Application of Microscopic Simulation of Traffic Flows in Developing Evacuation Plans for Inhabitants

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Abstract: The paper presents the possibilities of implementing micro-simulation traffic tools in order to develop the evacuation plans. Well elaborated evacuation plans are the basis for alleviating the consequences resulting from emergencies. The simulation tools allow the design and verification of various evacuation planning scenarios with minimisation of costs and time. The paper provides detailed presentation of the basic characteristics of microscopic simulation of traffic flows, as well as examples of their implementation worldwide. The characteristics of the software tools are described through an overview of the basic settings of PTV VISSIM (Planung Transport Verkehr in Städten—Simulations model) program as one of the most significant representatives of these tools. The necessity of implementing the traffic tools in evacuation results from the crucial role of traffic in reducing the consequences of emergencies. These tools allow also a detailed analysis of the output data in order to select a suitable solution. The concluding part of the paper presents an example of evacuation of the population through the Jankomir node as part of the European project “preparedness for evacuation in case of a nuclear accident”. The evacuation was performed through three scenarios in circumstances of higher or lower transport demand.

Key words: Evacuation plans, micro-simulation traffic models, nuclear accident, PTV VISSIM.

1. Introduction

Emergencies in the world, which include: terrorist attacks, earthquakes, hurricanes, radiological accidents, leakage of toxic materials, etc., are increasing phenomena [1]. One of the consequences of such situations is the occurrence of massive evacuation of people, and since these often include serious injuries and even loss of lives, the cities need to have well developed evacuation plans in order to reduce these consequences to a minimum. The hurricanes Katrina and Rita in the USA in 2005 showed the importance of detailed elaboration of the evacuation plans, regarding the complete blockage of the roads and high losses of lives and assets due to poor organization of evacuation. Similarly, the nuclear accident in Fukushima showed that the planned zone of evacuation covering a radius of 10 km was insufficient. The transport, as the most important part of the process of evacuating the inhabitants to safe places, includes relocation of a large number of people across a wide area coverage within a limited period of time. The efficiency of evacuation does not depend only on the competence of the infrastructural facilities along the evacuation routes, but rather also to a great extent on the evacuation strategies management. Therefore, the increasing occurrences of disastrous events have stimulated increased usage of traffic simulation programs for modelling the traffic flows in emergencies [2]. The simulation models allow testing of various assumptions and variations of situations incurring minimal costs and risks. Such approach, based on simulations, represents a good way to jointly process the data such as: traffic network, traffic flow management, transport demand and supply, and restrictions in the decision-making process.

This paper presents the use of micro-simulation tools PTV VISSIM (Planung Transport Verkehr in Städten—Simulations model) in case of evacuation of the inhabitants through the Jankomir node in case of
nuclear accident at the nuclear power plant Krško.

2. Basic Assumptions of Microscopic Simulation of Traffic Flows

2.1 Microscopic Simulation of Traffic Flows

Simulation models are usually classified according to the level of detail in presenting the traffic flow thus defining [3]:

- microscopic models;
- mesoscopic models;
- macroscopic models.

In this paper, the microscopic simulation will be used, which is dynamic (variable in the analyzed time period) and stochastic (random variations) modelling of movement of individual vehicles in different systems of transport networks [4]. Each vehicle moves through the transport network in a given time period depending on the technical characteristics of the vehicle (length, maximal acceleration, etc.), basic laws of motion and rules of driver’s behavior (rules of car following, rules of lane-changing, etc.) [4]. Simulation of vehicle movement is realized in series of pre-determined time sections. At the end of each time section the following is recorded: position, speed and acceleration/deceleration of vehicle. The number of time sections per second affects the precision and duration of the simulation of micro-simulation model.

When generating a vehicle in traffic network each vehicle is randomly assigned the type of vehicle and type of driver (according to degree of aggression and concentration) based on the pre-determined structure of the traffic flow and shares of individual motorist types. The type of vehicle is determined on the basis of its dimension, maximum speed, acceleration and deceleration.

The most common micro-simulation tools used today are: PTV VISSIM, AIMSUM (Advanced Interactive Microscopic Simulator for Urban and Non-Urban Networks), CORSIM (Corridor Simulation), ParaMicS (Parallel Microscopic Simulation), SimTraffic (Simulation Traffic), TransModeler, WATSim (Wide Area Traffic Simulation), etc. [4].

After having developed the model and after having checked the possible errors the calibration procedure needs to be performed. Without model calibration, the model developer cannot be sure of the quality of the output data of the existing condition nor of the forecast of the future traffic flows on the network [5]. According to Dowling et al. [3], calibration is the adjustment of model parameters in order to improve the capability of the model to reproduce the local behaviour of the drivers and characteristics of the traffic flow. The importance of calibration results from Ref. [6] where six different software tools have shown that the deviation of the calculation of the existing highway section capacity between the simulation model and HCM (highway capacity manual) method of 4% can be increased to 69% in the forecast periods. One of the drawbacks and restrictions of the simulation models is that with their parameters about driver behaviour they cannot realistically describe the driver behaviour in cases of evacuation [7].

The output results of micro-simulation are animations and numerical data. The 2D or 3D animations show the movement of individual vehicles through the traffic network in the simulation time. Numerical data can be detailed for each vehicle or averaged for the entire traffic network or a part of it: travelling time, number of vehicles, travelling speed, 95% queue length, level of service, delay time, etc.

One of the most important advantages of applying micro-simulation tools is fast testing of several alternative solutions and based on the obtained output results the selection of the optimal one.

2.2 In General about the Software Tools PTV VISSIM

The name of the software tools PTV VISSIM is a German acronym for: Traffic in the cities—simulation model (Verkehr in Städten—Simulations model) [8]. This is a stochastic microscopic simulation tool which
has the capability of analyzing public urban transport, passenger vehicle transport, bicycle and pedestrian traffic. It was developed in Germany by the Company PTV AG, and it found its wide application in Europe, Asia and the United States of America. Today over 1,000 organizations worldwide use this software tools: 600 organizations in Europe, 250 in North America, and 150 in Asia, South America and Africa [9].

In relation to less complex models that use constant values of speed and determined logic of car following, VISSIM uses the psychophysical model of driver behaviour developed by Wiedemann in 1974. The model was calibrated on several research polygons at the Technical University in Karlsruhe, Germany [10]. The basic idea of the Wiedemann’s model is the assumption that the driver can be in four driving modes [10]:
- Free driving—no influence of the vehicle in front, and the vehicle moves at a desired speed with minor oscillations;
- Approaching—process in which the drivers adjust their speed to the speed of the slower vehicle in front. While approaching the drivers decelerate so when they reach the desired safe distance, the difference of speed between the vehicles equals zero;
- Following—the driver follows the vehicle in front without accelerating and decelerating, maintaining the safe distance;
- Breaking—process of applying deceleration according to the function of distribution of deceleration in case the safe distance between the vehicles is reduced. It occurs in situations when the vehicle in front suddenly decelerates or a third vehicle by changing lane comes in between the two observed vehicles.

Defining the driver’s behavior (car following and lane-changing) in VISSIM is defined by a large number of parameters and their change and adjustment to local situations is very demanding and requires experience and research in the field. The driver behavior is related to the link (road), i.e., type of link (urban area, highway, pedestrian and cycling paths) and for each class of vehicle the driver behavior can be defined.

For the mentioned driving modes, acceleration is defined as the result of speed, difference of speeds between the following vehicles, distance between the vehicles and individual characteristics of the driver. The driver shifts from one mode to another as soon as the pre-defined threshold is reached, consisting of the combination of the difference of vehicle speeds and distance. Possibility of perception of the difference in speeds and estimate of the distance between the vehicles varies among the driver population, as well as the desired speed and safe distance. It is precisely because of this combination of psychological and physiological restrictions of the driver perception that this model is called the psychophysical car following model.

Wiedemann 74 model is mostly used in describing the driver behavior in urban conditions, and according to [10], it is calculated in the following way:

\[ d = ax + bx \]  
(1)

\[ bx = (bx_{add} + bx_{mult} \cdot z) \cdot \sqrt{v} \]  
(2)

where:
- \(d\) — distance between two vehicles;
- \(ax\) — distance between stationary vehicles;
- \(bx_{add}, bx_{mult}\) — calibration parameters that define the variation of the desired safe distance;
- \(z\) — driver safety parameter in the value of (0, 1), which is normally distributed around 0.5 with standard deviation of 0.15;
- \(v\) — vehicle speed (m/s).

Apart from car following in VISSIM also the rules of vehicle changing lanes laterally are defined. Thus, there are two types of changing lanes:
- Mandatory lane-changing—for instance in order to capture the connector of the travelling route;
- Discretionary lane-changing—for instance as result of overtaking and acceleration.

3. Application of Micro-simulation Tools in the Presentation of the Evacuation Situations

The necessary condition for the development of
evacuation simulations of larger areas and cities is to have the data about the number of population and vehicles in individual evacuation zones. The cities should have evacuation zones with regularly updated data on the number of inhabitants and developed evacuation plans of certain zones depending on the types of danger.

According to Fengxiang et al. [11], a model in PTV VISSIM of the simulation of population evacuation in case of accident at the nuclear power plant Sequoyah in the valley of Tennessee in the USA was developed. Several scenarios have been developed (traffic management control by the police, change of direction of traffic lanes) in order to select the optimal scenario. The results have shown that the pre-defined operative strategies in case of crisis increase the number of evacuated inhabitants. Also, greater efficiency of evacuation has been shown by the application of dynamic assignment of trips in VISSIM, than according to the existing urban evacuation plans.

According to Fengxiang et al. [11], McGhee and Grimes made in 2007 a simulation of evacuation of the inhabitants of the city of Hampton in case of the occurrence of hurricane of different levels of intensity. VISSIM is used for the evaluation of traffic management at entry and exit ramps of the highways, redirected traffic lanes, etc. The results of studies have shown that in case of high traffic loads only the traffic management at entry/exit road ramps can ensure the evacuation of vehicles at acceptable speeds.

At the end of 2012, a detailed plan of evacuation of the city of Plymouth was developed (93,000 inhabitants) in the USA in the zone of the nuclear power plant Pilgrim [12]. By applying the simulation model an expected evacuation encompassed 90% of inhabitants of the zone of up to 9 km from the nuclear power plant in the duration of two to three and a half hours depending on the weather conditions and time of day.

4. Micro-simulation Model of Evacuation through Jankomir Node

As part of the project funded by the European Union: “Preparedness for evacuation in case of a nuclear accident” with participation of the district of Krško, city of Zagreb and city of Cernavoda in Rumania in one of the measures it was necessary to present the simulation of evacuating the inhabitants from the district of Krško. The Jankomir node at the entrance into the city of Zagreb was selected as the demonstration example.

The Jankomir node was built in 1979 as a grade-separated intersection in the form of a “clover” without one indirect ramp. It is located at the western entry into the city of Zagreb at the intersection of the highways A2 (Zagreb-Macelj) and A3 (Bregana-Lipovac), i.e., the European roads E59 (Prague-Vienna-Maribor-Zagreb) and E70 (A Coruna-Bordeaux-Lyon-Turin-Verona-Trieste-Ljubljana-Zagreb-Belgrade-Timisoara-Bucharest-Varna). This node is also part of the Pan-European corridor X (Salzburg-Ljubljana-Zagreb-Belgrade-Niš-Skopje-Velies-Thessaloniki) and its branch Xa (Graz-Maribor-Zagreb).

The micro-simulation presentation of the Jankomir node has been made by means of the software tools PTV VISSIM 5.40-08. in three different scenarios of traffic flow regulation. Since the software tools cannot simulate the driver behavior in cases of panic the aggressiveness of the drivers was increased by using the Wiedemann 74 model in order to present as realistically as possible the evacuation situation. Because of the limitation of the licence in the permitted length of links of 10 km, it was not possible to determine the precise lengths of queues since according to results they exceeded the distance of 10 km. Similarly, the simulation did not take into consideration the influence of the node of Lučko which, because of its closeness can substantially affect the increase in the evacuation time at the Jankomir node. Further, in the paper, it is certainly recommended to
develop a simulation of both nodes. The number of evacuated vehicles has been determined in the simulation under the constant peak traffic load which exceeds the node capacity in order to be able to analyze the vehicle flow and driver behavior during lane-changing and weaving into flows.

The analysis of the traffic flows in case of population evacuation because of a nuclear accident at Krško has been presented through three scenarios with the assumed higher or lower transportation demand and vehicle occupancy of 2.5 persons. The data about the transportation demand, i.e., the number of evacuated inhabitants were obtained from the district of Krško. For each scenario, the time of evacuation through the Jankomir node has been analyzed, as well as the number of evacuated vehicles in half-hour intervals. Also the travelling times through the node and the average delay time have been determined. The average travelling times and delays have been calculated from the entry of vehicle into the node until leaving the node, i.e., the measuring segments match the lines in Figs. 1 and 2 (first, second and third lines). In the third scenario in Fig. 3 in case of the fourth flow, the times have been calculated up to the vehicle leaving the network.

4.1 Scenario 1—Permitted Directions: West-South and North-South

In the first scenario of traffic regulation, the vehicles from the direction of Bregana and from the direction of Maribor would be let pass through four traffic lanes for each driving direction, i.e., a part of the vehicles would be redirected to lanes that are otherwise planned for the opposing driving direction. In Fig. 3, second line/flow denotes the flows which use lanes that are in normal conditions used for the driving west-south and north-south, and first line/flow denotes flows using lanes of the opposing direction.

According to the obtained simulation results in case of applying this regulation the total number of vehicles would be evacuated through the Jankomir node in the time period between 2 and 2.5 hours. Table 1 shows the assumed number of evacuated inhabitants in the scenarios of higher and lower demand.

4.2 Scenario 2—Permitted Directions: West-South, North-South and West-North

In the second scenario presented in Fig. 2 evacuation would be provided in the direction west-north (third line/flow) over indirect ramp, but the direction north-south would use only two traffic lanes. Table 2
Table 1  Presentation of the assumed transportation demand in the first regulation scenario.

<table>
<thead>
<tr>
<th>Total number of inhabitants at the distance of 25 km from NE Krško</th>
<th>240,000 inhabitants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of inhabitants evacuated through the Jankomir node</td>
<td>Higher demand (90,000)</td>
</tr>
<tr>
<td>By passenger car</td>
<td>60,000</td>
</tr>
<tr>
<td>By bus</td>
<td>30,000</td>
</tr>
<tr>
<td>Total number of vehicle units</td>
<td>Number of passenger vehicles</td>
</tr>
<tr>
<td>Number of passenger vehicles</td>
<td>24,000</td>
</tr>
<tr>
<td>Number of buses</td>
<td>600</td>
</tr>
</tbody>
</table>
Table 2  Presentation of the assumed transportation demand in the second regulation scenario.

<table>
<thead>
<tr>
<th>Total number of inhabitants at the distance of 25 km from NE Krško</th>
<th>240,000 inhabitants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of inhabitants evacuated through the Jankomir node</td>
<td></td>
</tr>
<tr>
<td>Higher demand (90,000)</td>
<td>Lower demand (45,000)</td>
</tr>
<tr>
<td>By passenger car</td>
<td>By passenger car</td>
</tr>
<tr>
<td>60,000</td>
<td>30,000</td>
</tr>
<tr>
<td>By bus</td>
<td>By bus</td>
</tr>
<tr>
<td>30,000</td>
<td>15,000</td>
</tr>
<tr>
<td>Number of passenger cars</td>
<td>24,000</td>
</tr>
<tr>
<td>(5,265 direction west-north)</td>
<td>12,000</td>
</tr>
<tr>
<td>Number of buses</td>
<td>600 (135 in direction west-north)</td>
</tr>
</tbody>
</table>

Table 3  Presentation of the assumed transportation demand in the third regulation scenario.

| Total number of inhabitants at a distance of 25 km from NE Krško + number of inhabitants from Zagreb | 240,000 inhabitants + 100,000 inhabitants of the City of Zagreb who gravitate to the Jankomir node |
|-----------------------------------------------------------------------------------------------------------------|
| Number of inhabitants evacuated through the Jankomir node |
| High demand (90,000 + 35,000 from Zagreb)                                                                     | Low demand (45,000 + 17,000 from Zagreb) |
| By passenger car                                              | By passenger car |
| 95,000                                                        | 47,000           |
| By bus                                                        | By bus           |
| 30,000                                                        | 15,000           |
| Number of passenger cars                                      | 38,000           |
| Number of buses                                                | 600              |
| Number of passenger cars                                      | 18,800           |
| Number of buses                                                | 300              |

Table 4  Summed presentation of parameters according to different evacuation scenarios.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High demand</td>
<td>Lower demand</td>
<td>High demand</td>
</tr>
<tr>
<td>Average time of delay (s)</td>
<td>434.5</td>
<td>170.16</td>
<td>344.5</td>
</tr>
<tr>
<td>Level of service</td>
<td>F</td>
<td>F</td>
<td>F</td>
</tr>
<tr>
<td>Average travelling speed (km/h)</td>
<td>23.47</td>
<td>43.36</td>
<td>29.88</td>
</tr>
<tr>
<td>Average travelling time (s)</td>
<td>574.075</td>
<td>255.62</td>
<td>583</td>
</tr>
</tbody>
</table>

shows the estimated transportation demand in the direction west-north. According to data obtained by simulation the time of evacuation, by adding a new flow of evacuation, would be kept within the interval of 2 h and 2.5 h under the conditions of high demand.

4.3 Scenario 3—Permitted Directions: West-South, North-South, West-North and East-South

In the third scenario, evacuation would be made possible also to the inhabitants of the Zagreb districts which gravitate to the Jankomir node: Jankomir, Prečko, Špansko and Malešnica. In Fig. 3, these flows have been presented by fourth line/flow. The evacuation of 35,000 inhabitants has been assumed, i.e., 17,000 in case of lower demand (Table 3).

In case of permitting evacuation also to a part of inhabitants from the city of Zagreb through the Jankomir node the time of evacuation would be prolonged to a period between 3 h and 3.5 h.

Table 4 shows a summary view of the results of micro-simulation evacuation of inhabitants through the Jankomir node. According to the presented results the highest efficiency in evacuation would be achieved by applying the second scenario. If a part of inhabitants from Zagreb were included in the evacuation flows through the node of Jankomir, this would result in a significant increase in the time of evacuation. Therefore, it is necessary to elaborate in detail the evacuation plans of the city of Zagreb.

5. Conclusions

The paper presents on one simple example the advantages of applying the micro-simulation tools in
the analysis of evacuation of inhabitants. The development of evacuation plans is one of very significant measures of alleviating the consequences of emergencies. The traffic system as one of the major factors of successful evacuation is a very complex system, dependent on a number of parameters. In limited financial and time conditions, modelling and simulating is the only method of presenting these complex relationships. Therefore, the recommendation to the cities is to make evacuation plans and to test them by means of micro-simulation software tools.

In further work an attempt should be made to define the parameters of driver behavior in the conditions of emergencies, and to test the changes in evacuation times due to incident situations on the roads (collisions, lane blocking, and passage of emergency vehicles).

In this paper, only one node has been analyzed which was used to show the time of evacuation under the conditions of constant influx of vehicles. In further work, the adjacent nodes should be combined and their mutual influence on the traffic flows should be considered.

References