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# Cellular automaton traffic flow model with vehicle type and number of persons

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## ABSTRACT

The paper deals with microscopic modeling of the traffic flow using cellular automaton in the Tunnel Simulator based on PLC. Model with lane changing logic is implemented in the SCADA visualization screen of the tunnel with unidirectional two-lane traffic. Tunnel Simulator is able to simulate unexpected events in the road tunnel such as fire, so vehicle type is also included in the traffic model to specify the heat release rate of the fire for car, van, bus and truck fire scenario. Number of persons in the vehicles and location of the persons in the tunnel are planned to be used as the input for the model for evacuation time estimation.

**Keywords: PLC, tunnel, simulation, microscopic traffic flow model, cellular automaton**

## 1. Introduction

Road tunnels are important part of traffic infrastructure since they shorten the paths in mountainous regions and in towns. Shorter travel times and traffic below the surface lead to economic and ecological effectiveness. Occurrence of traffic accidents in the tunnel is less common, but consequences can be more serious. Heterogeneous technological equipment is necessary to provide the required level of safety in the tunnel. Simulation experiments concerning optimization of technological equipment and control algorithms cannot be realized during 24/7 operation in real tunnel, therefore Tunnel Simulator (TuSim) has been developed.

### 1.1. Tunnel simulator

TuSim is complex SW/HW system based on BR Automation industrial PC (PLC) with UPS unit. Fig. 1 shows TuSim hardware from the top to the bottom: Masterview LCD switch, visualization server, UPS unit on the bottom left part of the figure and industrial PC on bottom right part of the figure.

**Fig. 1. TuSim hardware [own study]**

All important devices of the tunnel technological subsystem equipment are simulated by the software inside the PLC [1]. Equipment of three tunnels is implemented: City tunnel, Motorway tunnel with two tubes and Motorway tunnel with one tube.

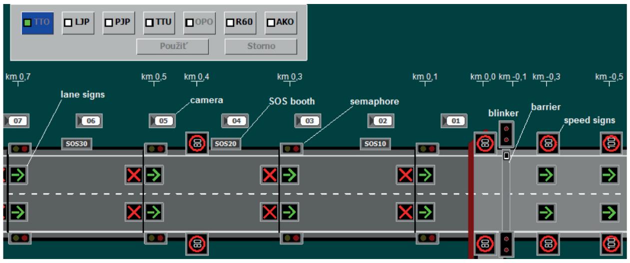


Fig. 2. Part of the traffic screen [1]

TuSim supports in addition to the simulation of the technological equipment also the control of the traffic sequences. Fig. 2 shows the part of the visualization traffic screen with the status of the traffic sequence together with implemented devices of traffic control equipment. Each tunnel tube can operate in following traffic sequences: tunnel tube open (TTO), left lane closed (LJP), right lane closed (PJP), speed limit 60 km/h (R60), adaptation lighting failure (AKO), tunnel tube closed (TTU). Switching from one sequence to another follows the time requirements which allow all vehicles to adapt to the new conditions. TuSim supports several simulated responses of the control system to unexpected events in the tunnel like: complete or partial power failure, fire, traffic alarm or pre-alarm, lighting malfunction, SOS button activation, physical measurements alarm or pre-alarm [1]. No models important for unexpected events analysis have been implemented to initial version of the software. Whole source code concept from the PLC software to the visualization screens is open for enhancements so models e.g. traffic model can be easily implemented. There are many graphical screens to visualize the state of each subsystem of the technological equipment – at least one for each subsystem. Handling of the screens and separate connections to the simulator is realized by visualization server and two client PCs with HMI/SCADA CIMPLICITY software which uses client/server architecture. Server is responsible for collection and distribution of the data from the PLC; clients allow interacting with the data distributed by the server and perform control actions.

# 2. Traffic models

Traffic model should be implemented as one of the first models because its outputs are used as inputs for other models. Vehicle type is important for the fire scenario simulation; number of persons and their location are important for evacuation time estimation. Traffic models can be divided into three main categories: microscopic, mesoscopic and macroscopic. Macroscopic modeling looks at the traffic flow from a global perspective and assumes traffic flow as homogenous. It represents how one parameter of traffic flow changes with respect to another. Intensity (veh/h) is equal to the multiplication of the density (veh/km) and speed (km/h). Microscopic modeling describes the behavior of the drivers in individual vehicles, motion and interaction between these vehicles: car following, lane changing, gap acceptance, willingness to pass the other vehicles. The more the complexity of the model the higher computation costs. Mesoscopic modeling describes the movement of the group of the vehicles and represents the compromise between more accurate microscopic models and computational more effective macroscopic models. Our implementation requires the positions of the vehicles in the tunnel, so microscopic model is preferred. AIMSUN, VISSIM and other commercial software tools are available for microscopic traffic simulation, but we want to use non-commercial, easy modifiable software interconnected with the TuSim. Cellular Automaton traffic model has been selected for the implementation because is well-known, simple and therefore easy-to-implement into the computer systems. A lot of modifications are present to adapt the model for real traffic conditions. On the other hand the speed and space are in the model divided into the discrete steps.

## 2.1. CA traffic model

Microsimulation model based on Cellular Automaton (CA) divides the space to the discrete elements called cells. Cell can be occupied by the vehicle or free. Its size is usually selected from interval 5 - 8 m and considers vehicle length with some extra space. The speed is also expressed in discrete steps (usually maximum 5 steps) and varies as can be seen in Table 1. Speed limit before the motorway tunnel in the TuSim is 130 km/h and speed limit inside the tunnel is 80 km/h, which is more important parameter for the simulation of unexpected events. The cell size 7.5 m fits best the expected continuous speed inside the tunnel, so it has been selected for the implementation. Values in TP02/2011 [8] specify a little bit shorter average vehicle length equal to 4.35 m and 2.5 m space between the vehicles in case of congestions. We can obtain the suggested density 146 veh/km from the total vehicle length 6.85 m.

Table 1. Cell size, speed and density [own study]

| Cell size [m] | Speed 5 [km/h] | Speed 4 [km/h] | Speed 3 [km/h] | Density [veh/km] |
|---|---|---|---|---|
| 5 | 90 | 72 | 54 | 200 |
| 6 | 108 | 86.4 | 64.8 | 166.6 |
| 7 | 126 | 100.8 | 75.6 | 142.8 |
| 7.5 | 135 | 108 | 81 | 133.3 |
| 8 | 144 | 115.2 | 86.4 | 125 |

Nagel and Schreckenberg [4] version of the model defined following rules:

1. Acceleration: $v = min(v+1, v_{max})$
2. Slow down: $v = min(v, d–1)$
3. Randomization: $v = max(v\text{-}1, 0)$ with probability $p$
4. Movement to the new positions: $x = x+v$

Where:

$v$ – speed of the vehicle,
$d$ – distance from the previous vehicle,
$p$ – slow down probability (0.25 - 0.3 for the motorway),
$x$ – position of the vehicle.

Fig. 3 shows the illustration of the basic rules. The speed of the vehicles is displayed above them in discrete units. Application of the rules is illustrated by numbered arrows.

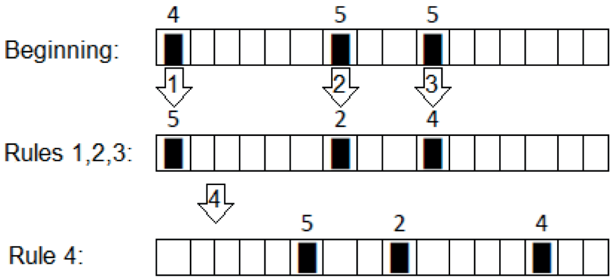


**Fig. 3. Basic rules of the CA model [own study]**

TuSim visualization screen has different speed limits before the tunnel and inside it, so $v_{max}$ should be defined for each road section separately. Acceleration rule nr.1 works same way as before. Additional rule has to be added for the vehicles, arriving to the section with lower speed limit, to slow them down. The rule is as follows:

Speed limit: $v = min(v_{max}, v)$

We should also mention modifications, which have not been implemented, but are still interesting to make the movement of the vehicles more realistic. BJH modification [9] of the model uses slow-to-start rule. When a vehicle stops completely, it doesn't start to move at first available opportunity but with certain probability. The drivers usually don't immediately notice that vehicle in front of them moves and usually they have to start the engine again. It is useful especially for studying the effect of congestions on the motorway. Also slow-to-stop rule [10] should be in case of congestions considered. When vehicle approaches the congestion or the vehicle before it slows down rapidly, the vehicle in reality cannot stop in one cell but has to slow down in more cells.

## 2.2. Lane changing

Two lanes motorway tunnel has been selected for the implementation of the CA model, so also lane changing rules should be included [5]. Rules can be divided into two groups: own benefit rules (1, 2) and safety rules (3, 4). The vehicles change the lane with the certain defined probability, if all following rules are met:

5. Distance from the previous vehicle is smaller than current discrete speed.
6. Distance from the previous vehicle in the next lane is greater than in current lane.
7. Cell in the other lane is free.
8. Distance from the next vehicle in the other lane is greater than its discrete speed

Fig. 4 shows the illustration of lane changing rules. The speed of the vehicles is displayed above them in discrete units. Application of the rules is illustrated by numbered arrows.

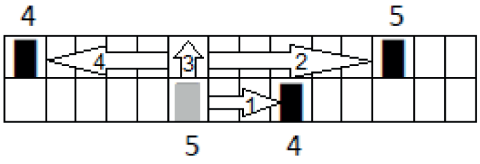


**Fig. 4. Lane changing rules of the CA model [own study]**

Fig. 5 shows the illustration of lane preference on two lanes motorway with 10% trucks and 5% brake probability according [2]. Below the intensity 2000 veh/h are vehicles more likely in the right lane. The curve is linearly approximated and vehicle arrivals are simulated according the traffic intensities for each minute of the day of daily profiles for both week days and weekends. Traditional CA model has a close boundary for each time step. That is enough for analysis of the traffic situation, but it does not meet the reality. Vehicle reaching the end of the road behind the tunnel won't enter the road before the tunnel immediately. We implemented the model with open boundary and queuing system on the road before the tunnel. Exponential distribution has been used for modelling the arrivals of the vehicles into the tunnel for each time step, although it's not suitable for both high and low traffic intensities. Vehicle reaching the end of the road will leave and new vehicle will arrive to the road before the tunnel with a certain probability.

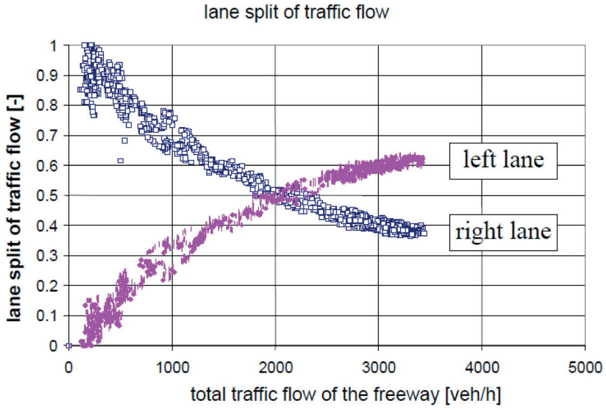


**Fig. 5. Lane preference in two lanes on the motorway [2]**

## 2.3. Vehicle type

Vehicle type should be considered to make the traffic model more realistic. Length and acceleration of the various types of vehicles differs and in case of truck and bus should be modeled by two cells instead of one. In Asian countries also motorcycle should be included as the smaller cell size of the model, since motorcycle is often used in towns. Such implementation can be found in [3], first step of our implementation uses same size equal to one cell for all vehicle types. Tab. 2 shows used vehicle types and heat release rate for simulation of unexpected events in the tunnel with fire scenario. Number of the persons in the vehicles can be generated randomly or fixed. Fixed numbers of persons according [11] and according risk analysis in TP02/2011 [8] can be found in third column in Tab. 2. The TP02/2011 also suggests the ratio of the buses equal to 3.5 % and ratio of the trucks equal to 20.0 % in the traffic flow. We can use the function RND from the visualization screen scripting language [7] to generate the vehicle type randomly. Function generates pseudo random real number from interval (0,1).

If the random number is in interval:

(0, 0.035> we mark the vehicle as bus – 3.5%,
(0.035, 0.235> we mark the vehicle as truck – 20%,

(0.235, 0.3> we mark the vehicle as van – 6.5%,
(0.3, 1) we mark the vehicle as car – 70%.

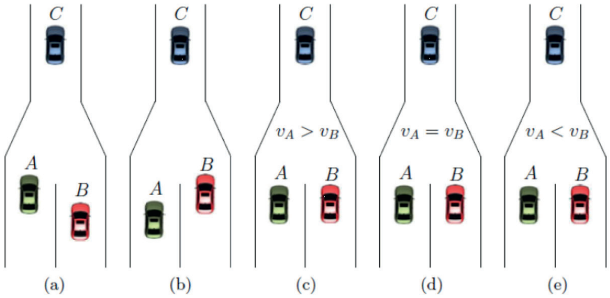
**Table 2. Vehicle type and Heat release rate [own study]**

| Vehicle type | Letter in visualization | Number of persons (if not random) | Heat release rate [MW] | Time to reach maximum heat [min] |
|---|---|---|---|---|
| Car | C | 3 (1.4) | 5 | 10-30 |
| Van | V | 5 | 15-20 | - |
| Bus | B | 20 (25) | 20-30 | 7-8 |
| Truck | T | 1 (1) | 100 | 8-18 |

## 2.4. Traffic sequences and maximum speed

Array with same size as number of cells has been used to allow the modification of the maximum speed with respect of the speed signs and lane signalization. Another array requires additional memory but allows also the partial phases of switching from one sequence to another. Fig. 7 shows the logic of variable maximum speed for each road section to support selected traffic sequences. We need to modify the lane switching rule nr. 1 of the CA model to support the single lane closed sequences in a following way:

1. Distance from the previous vehicle is smaller than current discrete speed and maximum speed limit is the same in both lanes or maximum speed limit in the other lane is higher.



(a) (b) (c) (d) (e)

Fig. 6. Closing the lane - possible cases [6]

Vehicles can change the lanes after modification of the rule in case of closing their lanes. It's also possible to consider more correct forming of the vehicles [6], Fig. 6 shows all possible cases. Cases (a) and (b) illustrate the different position of the vehicles and cases (c), (d) and (e) illustrate the same position with all speed possibilities.

Vehicles form the queue in case of unexpected event in the tunnel. CA model should support also this feature, because location of the persons in the vehicles is used as input for evacuation modelling. According simple queue model in [11] first queue is formed directly behind the incident, last queue is formed in front of the tunnel and the other queues are formed with respect of the lane signs inside the tunnel. Another array with maximum speed supports also this model of queuing; changing the maximum speed for the part of the road section to zero stops the vehicles crossing it.

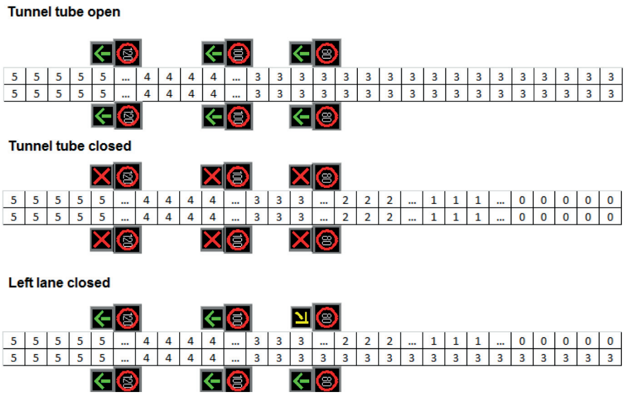


Fig. 7. Traffic sequence and CA maximum speed [own study]

## 2.5. Vehicle animation

Animation used in SCADA visualization screens expects the start and final position of the object and speed of the object movement is constant. It's not suitable for movement of the vehicles, because they can change the speed and lane any time during their movement, so different approach has to be used. Text font with constant width of letters animates the cars as rectangles or letters. Length of the whole text is equal to the number of cells of the CA model. Two text lines one below the other are used to display also the speed of the vehicle or number of persons. The speed signs and lane signalization signs have been moved to the side to place the vehicles in the middle of the road. The result of the implementation can be seen on Fig. 8. Number above the vehicle type means number of persons in it and it's generated randomly.

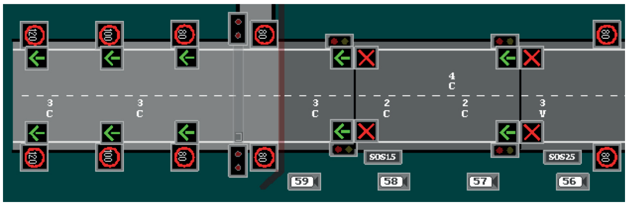


Fig. 8. Result of the implementation into the traffic screen [own study]

Macroscopic parameters of the traffic flow can also be counted from the CA model. Tunnel length in TuSim is 1 km, so number of vehicles in the tunnel is directly equal to the density (veh/km). Average speed in km/h can also be obtained from the discrete speed by multiplying the value with cell size (7.5 m) and 3.6.

Number of persons, traffic structure, lane preference and all other configurable parameters of the CA model are specified in INI file and updated after reloading the SCADA visualization screen to allow simple configuration of the traffic flow for the experiments.

## 4. Conclusion

Modified microscopic traffic model based on CA have been implemented into the graphical screen to extend the TuSim functionality. The vehicle type is important for the fire scenario simulation; number of persons and their location in the tunnel are important for evacuation time estimation. All vehicles are in current version represented as one cell, which is not really precise for the case of trucks and buses, but it's enough for the simulation of unexpected events in the tunnel. Maximum speed of the modified CA traffic model is variable and interconnected with speed signs and lane signalization to support all traffic sequences in the tunnel. Lane changing logic has also been implemented to allow the traffic simulation in two-lane tunnel. The behavior of the vehicles is not always correct in case of closing the lane, because vehicle can slow down the vehicles in the other lane. It can be changed in the future if necessary. Vehicles are displayed through simple animation as rectangles or letters describing the vehicle type, number of persons or actual speed of the vehicle. The position of the persons can be considered with respect to the position of the exits to count the distance for the evacuation.

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