Evaluation of car-following-models at controlled intersections

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KEYWORDS
Microscopic simulation, Traffic research, Open source framework

ABSTRACT

Traffic simulations can help to investigate new traffic and transportation management solutions for overcoming problems like traffic jams, accidents or environmental pollution. For this a valid simulation model is needed. This paper provides an overview of the open source traffic simulation framework SUMO (Simulation of Urban MObility) and evaluates the implemented car-following models at controlled intersections with regard to vehicle positions and speeds. Particularly intersections can be bottlenecks for high traffic volumes and have a higher risk for accidents. Therefore this study focuses on traffic behavior at urban intersections.

Introduction

The increasing vehicular mobility has been offering many advantages for the population in urban areas, e.g. more comfort and flexibility. On the other hand, the rising amount of vehicles also lead to traffic problems like traffic jams, environmental pollution and accidents. To reduce these problems, particularly traffic and transportation management focuses on intelligent traffic management strategies.
Due to the complexity of managing mobility in urban areas, it would be very time-consuming, expensive and to some extent dangerous to test traffic management strategies in real world or test fields without theoretical evaluations before. Consequently, theoretical methods are necessary to analyze the benefits of traffic and transportation management strategies; and simulation frameworks can be one opportunity. The microscopic traffic mobility framework SUMO (Simulation of Urban MObility) is a time-discrete and open source simulation tool enabling such evaluations (Krajzewicz et al. 2012). SUMO can simulate fast and easily the traffic mobility of a large traffic network and provides many useful tools to evaluate the simulated data. An example simulation in SUMO can be seen in Figure 1.

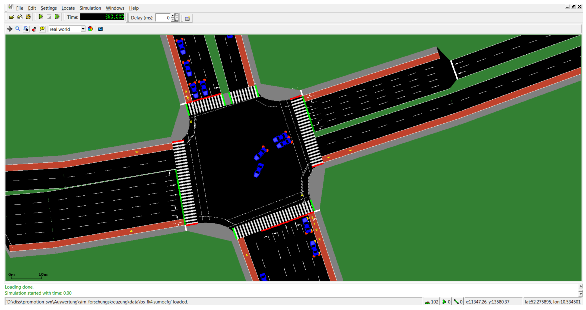

Figure 1: SUMO Simulation of the AIM Research Intersection in Brunswick

Many microscopic traffic simulation tools are based on car-following models, which are well studied in research (Brackstone and McDonald 1999). They focus on the idea that the speed of a vehicle highly depends on the speed of the leading vehicle. Usually, the traffic behavior at intersections is often neglected in these models. But for traffic efficiency and safety the vehicle interaction at intersections have a high influence and are therefore in the focus of this research.
The paper is structured as followed: first a short introduction of traffic simulations and a description of some of the most common car-following models (Krauss, IDM and Wiedemann) will be given. Next, a controlled intersection in Brunswick (Germany) and its real world traffic data will be described. Afterwards, the simulation tool SUMO and the used simulation scenario will be presented. Finally, the simulation results and concluding remarks will be stated.

Traffic Simulation Models

For modeling traffic a large variety of different simulation models are available. These models can be divided mainly into three different types (Krauss 1998):

1. Macroscopic: average vehicle dynamics are simulated, e.g. traffic density.

2. Microscopic: vehicle dynamics are modeled for every single vehicle individually

3. Mesoscopic: a mixture of macroscopic and microscopic model, for instance vehicle queues

For the simulation of vehicle interaction a microscopic model is necessary. Vehicle dynamics are normally described as a function of the velocity and the position of each vehicle. A common process to describe these dynamics is to apply car-following and lane change models. This research concentrates on car-following only. All described models are implemented in the most recent version of SUMO.

Car-following models

The basic idea of the car-following theory is that the change in velocity v of a vehicle i depends on the velocity of the leading vehicle $i+1$ as well as the position difference (gap) and static parameters like the sensitivity or reaction time τ. (Krauss 1998)

$$\frac{dv_i(t)}{dt} = f(v_{i+1}(t), x_{i+1}(t) - x_i(t), \tau, ...) \tag{1}$$

Krauss model
The default car-following model of SUMO is the Krauss model (Krauss et al. 1997, Krauss 1998). In traffic simulation each vehicle can have two different motion types: free motion and interacting motion. In free motion, no leading vehicle limits the speed of the following vehicle. Therefore, its speed is bounded to its maximum (depending of the speed limit and the drivers desired speed):

$$v \leq v_{\max} \tag{2}$$

In case two vehicles interact with each other, both vehicles always try not to collide with each other. In this case at least one of the drivers reduces its speed that is not higher than the maximum safe velocity v_{safe}:

$$v \leq v_{safe} \tag{3}$$

The model is collision free, which means that no vehicle is driving faster than a safe speed v_{safe}. The safe velocity will be computed every time step using the following equation (Krajzewicz et al. (2002)):

$$v_{safe}(t) = v_l(t) + \frac{g(t) - v_l(t)\tau}{\frac{v}{b(v)} + \tau} \tag{4}$$

t : time step
$v_l(t)$: velocity of the leading vehicle in t
$g(t)$: gap between vehicle and leading vehicle i in t
τ : reaction time of the driver (usually 1 second)
b : deceleration function

In real life the acceleration of a vehicle depends on its physical ability and other effects like air resistance and others. To prevent that vehicles in the simulation are driving faster that it is possible in reality the desired speed v_{des} is calculated. The desired speed of each vehicle v_{des} is the minimum speed of the safe speed v_{safe}, the current speed plus the maximum acceleration and the maximum speed (Krajzewicz et al. (2002)):

$$v_{des}(t) = \min[v_{safe}(t), v(t) + a, v_{\max}] \tag{5}$$

Due to the imperfection of the human drivers, a random error is subtracted from the desired speed v_{des} Krajzewicz et al. (2002):

$$v(t) = \max[0, rand[v_{des}(t) - \epsilon a, v_{des}(t)]] \tag{6}$$

Intelligent Driver Model - IDM
The Intelligent Driver Model (IDM) is based on the Optimal Velocity Model (OVM) (Treiber and Kesting 2010):

$$\dot{v} = \frac{(v_{opt}(s) - v)}{\tau} \tag{7}$$

s : current gap to the leading vehicle
$v_{opt(s)}$: optimal velocity depends on gap s
τ : Time to adapt to the new speed
The OVM does not take the speed of the leading vehicle into account. It reacts only to the distance to the leading vehicle. Additionally, the OVM is very sensitive to accidents. Therefore the IDM was modeled, with the following acceleration equation (Treiber et al. 2000, Treiber 2017):

$$\dot{v} = a\left[1 - \left(\frac{v}{v_0}\right)^{\delta} - \left(\frac{s*(v, \Delta v)}{s}\right)^2\right] \tag{8}$$

v : current velocity
v_0 : desired velocity
s^* : desired gap

The desired gap s^* is calculated as follows:

$$s^*(v, \Delta v) = s_0 + \max\left[0, \left(vT + \frac{v\Delta v}{2\sqrt{ab}}\right)\right] \tag{9}$$

Every vehicle can have other values for the parameter of the model:
T : the time headway (between 0.8 -2 seconds)
s_0 : is the minimum gap (default: 2 meters)
a : acceleration (between 1-2 m/s^2)
b : deceleration (between 1-2 m/s^2)

Wiedemann model
The commercial traffic simulation Vissim uses the Wiedemann Model (Menneni et al. 2009). The Wiedemann model is a psycho-physical spacing model. If a faster vehicle is approaching a slower leading vehicle it will start to decelerate until it reaches its individual

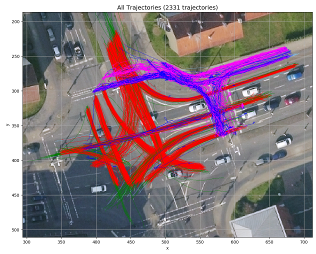

Figure 2: Real world picture of the intersection in Brunswick (Lines are representing detected trajectories red: vehicles, blue: bikes, pink: pedestrians, green: trucks)

threshold. The threshold is a function of speed difference and spacing. Human drivers are not able to perceive small speed differences and to keep their speed very accurate. Therefore, the vehicle will accelerate again if another threshold is reached (Fellendorf 1994).

Real World Traffic

The purpose of this research is to evaluate existing simulation models and compare the simulation results with data from human drivers. Therefore, one hour trajectory data (space-time-curves) from 23. January 2017 of human drivers recorded at a highly frequented junction (>20,000 traffic participants per day) in Braunschweig, Germany, intersecting two main roads was used. The Research Intersection is part of the test field AIM (Application Platform for Intelligent Mobility) and serves as a field instrument for detection and assessment of traffic behavior at complex urban intersections (Knake-Langhorst and Gimm 2016). Its infrastructure is equipped with several mono-cameras and multirange radar sensors to detect and track traffic participants in the inner part of the intersection. These trajectories provide static information about vehicle types (cars, motorcycles, trucks/vans, bicycles and pedestrians), vehicle sizes and time-variant information about their kinematic states (position, speed, acceleration) and headings when moving through the intersection. For details see (Knake-Langhorst and Gimm 2016) and (Schnieder and Lemmer 2012).

The trajectories' positions were mapped on the intersection as shown in Figure 2. The best view on the intersection is provided by the camera in the East (right street in Figure 2). Therefore, only trajectories from the East to the main street in the North were used for evaluation.

Simulation

SUMO is an open traffic simulation framework which is developed since 2001. A large amount of additional tools

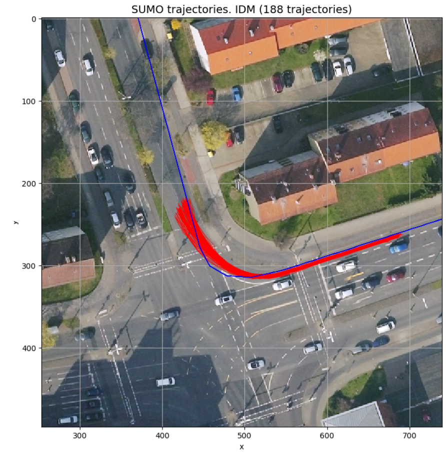

Figure 3: Real world trajectories (red) and simulated trajectories (blue)

e.g. for routing, evaluations and emission calculation are available within SUMO. Furthermore, SUMO supports intermodal traffic systems including the use of public transport and the simulation of pedestrians. The source code of SUMO is freely available and can be extended by the users with their own algorithms and models. The user can only interact with SUMO via an interface called TraCI. Different traffic networks can be imported for example OpenStreetMap, VISUM, VISSIM and NavTeq. SUMO has been used in several international research project e.g. COLOMBO (Leich et al. 2016), Amitran and VABENE (Flötteröd and Bieker 2012).

SUMO version 0.31 was used to simulate the intersection in Brunswick with the three presented car-following models, see Figure 1. In the configuration file of SUMO can be stated which car-following model should be used. The simulated data was exported as floating car data (FCD) in XML format. The data evaluation was done in Python and the diagrams created with matplotlib (Hunter 2007).

Results

For the evaluation in this study the real world traffic trajectories of the intersection were compared with the simulated trajectories. In Figure 3 the trajectories mapped on the intersection are shown. While the real world trajectories are varying in the lateral movement of the lane; the simulated vehicles are always keeping the middle of the lane. An extension in SUMO allows vehicle to move on sub-lanes but this model is normally only used for overtaking, especially from bicycles, motorcycles or in case of building rescue lanes and will not influence lateral positioning on a free road. The trajectory data could be used to extend the sub-lane model to are more realistic lateral movement behavior, but are neglected in this study.

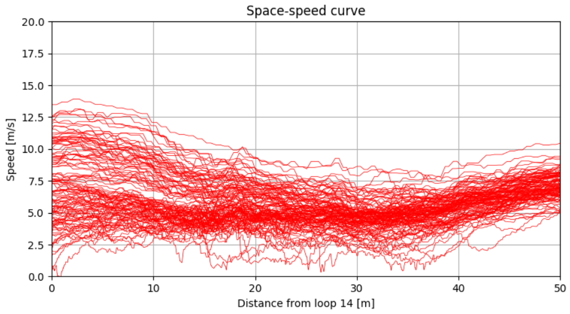

Figure 4: Real world traffic trajectories approaching a green traffic light

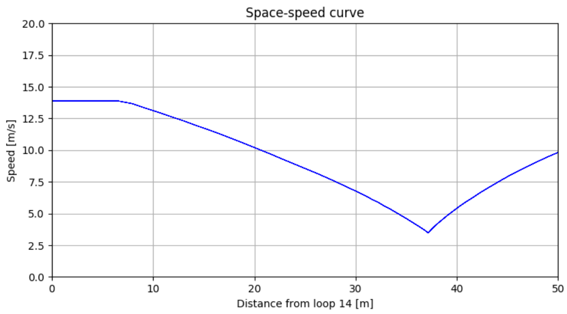

Figure 5: Simulated trajectories with Krauss model approaching a green traffic light

Figure 4 shows the approaching behavior of real world vehicles at a green traffic light. All trajectories which are passing the intersection without stop are considered in this study. It can be seen that the speed trajectories are oscillating a lot for human drivers. There is not one typical trajectory how the vehicles are driving over the intersection. In further research it would be interesting to see whether it is possible to cluster the trajectories to have a set of typical trajectories.
To simulate an ideal traffic case, only vehicles with could pass the intersect via green have been evaluated here. Compared to the real world trajectories, simulated trajectories appear to have less variation in all car following models (see Figures 5and 6). In Figure 5 the simulation results of the Krauss model are displayed. All vehicles have the same speed curves, which is due to the fact that drivers are keeping their desired speed until they approach the traffic light and are reducing their speed because of the pedestrian crossing. The IDM has a slightly larger oscillation of the speed curves, see Figure 6. The simulation results of the Wiedemann model are looking almost the same as the Krauss model and are therefore not illustrated here.
Furthermore, the simulation was feed with real world traffic demand to produce are a more realistic traffic behavior at the intersection. To compare the real world trajectories with the simulated trajectories the average speeds for every trajectory over the intersection were calculated and displayed in a box plot in Figure 7. While

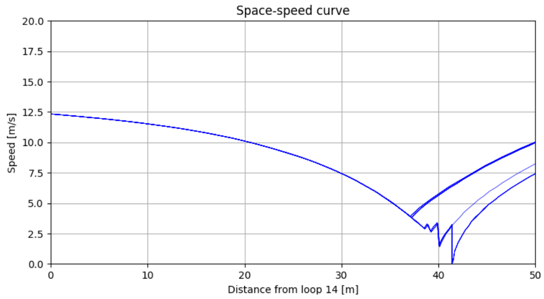

Figure 6: Simulated trajectories with IDM approaching a green traffic light

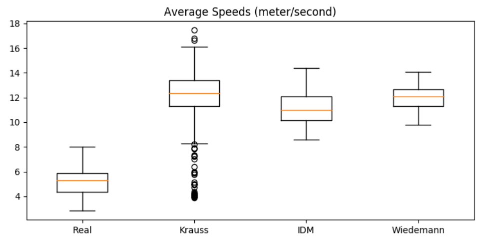

Figure 7: Comparison of the average speed for the vehicles in the area of the intersection

the average speed in the simulation reach almost the maximum of the allowed speed of 13.8 meters per second, the human drivers have to lower their speed significantly. One reason for this is that the driver have to decelerate and take care that no other traffic participant are in their blind spot. In the simulation the drivers always know where all other traffic participants are in each time step and therefore they do not have to break if no traffic participant is conflicting with its route.
The results how much time the vehicles needed to pass the intersection are similar and can be seen in Figure 8. The results of the IDM are closer to the results of the real world trajectories than the Krauss and the Wiedemann model. In average the vehicles need about 6 seconds to cross the intersection with the IDM and in real life while the Krass and Wiedemann model are underestimating the passing time by one second. The time difference might have not a high influence on the route of a single vehicle in the simulation but also might sum up for large simulation scenarios and routes.

Conclusions & future work

In this study the results of different car following models were compared with real world trajectories. Furthermore, this paper presented a short introduction to the traffic simulation framework SUMO. The SUMO framework includes a lot of tools for preparing a realistic traffic simulation and for the evaluation of the simulation results. In addition, SUMO provides differ-

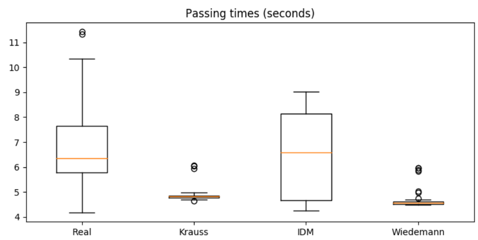

Figure 8: Comparison of the passing times for the vehicles in the area of the intersection

ent car-following models, which can be used for traffic evaluations. The described models are calibrated in other studies and are working well on highways and urban roads. But still some aspects like accident behavior are not modeled yet, every driver is always keeping a distance which is safe so that an accident should not happen.
Real world vehicle data can be used to modify the simulation models to have a more realistic driving behavior and therefore better simulation results. Our work can help to calibrate car following models to fit to the real world trajectories. Additionally, further studies can use this work e.g. for estimating the correct traffic light phases for induction loops or to develop a probabilistic car-following model.
Furthermore, traffic camera data could also provide live data for a SUMO simulation. Then the live simulation scenario could improve the traffic data results e.g. broken trajectories could be fixed by simulated trajectories or a trajectory forecast can be given by the simulation.

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