BRNO UNIVERSITY OF TECHNOLOGY FACULTY OF INFORMATION TECHNOLOGY
https://fit.vut.cz

Modelling and Simulation
2023/2024

Traffic simulation using cellular automata

Samuel Stolárik, Jan Pavlíček

Abstract
In this simulation study, we use stochastic discrete cellular automata models to simulate traffic on a first-class road. We simulate the same road with two different automata, one simulates a one-lane road, and the second one simulates a road where part of it has two lanes. Simulations of the model show a transition from the laminar flow to start-stop waves as observed in real freeway traffic. Later we compare the results obtained from both simulations.

Keywords: Cellular automata — Traffic simulation — Traffic congestion control

1. Introduction

In this simulation study, we focus on the problem of the **Strečno - Žilina** section of the **E50** road in the Slovak Republic. This road is infamous for its traffic congestion due to the long-missing highway tunnel. The E50 road is an important international route, highlighting the strategic importance of this section for both national and international traffic.

During the last year, part of the road (approx. 30%) was reduced from two lanes to a single lane due to the great risk of landslide under [2].

Therefore, we decided to simulate the traffic on this road and show the effect of this change on the state of traffic during peak times.

1.1 Model settings

We joined forces with the Statistical Office of the Slovak Republic, which made available to us the data on the number of vehicles and categories of vehicles on first-class Slovak roads. We also take into account three different types of vehicles (personal, bus, and truck) and also the fact that they accelerate and decelerate differently.

2. Analysis of the topic and technologies used

Cellular Automata (CA) have been part of traffic simulation for a long time (as seen [1], this is mainly because they offer an effective way to model traffic flow due to their simplicity and adaptability. CA models consist of a grid of cells, each representing a segment of the road. The state of each cell, indicating whether it is occupied by a vehicle or not, changes based on predefined rules, making CA suitable for simulating the dynamic nature of traffic.
Advantages of Cellular Automata in Traffic Modeling:

1. Efficiency: CA's simple rule-based approach allows for the efficient simulation of complex traffic systems, crucial for real-time analysis.
2. Scalability and Flexibility: CA models can be easily scaled and adapted to various traffic scenarios, including different vehicle types and road conditions, making them ideal for simulating the diverse traffic on the Strečno - Žilina section of the E50 road.
3. Local and Global Dynamics CA can model the interactions between individual vehicles and their collective impact on overall traffic flow, capturing both micro and macro traffic dynamics.

In our study, we apply CA to understand the impact of lane reduction on the E50 road. This approach allows us to simulate the specific conditions of the road and analyze traffic behavior during peak hours.

2.1 Description of the methods used

While designing the models we used for traffic simulation, we first started with the baseline **NaSch model** as described in [3]. Then, for the one-lane simulation, we changed just the model's parameters to better reflect the data we acquired.

Vehicle type	Length [cells]	Distribution
Car	1	82.9%
Bus	2	0.4%
Truck	3	16.7%

Table 1. Vehicle categories and distribution

		C4
C2	C3	C2

Figure 1. Overtake rule demonstration

Variable	Value	Source
Road length	10 000 m	Map data
Meters per cell	5 m	[1]
Max speed	90 km/h	Road traffic rules
Vehicle arrival interval	3 sec	Statistical Office

Table 2. Traffic parameters

We added the categories of vehicles as seen in 1.

The category distribution data in 1 was acquired from the data provided by the Statistical Office of the Slovak Republic. For conversions between meters and data, see 3.1.

Secondly, for the two-lane simulation model, we had to get a little more creative. We added a stochastic decision process for lane-switching. There are only two reasons why a vehicle might decide to switch lanes.

1. The distance to the vehicle in front is smaller than the distance traveled in the current time step - **Overtake**
2. There is an opportunity to switch from the left lane to the right lane - **Legal obligation**

However, a vehicle might decide to ignore the **Overtake** rule stated in 2.1, stay in the right lane, and slow down.

Also, the car will not switch from the right lane to the left lane if the driving distance to the vehicle in the left lane is not greater than in the right lane as demonstrated in 1, where the car with speed 3 (C3) won't overtake but instead change its speed to 1.

2.2 Stochasticity and parameters

In this section, we describe the parameters and random variables used in our simulations, some of the parameters were acquired from the data set provided by the Statistical Office of the Slovak Republic (such as 3), some are just facts transferred from the real world to the simulation (such as 2), and some were acquired by experiments (such as 4.

Variable	Value
Car portion	82.9 %
Bus portion	0.4 %
Truck portion	16.7 %

Table 3. Vehicle distribution

Variable	Value
Overtake probability	80 %
Random deceleration probability	5 %

Table 4. Random variable

3. Concept

3.1 Modelling topics

While designing our simulation models, we had to take into account that cellular automata are discrete models, therefore we had to discretize the real-world traffic which we did as follows:

- Distances: We discretized all distances to the multiples of cell size. The size of one cell is 5 meters as this is a good size for vehicle sizes
- Speed: As speed is directly related to distance, we had to also discretize all speeds. However, we use continuous values of acceleration and deceleration to achieve better model precision. Therefore, the vehicle speed is a continuous variable and is floored when sampled.
- Time: In our simulations, we chose to use a discrete time step of one second.

Our simulation models have the following cell types:

- Vehicle::Car
- Vehicle::Bus
- Vehicle::Truck
- Road::Empty
- Road::Blocked (to partially block the left lane for two-lane simulation model)

3.2 Implementation topics

We used **C++** for the implementation of our simulation models. We represent cellular automaton as a two-dimensional vector of cells. Where a cell is an optional data type that either holds a Vehicle or nothing.

When to be moved, a vehicle always checks its driving distance to obtain information about an overtake possibility or the need to slow down.

The abstract simulator internally holds an instance of the cellular automaton (which is essentially a road), which is updated at each time step. The simulator also inserts vehicles at random times sampled from exponential distribution as described in 2.2.

4. Simulation model architecture

In this section, we describe the mapping between real-world objects and processes important to the concept of traffic simulation.

4.1 Simulation implementation

1. Vehicle: A class for representing real-world vehicles. Internally holds the category of the vehicle speed as a continuous variable, and allows discrete speed sampling and setting.
2. Cell: An optional data type that either holds a vehicle or is empty to represent a free space on the road.
3. Road:
4. Simulator: Class holding an instance of **Road** which invokes the update method on each time step and also inserts new vehicles to the road.

5. Simulation experiments

Our main goal in this study is to show the amount of decrease in the quality of traffic on the**Strečno - Žilina** section of the **E50** international road after removing the two-lane part of the road which took 30% of the whole length.

5.1 Simulation procedure

We ran the following experiments:

- One-lane simulation
- 70% One-lane, last 30% two-lane simulation

The second simulation allowed overtaking in the last 30% of the whole section. During the simulations, we collect the following data:

- Average speed
- Traffic density [% vehicles on the road]
- Traffic flux [Number of vehicles per minute]
- Road snapshot

5.2 Experiment runs

We ran the experiments with parameters set as described in 2.2, these parameters were set either based on the data or based on the previous simulation experiments.

The following data was collected during ten runs of both one-lane and two-lane simulations and then averaged across the runs.

As we can see in 2 and 3 the simulation with only one lane (the current real-world situation after lane reduction) performs significantly worse in terms of **average speed** and **traffic density**.

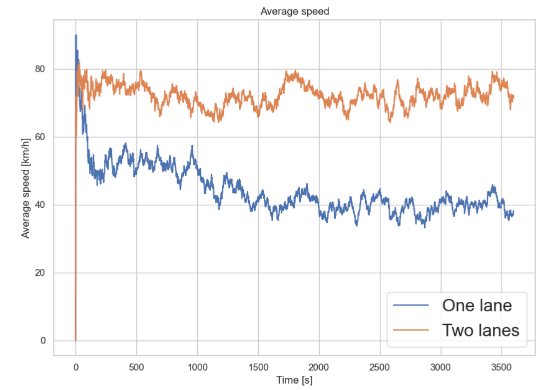

Figure 2. Average speed achieved in models [km/h]

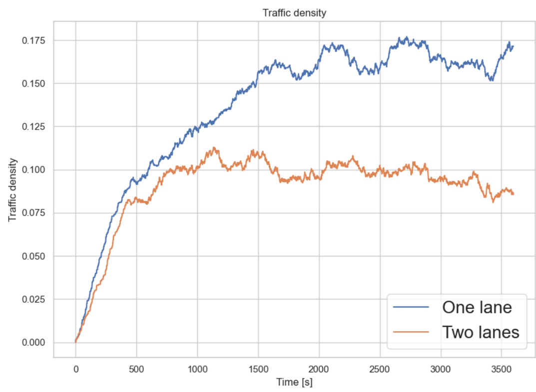

Figure 3. Traffic density

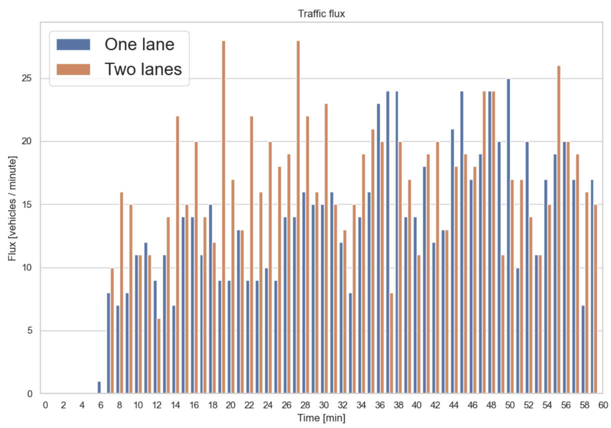

Figure 4. Traffic flux [vehicles per minute]

In figure 4 we see a smaller difference but the results are still in favor of the two-lane version of the road.

5.3 Experiment conclusion

We ran many experiments while tweaking the simulation parameters, thanks to which we were able to remove some imperfections in the simulation models, such as cars decelerating to zero just by random deceleration. After the modifications had been completed, we ran ten experiments on both simulation models.

6. Summary of simulation experiments and conclusion

The simulation experiments proved that the lane reduction on the discussed section of the international road **E50**, decreased the average speed of the vehicles in the section by approximately **25 - 30%**. Also, the traffic density increased by the same amount. We expect noticeable consequences on the quality of the quality of travel in this section.

References

[1] NAGEL, K. and SCHRECKENBERG, M. A cellular automaton model for freeway traffic. *Journal de Physique I*. december 1992, vol. 2, p. 2221.

[2] TASR. *Z Troch Pruhov Budú DVA, pod Strečnom Začali menit' Značenie*. SME.sk, Mar 2023. Available at: https://domov.sme.sk/c/23150686/pod-strecnom-zacali-odstranovat-treti-jazdny-pruh.html.

[3] TIAN, J., ZHU, C. and JIANG, R. *Cellular automata approach to synchronized traffic flow modelling*. 2018.