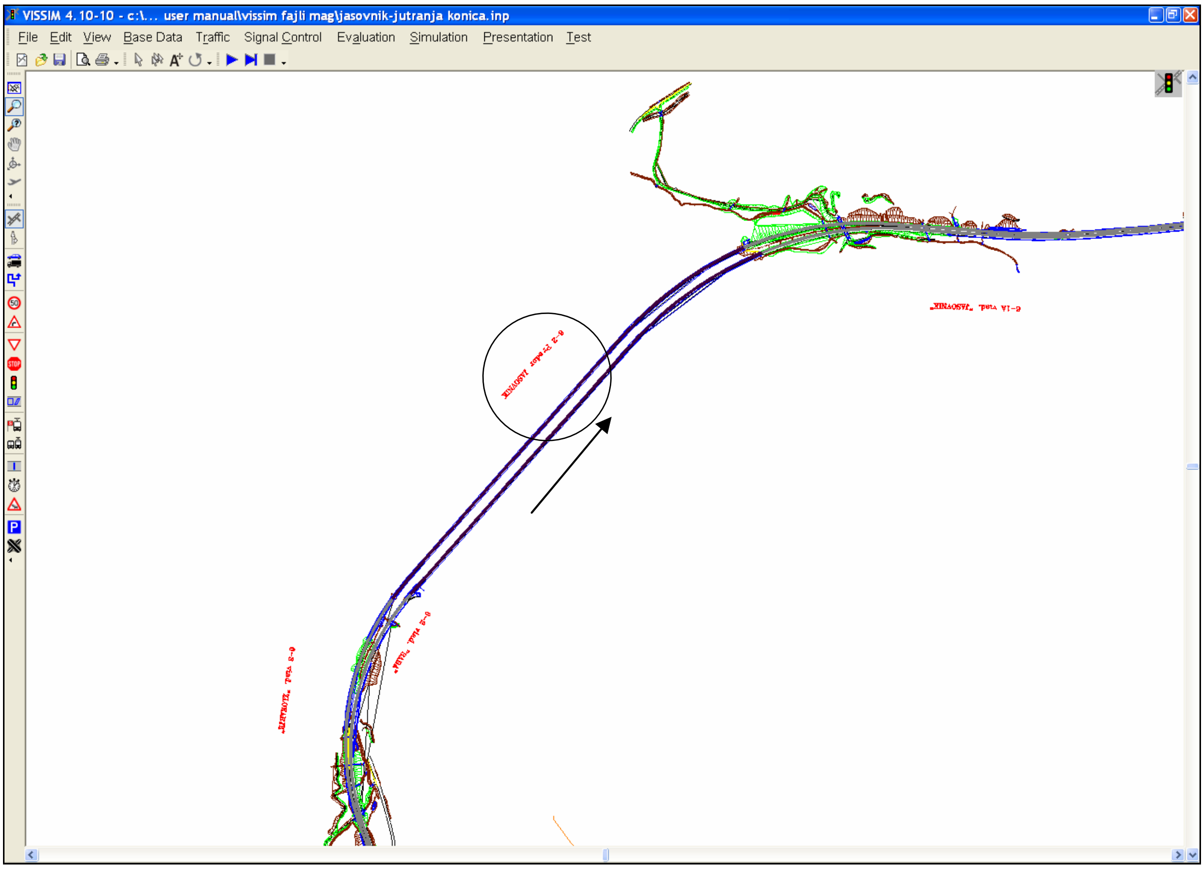


Fig. 4: Model of laying out in the Vissim code

Fig. 3 shows vehicles R1 (cars), R2 (vans) and R3 (lorries). Labels R1, R2 and R3 are used by DARS to mark the type of vehicle. For every single vehicle that entered the tunnel all necessary parameters were gathered.

The model of actual velocities was based on the performed measurements of velocities on the chosen date, gathered from the supervisory toll station Vransko. From the curve of actual velocities a mathematical model of velocities was formed. Thus, we tried to come close to the real habits of drivers in this area.

Input data:

- project – technical (among others a digital shot of the laying out, upon which the mathematical model was based),
- traffic – technical (among others actual speed limits and traffic signalisation for the individual section of the defined area),
- actual traffic loading and velocities, obtained by automatic counting of traffic.

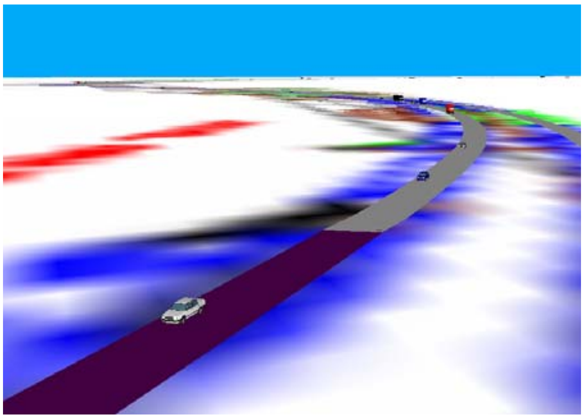
When the mathematical model was made, the calibration of the "real time" simulation followed on the basis of input data and presuppositions. Next, a comparison of model and decisive traffic loadings in individual sections of the network was made. This indicates the reliability of the entire model. With the help of links (parts of driving area) and connectors (links between parts of driving area) the entire laying out of the driving area was formed. The driving area was set as a background of the construction documentation. Fig. 4 shows the model of the laying out in the Vissim programme, when the laying out is already drawn, the grounding is added, and the entire data needed for the start of the simulation is entered. Several simulations of traffic blocks with various scenarios were made. Fires, spilt dangerous liquid, accidents, and traffic in the right tube of the tunnel were not included in our simulation models.

5 Analysis of results

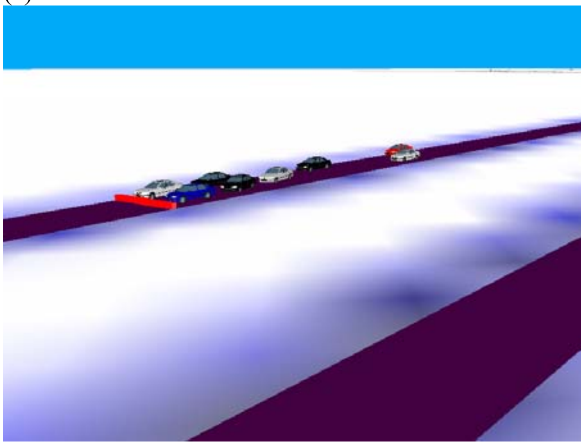
Fig. 5 (lighter colour marks the driving area outside the tunnel, darker colour the driving area inside the tunnel) shows a traffic queue formed after the traffic block in the Jasovnik tunnel (the circle marks a section of the Jasovnik tunnel, the arrow marks the direction of the traffic in the left tube towards Maribor). In the Jasovnik tunnel (left tube) as many as 197 vehicles became congested, which can be potentially dangerous and cause new accidents. In the case of a fire, a great material damage as well as casualties among the trapped drivers and co-drivers can be expected.

Fig. 6 a) and b) shows the driving of vehicles in the simulation and the place of stopping of vehicles in the tunnel after the traffic block (the driving area in the tunnel is marked with a darker colour than the driving lane outside the tunnel).

Fig. 5 Traffic block in the left tube of the Jasovnik tunnel



(a)



(b)

Fig. 6 (a) The driving of vehicles, (b) the place of stopping of vehicles in the tunnel – traffic block

With the performed simulation of the stopped traffic (due to accident) in the Jasovnik tunnel, we found out that six vehicles have been jammed in the tunnel. The other vehicles have been stooped in front of the tunnel, due to activation of red light after five seconds (assumption) of reaction time.

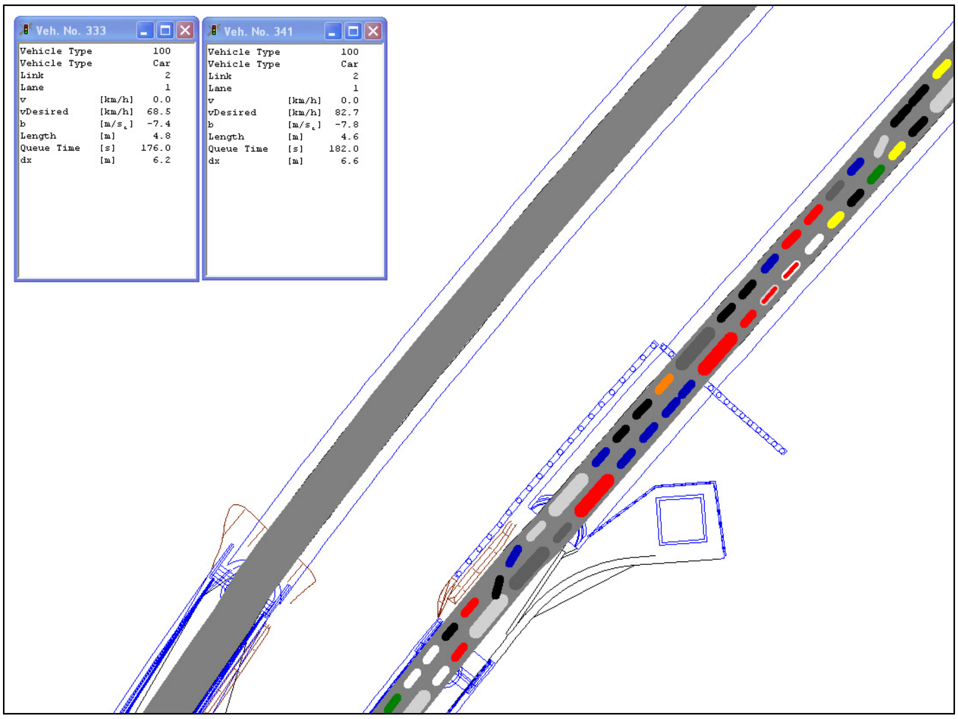


Fig. 7 Stopping at the left line of tunnel tube

Other vehicles have been stopped all the way to the entry of Jasovnik tunnel all over to the exit of Trojane tunnel. Moreover, after few second of simulation, the stops of vehicles in the tunnel Trojane can be perceived. This situation must be, in real circumstances, due to safety demands, prevents. Solutions could be, (i) activated red light in front of the Tronjane tunnel entry; (ii) diversion of the traffic flow to the old road to Maribor.

Fig. 7 shows the stopping at the left line of tunnel tube, where the column proceed backwards on the driving line. Also, the possibility of changing the parameters is also shown on this Fig. 7; for each type of vehicle we can defined the changing of direction.

On the basis of the performed simulations a comprehensive analysis was made for the afternoon peak traffic (Figs 8, a, b and c), which indicated that the speed limit 60 km/h is adequate and recommendable when the driving lane is closed to traffic (due to a hold-up vehicle) and the entire traffic flows on the overtaking lane in the Jasovnik tunnel. From the diagram on Fig. 8 follows that with the speed 80 km/h there is the minimum value of the average length of the queue and of the maximum length of the queue, but due to a higher speed the risk of accidents is also bigger.

Fig. 9 shows cumulatively captured vehicles in the tunnel in dependence on the traffic flow and time.

Fig. 10 shows the number of vehicles that have stopped after the traffic block, which is between 6 and 21 in the interval of 300 s. Stops are relatively high, therefore, at insufficiency of drivers attention, the accident with hard consequences can happened (also fire in the tunnel can occurs, which is one of the most dangerous scenario of the tunnel accident) Due to this reason, the traffic has to be forbidden through the tunnel till the consequences of the accident are set out.

The traffic block was formed in 900 s of simulation on 713 m of the tunnel (the length of the Jasovnik tunnel is 1612 m).

Figure 11 shows the average length of the traffic queue for the simulation 2.4 m, which is after the traffic block between 12 and 121 m in the interval of 300 s.

Figure 12 shows the number of vehicles that have stopped in the left tube of the Jasovnik tunnel, which can reach 209 in the present simulation. The vehicles then accumulate to the Trojane tunnel.

A comprehensive analysis of the performed simulations and results are detailed presented in work [10].

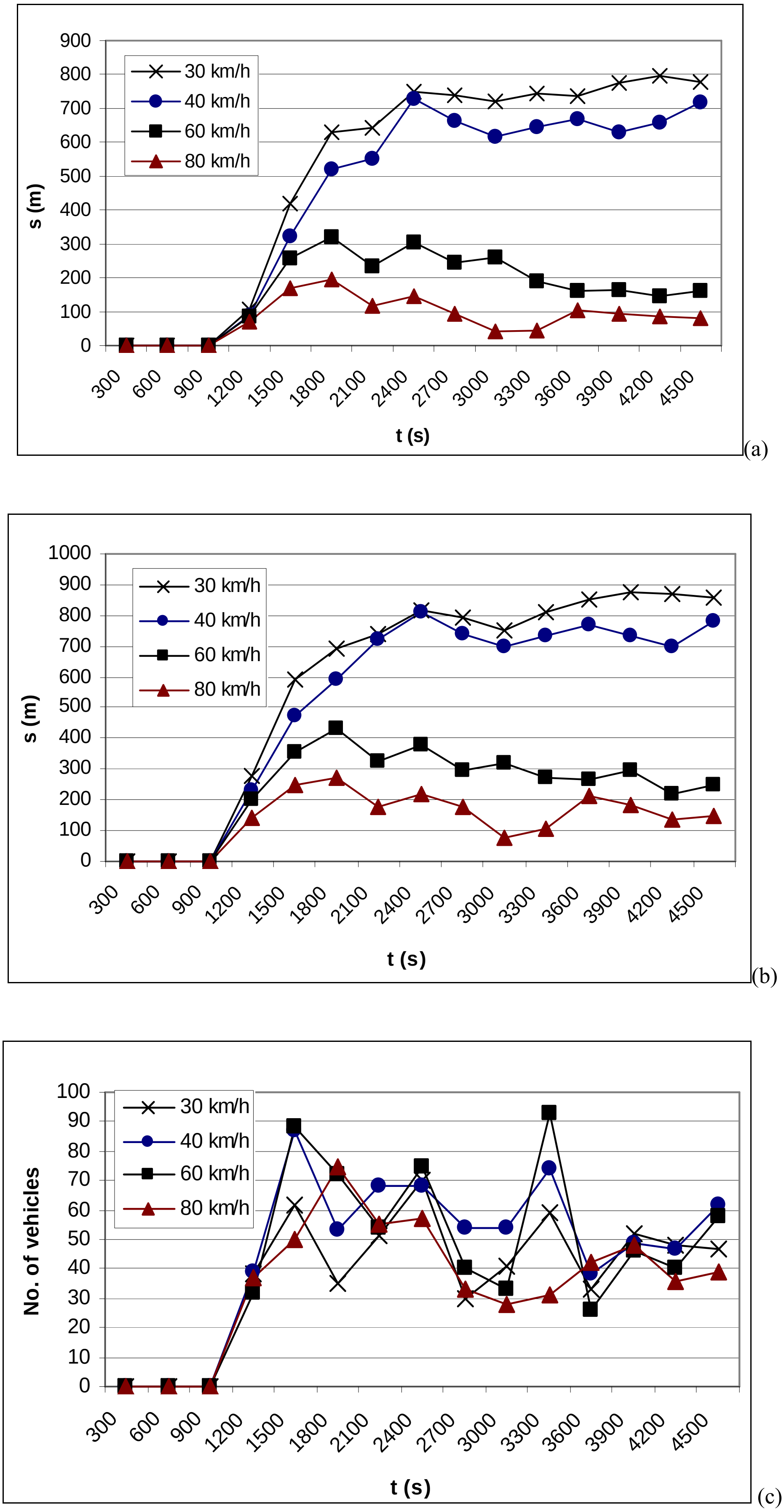


Fig. 8 The influence of the velocity on the: (a) average stopping line in the 300 s interval and (b) maximal stopping line in the 300 s interval; (c) number of vehicles stops in the 300 s interval

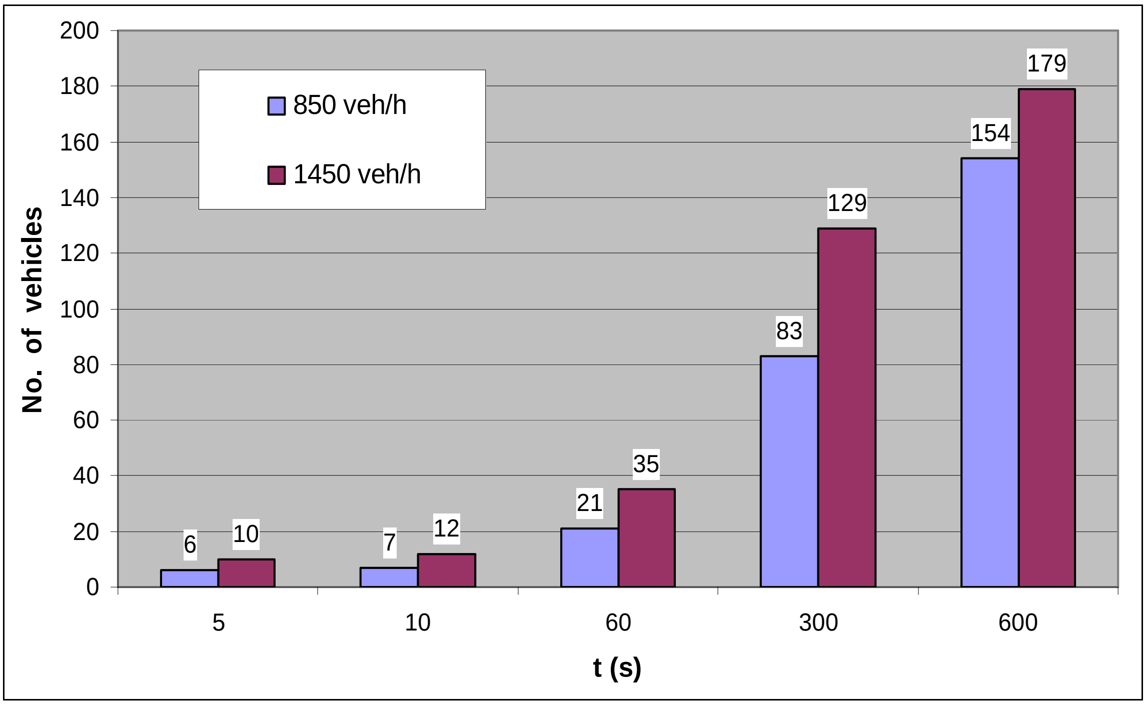


Fig. 9 Vehicles that are trapped in the tunnel in dependence on the traffic flow and time (traffic block, the driving and overtaking lanes are closed)

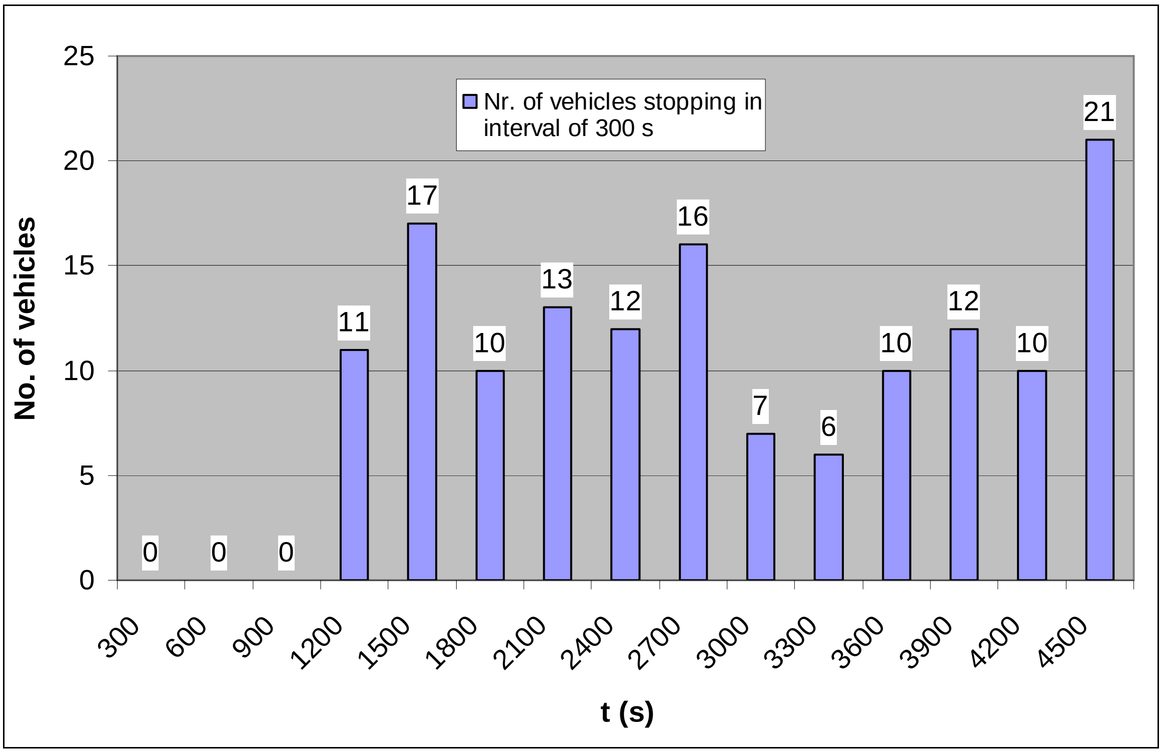


Fig. 10: The number of vehicles that have stopped in the interval of 300 s

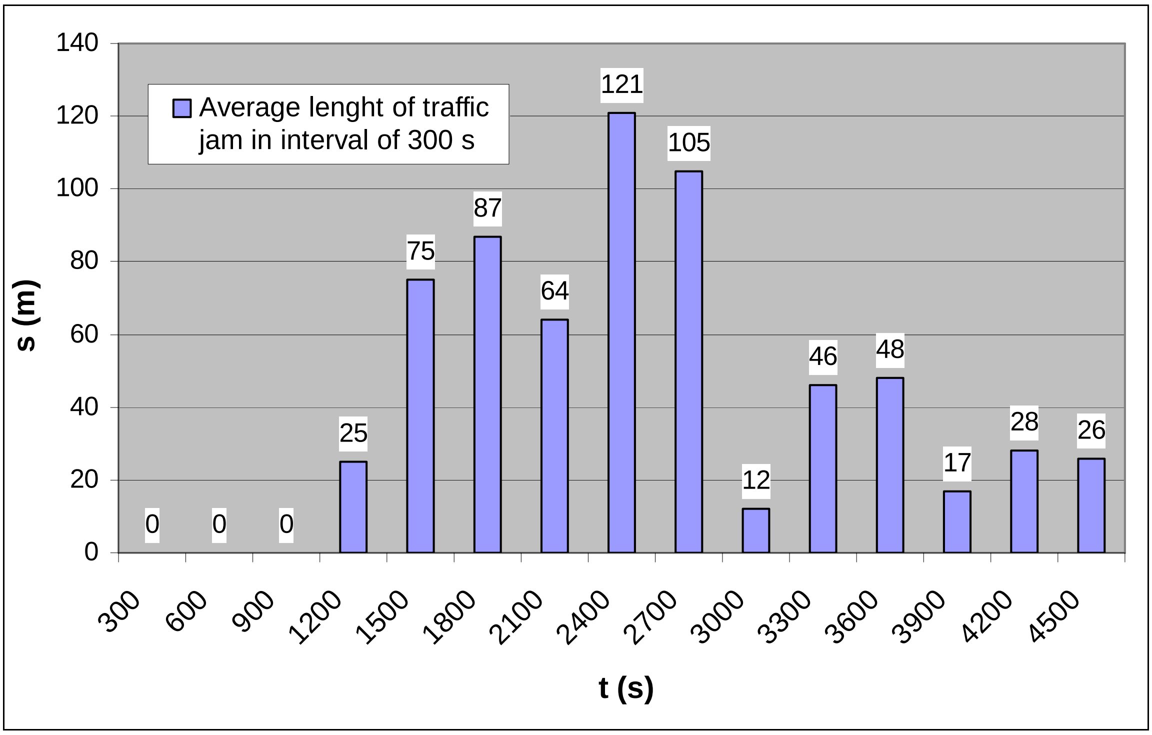


Figure 11: The average length of the queue in the interval of 300 s

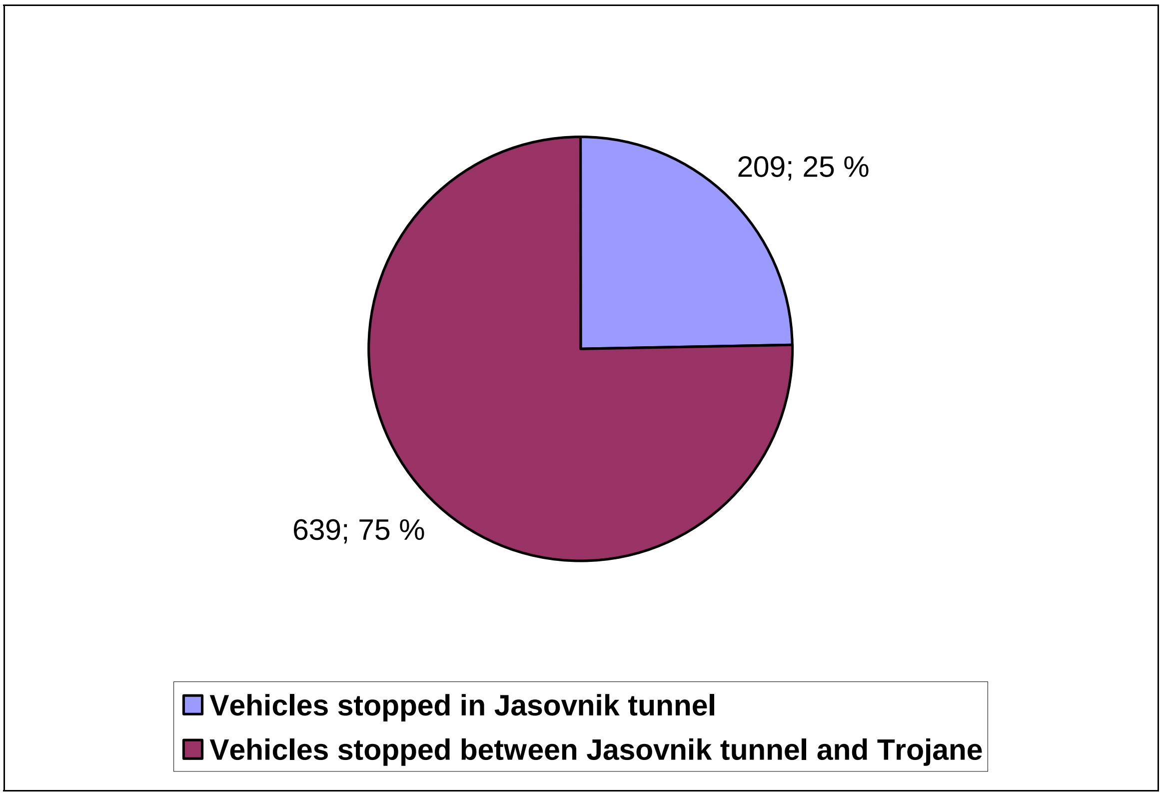


Figure 12: The number of vehicles that have stopped in the Jasovnik tunnel as well as between the Jasovnik and Trojane tunnels

6 Conclusion

With the computer-based simulation, traffic flows in the highway tunnel as well as possible traffic blocks were analysed. This was the basis for the suggestion of measures to raise the level of the existent traffic safety, considering professional directions and the latest achievements in the area of assuring traffic safety in highway tunnels.

The following are fundamental advantages of micro-simulations in traffic, which also present the possibility of a further development of this approach when researching principles of traffic flow in the roadway network:

- investigating features of the traffic without performing experiments in the nature;
- quickly completing the most demanding tasks;
- enabling the performance of tasks which cannot be fulfilled with the analytical approach ;
- the possibility of accepting more information;
- researching the probability of certain occurrences in the traffic flow;
- the possibility of repeating desired circumstances, which are possible and hypothetic;
- the possibility of researching the movement of traffic flows in the roadway network, which are not really possible;
- the possibility of testing alternative systems in the phase of projecting systems for identical demands of the future traffic.

The micro-simulation model, which was used for this paper, gives a good comparison with the real traffic flow dynamics. The commercial micro-simulation programme Vissim 4.10 enables a very exact calibration of the model as well as entering the necessary changes and gathering the necessary input data. When making the micro-simulation, data collecting is an extremely important phase which should be paid special attention.

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