USE OF MICROSCOPIC TRAFFIC FLOW SIMULATOR TO ASSESS SAFETY OF ROAD TUNNELS

BY ALEKSANDER KRÓL and MAŁGORZATA KRÓL

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Introduction
Road tunnels are fundamental elements of a road network. Incidents in road tunnels are rarer than at other sections of the transportation network because a tunnel itself calms traffic.\(^1\)\(^,\)\(^2\) On the other hand, if an accident happens, its consequences are more severe than in other places.\(^3\) The threatened are not only the persons directly involved in the accident, but all the people in the tunnel as well. This is because of the possibility of a fire outbreak, and even a not-fully developed fire fills a significant part of the tunnel with toxic and hot fire gases. The danger to human health and life in this zone expands fast, covering the successive parts of a tunnel in a few minutes. Therefore, it is extremely important for people in the tunnel to undertake self-evacuation in the initial phase of fire development. For this to happen, all tunnel safety systems must operate properly and support self-rescue of the people.\(^4\)\(^–\)\(^8\)

To best design the process of self-rescue of people from a road tunnel during a fire, appropriate fire scenarios should be prepared. In the case of fire scenarios for road tunnels, it seems crucial to determine the number of people staying in the tunnel when a fire breaks out. The number of people whose health and life could be threatened in a case of fire in a road tunnel depends on the number of vehicles trapped inside and the content and/or number of people in these vehicles. In turn, the number of trapped vehicles depends on traffic conditions, the traffic mode, the number of lanes, and the location of a road accident.

Determining the number of trapped vehicles is a complex task. To solve it, theoretical models or numerical simulations of road traffic must be applied and statistical data based on traffic measurements must be provided. This article proposes to use the commercial VISSIM program to determine the number of vehicles remaining in the tunnel during the fire. This determines the number of threatened people.
Modeling Traffic and Congestion Formation

Today, many commercial (VISSIM) and non-commercial (TRANSIMS, SUMO) software packages offer sufficiently reliable model road traffic in different spatial scales.\cite{9-11} In the simulation approach, the idea of cellular automata is commonly applied.

Eventually, the VISSIM software was selected to simulate the process of congestion formation as a result of a road accident. VISSIM is a microscopic traffic flow simulator developed by Planung Transport Verkehr (Germany). The term “microscopic” means that every real entity (a vehicle, a pedestrian, a traffic light, a road lane) involved in the traffic is simulated individually.

VISSIM implements the principle “car following” introduced by Wiedemann.\cite{12} This is a psychophysical model of driver behavior: The driver slows down when approaching the preceding vehicle and accelerates when this vehicle moves away. The key issue is that perceiving the distance between cars is subjective, and the driver’s reaction is often excessive and a bit delayed, which leads to alternate braking and acceleration. VISSIM builds a detailed model of a transportation network with accurately adjusted traffic parameters. Parameters like traffic intensity or the generic structure of the traffic are set as average values, but the software generates traffic flows randomly. The seed of the pseudorandom numbers generator is adjustable, so particular simulations can be repeated.

Traffic conditions depend on the traffic intensity expressed by the number of vehicles passing per one lane and hour. The fundamental relation binds the basic quantities describing the road traffic:

\[ Q = K \nu \]

where

- \( Q \) - average traffic intensity [veh/h]
- \( K \) - average traffic density [veh/km]
- \( \nu \) - average traffic velocity [km/h]

Despite apparent simplicity, this relationship is complex due to non-linear dependence of traffic velocity on traffic density (Figure 1).
Traffic conditions can vary from free flow, where each driver chooses his speed at his own proximity to the congestion state, where vehicle density takes the maximum value, and the average velocity becomes close to zero (traffic breakdown). In road traffic engineering, traffic conditions can be qualitatively described by six levels of service (LOS)\textsuperscript{[13]} coded from A (completely free flow) to F (congestion state), as shown in Figure 1.

For purposes of such research, two opposite states was selected: a) an almost free traffic flow of LOS B (1,000 veh/h/lane) and b) a state close to a congestion of LOS F (2800 veh/h/lane). Such choice is somewhat arbitrary; however, it covers two quite different but likely states of road traffic. The values of traffic intensity were adopted to meet the definitions of relevant degrees of LOS. The congestion state was additionally restricted by introducing a zone of lowered speed (10 km/h) at some distance behind the exit portal. The generic structure of vehicles was adopted according to the averaged data from General Traffic Measurement 2015 as shown in Table 1.

Table 1. Generic Structure of Vehicles\textsuperscript{[29]}

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Share [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger Cars</td>
<td>84</td>
</tr>
<tr>
<td>HGVs</td>
<td>15</td>
</tr>
<tr>
<td>Buses</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 2 shows examples of simulated congestion that formed in the tunnel. For different traffic conditions (LOS B or LOS F), different accident locations (in the middle or near one of the tunnel portals), and different traffic modes (uni- or bi-directional), six runs of VISSIM are carried out at a state of 15 seconds after the alarm triggering and the tunnel entrance closing. It corresponds to a situation in which all tunnel users should be aware of what has happened and are deciding on their actions. As can be seen, the stochastic nature of the traffic and the congestion formation resulted in significant differences in the number of
trapped vehicles and people.

Figure 2. Examples of Formed Congestion

Applying Traffic Modeling Results
The results obtained from the VISSIM program were used to model evacuation from the road tunnel. To this end, an evacuation model should be built for each case that is the result of VISSIM calculations. It is still necessary to propose vehicle manning. Vehicle manning can be generated randomly to gain accordance with the measurements of real fillings. The adopted average values are shown in Table 2. This table also shows the lengths of modeled vehicles. All vehicles were the same width of 2 m (6.56 ft). The vehicles can be modeled as spaces delimited by walls and equipped with doors. The inner space of a vehicle was divided by bulkheads to prevent evacuees from shortening their way by crossing a vehicle. Examples of vehicle models made in PATHFINDER are shown in Figure 3.

Table 2. Average Vehicle Manning

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Average Manning</th>
<th>Length [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger Cars</td>
<td>1.4</td>
<td>4.5</td>
</tr>
<tr>
<td>HGVs</td>
<td>1.3</td>
<td>11.0</td>
</tr>
<tr>
<td>Buses</td>
<td>50.0</td>
<td>13.0</td>
</tr>
</tbody>
</table>
The number of vehicles trapped in the tunnel can be used in any evacuation modeling program. The parameters of evacuees’ behavior are adopted in accordance to literature review, but the available data differ significantly depending on reported research. Delay time before evacuation start and movement speed are random variables of normal distribution. Mean values and standard deviations are adopted to cover most of the literature data and to account for diversity of physical fitness.

**Conclusion**

The safety study on using road tunnels requires preparing fire scenarios for each facility. Efforts are being made to ensure that fire scenarios reproduce tunnel conditions as accurately as possible during evacuation. However, many factors that influence the course of this evacuation must be assumed at the beginning of creating such a scenario. One of them is the number of cars involved in a road accident or trapped in a tunnel during a fire. This number directly affects the assumed number of people who will evacuate from the tunnel. Therefore, determining the number of cars is important to make the fire scenarios created to assess the safety of road tunnels real. The use of traffic modeling to obtain this information may be a solution.

**References**


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ALEKSANDER KRÓŁ and MAŁGORZATA KRÓŁ are with Silesian University of Technology, Poland.