

GENERATION AND SIMULATION OF SURROUNDING VEHICLES IN A DRIVING SIMULATOR

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Abstract

Driving simulators are used to conduct experiments on driver behavior, road design, and vehicle characteristics, etc. It is important that a driving simulator include a realistic simulation of surrounding vehicles in order to be a valid representation of real driving. This paper describes a model that generates and simulates surrounding traffic for a driving simulator. The model is built on established techniques for time-driven micro-simulation of traffic. The model only considers the closest neighborhood of the driving simulator vehicle. This neighborhood is divided into one inner region and two outer regions. Vehicles in the inner region are simulated according to advanced behavioral models while vehicles in the outer regions are updated according to a less time-consuming mesoscopic model. The sub-models for driving behavior are enhanced versions of the sub-models in the HUTSIM/TPMA model and the VTISim model. The developed simulation model also includes a new sub-model for the behavior during overtakings.

The developed model has been tested within the VTI Driving simulator III. A driving simulator experiment has been performed in order to check if the participants observe the behavior of the simulated vehicles as realistic or not. The results were promising but they also indicated that enhancements could be made. The model has also been validated on the number of vehicles that catches up with the driving simulator vehicle and vice versa. The agreement is good for active and passive catch-ups on rural roads and for passive catch-ups on freeways, but less good for active catch-ups on freeways.

Résumé

Les simulateurs de conduite sont utilisés pour mener des expériences sur le comportement du conducteur, la conception de routes et des caractéristiques de véhicules, etc. Il est important qu'un simulateur inclue une simulation des véhicules environnants pour représenter de façon valide la conduite réelle. Cet article décrit un modèle qui produit et simule le trafic environnant en simulateur de conduite. Le modèle est basé sur des techniques éprouvées de micro-simulation de trafic. Il considère uniquement le voisinage le plus proche du véhicule simulé. Ce voisinage est divisé en une région interne et deux régions externes. Les véhicules de la région interne sont simulés selon un comportement détaillé alors que ceux des régions externes sont mis à jour selon un modèle mésoscopique qui consomme moins de temps. Les sous-modèles pour le comportement de conduite sont des versions améliorées des sous-modèles du modèle HUTSIM/TPMA et VTISIM. Le modèle de simulation développé inclut aussi un nouveau sous-modèle sur le comportement pendant les dépassements.

Le modèle développé a été testé dans le simulateur III VTI. Une expérience a été réalisée pour vérifier si les participants considèrent le comportement des véhicules simulés comme réaliste ou non. Les résultats étaient prometteurs mais ont aussi montré que des améliorations sont possibles. Le modèle a également été validé en ce qui concerne le nombre de véhicules qui interagissent avec le véhicule simulé et vice versa. Le résultat est valable pour des interactions actives et passives sur des routes rurales et des interactions passives sur autoroute, mais il l'est moins pour des interactions actives sur autoroute.

Introduction

Driving simulators are designed to imitate driving a real vehicle. They are used to conduct experiments on driver behavior, road design, and vehicle characteristics, etc. It is important that the performance of the simulator vehicle, the visual representation, and the behavior of surrounding objects are realistic in order for a driving simulator to be a valid representation of real driving. It is for instance clear that the surrounding vehicles must behave in a realistic and trustworthy way. Microscopic simulation of traffic is one possibility for simulating these surrounding vehicles. Micro models use different sub-models, for car-following, lane-changing, speed adaptation, etc. to simulate driver behavior at a microscopic level. This paper concerns simulation of surrounding vehicles in driving simulators using traditional techniques for microscopic simulation of traffic.

The most common approach for simulation of vehicles in driving simulators is to use deterministic models, i.e. all vehicles behave according to predetermined patterns. There are for experimental design issues desirable to keep the variation in test conditions between different drivers as low as possible. Deterministic models make it easier to create driving simulator scenarios in which all participants get the same test conditions. By using stochastic simulation of surrounding traffic, drivers will experience different situations at the micro level depending on how they drive. The simulator drivers' conditions will still be comparable at a higher, more aggregated, level if this is sufficient or not varies depending on the type of experiment. The main reason for using stochastic simulated traffic is that it increases the realism of the surrounding traffic and thereby decreases the risk for getting experimental results that is not valid for real driving. Simulated traffic also makes it possible to conduct driving simulator experiments with high-density traffic conditions.

A couple of models for simulation of surrounding vehicles has been developed, for example the ARCHISIM model (El hadouaj et al., 2002, Espié, 1995), the NADS model (Ahmad et al., 2001), and the DRIVERSIM model (Wright, 2000). There are also some trials to simulate surrounding vehicles in driving simulators using traffic simulation packages as *AIMSUN* (Barceló et al., 2002) and *VISSIM* (PTV, 2003), see for example Bang et al. (2004) and Jenkins (2004). The main focus within this research area has been simulation of freeways, although some research regarding simulation of rural highways have been conducted, see for example Janson Olstam (2005b) and Ahmad et al. (2000). There has been little or no focus on methodology and algorithms for generation of realistic traffic streams.

The objective of this project is to develop, implement, and validate a real-time running traffic simulation model that is able to generate and simulate surrounding vehicles in a driving simulator. The model should both simulate individual vehicle-driver units and the traffic stream that they are a part of, in a realistic way.

The simulation model has been delimited to only deal with freeways with two lanes in each direction and to rural roads with oncoming traffic. The model does not deal with ramps on freeways or intersections on rural roads. This paper does neither deal with models for changing from stochastic simulation of surrounding vehicles to predetermined critical situations.

The paper starts with a description of the developed model, including the overall framework, the model for generation of vehicles, and the sub models for driving behavior. The paper then

continues with a presentation of the performed validation. The paper ends with some concluding remarks and suggestions for further research.

The simulation model

The developed simulation model is based on established techniques for time-driven micro-simulation of road traffic. The model simulates surrounding traffic corresponding to a given target traffic flow and traffic composition. The model uses the simulator vehicle's speed, position, etc. as input and generates the corresponding information about the ambient vehicles as output. As in most traffic simulation models vehicles and drivers are treated as one unit, i.e. the interaction between the driver and the vehicle is not modelled. These vehicle-driver units are described by a set of driver or vehicle characteristics, including desired speed, desired following time gap, power/mass-ratio, etc. Both the vehicle and the driver characteristics vary between different vehicle types. At the moment the model includes the vehicle types: Cars, Buses, Trucks, Trucks with trailer with 3-4 axes, and Trucks with trailer with 5 or more axes. However, buses and trucks without trailers are assumed to have equal characteristics.

The moving window

The model is based on an approach where only the closest neighborhood of the simulator vehicle is simulated. Similar approaches has been used in the ARCHISIM model (Espié, 1995) and in the NADS model (Bonakdarian et al., 1998). This neighborhood or area moves with the same speed as the simulator vehicle and can be interpreted as a moving window, which is centered on the simulator vehicle. The basic idea is to avoid simulating vehicles several miles ahead or behind the simulator vehicle, which is not very efficient.

In order to get a wide enough window but at the same time limit the computational efforts, the window is divided into one inner and two outer regions. Vehicles traveling in the inner region are simulated according to models for car-following, overtaking and speed adaptation, etc. Vehicles, traveling in the outer regions, are simulated according to a simple mesoscopic model, which uses speed-flow functions to calculate the vehicles' speed.

Traffic generation

Vehicles traveling much slower or faster than the simulator vehicle will travel out of the inner region, into the outer regions and finally out of the system. Thus, the system will become empty if no new vehicles are generated. Since our model does not include intersections or ramps, all new vehicles are generated at the edges of the window. As the edges consequently move with the speed of the simulator vehicle, new vehicles cannot be generated in the same way as in ordinary traffic simulation models, where new vehicles are generated at the geographical places that define an origin in the simulated network. A new generation technique has therefore been developed that only generates faster vehicles behind and slower vehicles in front of the simulator vehicle. The basic principle is to generate new temporarily vehicles until a faster/slower one is generated and then discard the temporarily ones. The time headways and desired speeds of the discarded vehicles are then used to calculate a correct arrival time for the faster/slower vehicle.

Sub-models for driving behavior

The utilized car-following and lane-changing model is based on the HUTSIM/TPMA (Kosonen, 1999) model with some modifications, see Janson Olstam (2005a) for details. The car-following model uses three regimes: *Free*, *Stable*, and *Forbidden*. The regimes are defined by time headways that depend on the speed of the leader and follower vehicle, and the follower vehicle's desired following time gap and desired average acceleration. When a vehicle is in the free regime, the driver accelerates or decelerates in order to reach its desired speed. In the stable area the driver do not take any action. If a vehicle enters the forbidden regime the driver decelerates in order to reenter the stable regime.

The lane-changing model uses a pressure function for deciding whether or not a driver desire to change lane. The pressure is defined as

$$P = \frac{(v_{des} - v_{obs})^2}{2 \cdot s},$$

where v_{des} is the desired speed of the rearmost vehicle, v_{obs} is the speed of the obstacle vehicle, and s is the distance between the two vehicles. Decision for changes to the left is based on the pressure to the first vehicle in the own lane and to the first vehicle in the left lane according to the rules presented in Figure 1. For changes to the right the pressure from the back vehicle in the left lane is used. The parameters c_l and c_r are calibration parameters, which controls the willingness to change to the left and right, respectively.

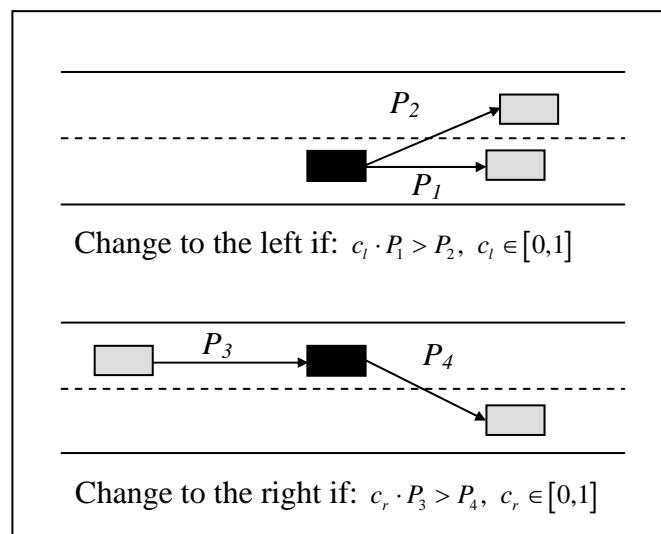


Figure 1 The lane-changing logic, based on the model presented in Kosonen (1999).

The sub-model for determining a vehicle's desired speed at a section is based on the speed adaptation model in VTISim (Brodin et al., 1986). This model describes speed adaptation on rural roads and has therefore been recalibrated for freeways, see Janson Olstam (2005a). The model starts from an average basic desired speed, v_0 , that is reduced with respect to speed limit, road width, and curvature to an average desired speed, v_3 , for a specific road section. The desired speed for a vehicle n at a road section is finally calculated as

$$v_{3n} = \left(v_{0n}^Q - (1-\alpha) \cdot (v_0^Q - v_3^Q) \right)^{1/Q},$$

where v_{0n} is the basic desired speed of vehicle n and $0 \leq \alpha \leq 1$ is a vehicle type dependent parameter. The parameter Q is a transformation measure that depends on the reason for reduction.

The model used for overtaking on rural roads with oncoming traffic is based on the VTISim model (Brodin et al., 1986). This model is based on probability functions that describe the probability of starting an overtaking as a function of the available overtaking gap. The probability function is defined as

$$P(d_{gap}) = e^{-A \cdot e^{-k \cdot d_{gap}}},$$

where d_{gap} is the available gap, that is

$$\min\{\text{distance to oncoming vehicle, distance to natural sight obstruction}\},$$

and A and k are constant that depend on: type of overtaking {flying, accelerated}, type of sight limitation {oncoming vehicle, natural}, type and speed of vehicle being overtaken, and the current road width. Calibrated values of A and k for Swedish road conditions is available in Carlsson (1993).

When overtaking, the overtaking vehicle must continuously reevaluate the distance to the vehicle in the oncoming lane and the distance left of the overtaking. This was not included in the model presented in Brodin and Carlsson (1986). The overtaking model has therefore been enhanced with a more detailed modeling of overtakings including decision rules for abortion of overtakings. The developed model for overtaking abortions is based on the assumption that a driver takes action if the time to collision, TTC , with the oncoming vehicle is less than the estimated time left of the overtaking. That is if $TTC + t_{safety} < t_{left}$, where t_{safety} is a safety margin and t_{left} is the time left of the overtaking estimated as

$$t_{left} = -\frac{v_n - v_{n-1}}{a_n} + \sqrt{\left(\frac{v_n - v_{n-1}}{a_n}\right)^2 + 2\frac{\Delta d}{a_n}} + 0.5 \cdot t_{change},$$

where $\Delta d = x_{n-1} - x_n + l_n + d_{min}$. d_{min} is the critical lag gap for lane changes to the right and t_{change} is the time it takes to perform the lane change back to the normal lane. The variables v_n , x_n , v_{n-1} , and x_{n-1} refer to the speed and position of the overtaking vehicle and the vehicle being overtaken, respectively. The acceleration a_n is calculated according to the acceleration model used in the free car-following regime. In situations where $TTC + t_{safety} < t_{left}$ and the driver has not yet passed the lead vehicle, the driver is assumed to abort the overtaking. The driver then falls back and merges into the normal lane behind the lead vehicle. If the vehicle is side-by-side or has passed the lead vehicle, the driver instead increases the desired speed to a level needed to end the overtaking without colliding with the oncoming vehicle. If the vehicle's power/mass ratio is too low in order to be able to accelerate to the new desired speed the vehicle is temporarily assigned a new power/mass value. However, if the power/mass ratio needed to drive at the new desired speed exceeds the maximum power/mass ratio for the

current vehicle type, the driver abort the overtaking and falls back in order to merge into the normal lane behind the overtaken vehicle.

Validation

The primary outputs of the developed model are the behavior of the simulated vehicles, thus the primary output is at a microscopic level and not at a macroscopic level which is the case for most applications of traffic simulation. The simulation model has therefore been validated at a microscopic level. The overall objective for our application is that the simulator drivers consider the surrounding vehicles' "behavior" as realistic. If this is not the case the simulator drivers may behave differently compared to when driving a real car. The problem is that it is hard to define "realistic". It is also hard to state how realistic the behavior has to be in order for the model to be valid. The ultimate goal is, of course, a model where the simulator driver cannot conclude whether an ambient vehicle is driven by another human or by a computer.

Two separate validation studies have been performed within this project. The first is a study on overtaking rates of the driving simulator vehicle and the second one is a study on how realistic human drivers think that the simulated drivers behave.

Overtaking rates

An important part that is connected to the observed realism is the number of vehicles that catch up with the driving simulator and the number of vehicles that the simulator driver catches up with. When driving at a certain speed you may not be able to say whether the number of vehicles that overtake you is comparable to when driving on a real road, but you certainly react if the proportion between vehicles that catch up with you (passive catch-ups) and that you catch up with (active catch-ups) is not realistic. We have in this project compared active and passive catch-ups generated by the model with an analytical expression for estimating number of catch-ups of a floating car, originally presented in Carlsson (1995). Passive catch-ups is according to this expression estimated as

$$U_p = qL \int_{v_0}^{\infty} \left(\frac{1}{v_0} - \frac{1}{v} \right) f_t(v) dv,$$

where q is the traffic flow (vehicles/h), L is the length of the observed road section, v_0 is the speed of the studied vehicle, and $f_t(v)$ is the time mean speed distribution. The number of active catch-ups is calculated in a similar way. One of the underlying assumptions for these functions is that every vehicle can overtake each other without any time delay. The equations can thus be expected to give upper limits on the number of active and passive catch-ups.

The values from the model were generated by not only simulating the surrounding vehicles but also simulating the driving simulator vehicle. Simulations were performed with varying desired speed of the simulator vehicle and at varying traffic flows. For rural roads the simulated values correspond quite well to the analytical calculation, see example with 400 vehicles/h in each direction in Figure 2a and b. However, for freeways the simulated number of active catch-ups seems to be too low, see example with 1000 vehicles/h in Figure 2c and d. The reason for this seems to be a too high frequency of lane changes. Noticeable is however that the analytical expression is an upper limit and that the simulated values is generally smaller than the corresponding analytical value.

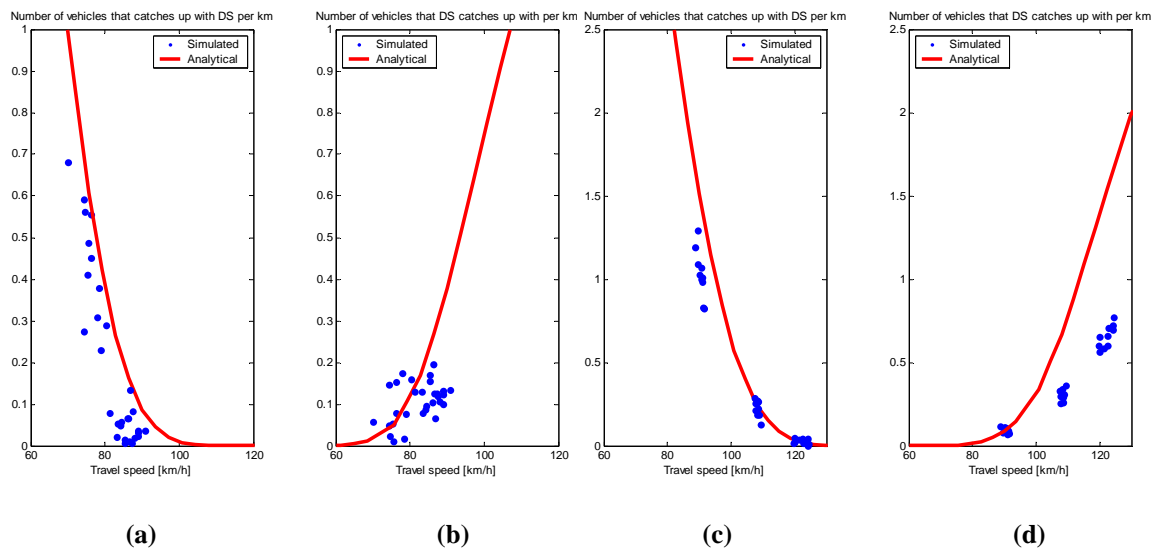


Figure 2 Simulated and calculated number of passive (a & c) and active (b & d) catch-ups per km of the driving simulator vehicle (DS) on a straight and plain rural highway with oncoming traffic (a & b) and a freeway (c & d).

User evaluation

We have in this work also tried to validate the simulation model by using simulator drivers as measurement devices. The human mind is a very useful tool that can be used both for detecting unrealistic behavior and to get statements on how realistic the behavior of the simulated vehicles are. In order to get these statements a small driving simulator experiment with 10 participants, 3 females and 7 males, has been conducted. The experiment was performed in the VTI Driving Simulator III (VTI, 2006). After 10 minutes of warm-up driving, the participants drove 15 minutes along a rural road and 15 minutes on a freeway. For the rural scenario the part of the National Road Rv 34 between Målilla and Hultsfred was used. The road is 9 meter wide with a carriageway of 7 meters. The posted speed limit is 90 km/h. For the freeway scenario a part of the European Road E4 between Linköping and Norrköping was used. The road has 2 lanes in each direction and a posted speed limit of 110 km/h. All intersections and ramps were removed from the scenario roads. The Rv 34 and E4 were chosen as they are good representatives of Swedish highways and freeways. The participants were not exposed to any critical situations. The participants were instructed to drive as they normally do in the two road environments.

After the ride, the participants were asked to give comments about the simulated vehicles' behavior by filling in an evaluation form and answering some interview questions. The participants were first asked questions about the realism of other parts of the driving simulator (steering, accelerator pedal, screen depth, etc) in order to avoid that opinions about those things influenced the answers on the forthcoming questions. The participants were then, among others, asked to estimate to which extent they thought that the other road users behave like real drivers. The results were quite good, with a mean of 5.4 on a seven-grade scale for both the rural road and the freeway. The most common comments were that the simulated drivers drove aggressively on the rural road and that the simulated drivers drove slower than in reality. Some participants also thought that some of the simulated drivers drove long time in the left lane on freeways before changing back to the right lane.

The reason for the aggressive behavior was probably due to a too small safety margin at overtakings. Later conducted tests with a larger safety margin indicate that this seem to solve this problem. A probable reason for that some of the participants think that the simulated drivers sometimes started overtakings at risky places, e.g. places with limited sight, is that it can be quite hard for the participants to distinguish objects far away on the simulator screen while the simulated vehicles have “perfect” vision. The best way to solve this is probably to limit the simulated vehicles’ sight so that it better correspond to the sight distances experienced by the simulator driver.

The reason for that the simulated drivers seemed to drive slowly was probably due to that the speedometer in the driving simulator shows the actual speed and not a speed 5-8 km/h higher than the actual speed, which is the case in most real cars. The result is that the participants drives faster in the simulator than they think that they normally do, which leads to that the surrounding vehicles seems to drive slower than in real life. This can easily be fixed by adjusting the speed in the speedometer so that it better corresponds to a real vehicle.

Concluding remarks

In this paper a model for generating and simulating surrounding vehicles in a driving simulator is presented. The model is able to simulate rural roads with oncoming traffic and freeways without intersections and ramps. The presented simulation model includes a more complete model for overtakings on rural roads than the one used in the VTISim model (Brodin et al., 1986). The enhanced model deals with drivers’ behavior during overtakings, including abortions of overtakings, in a more realistic way.

The model has been tested within the VTI Driving simulator III. The performed user evaluation showed that the participants to a quite large extent observe the simulated vehicles and their behavior as realistic. Observations and comments from the two validation studies also indicate that further work is needed. Some of the observed drawbacks have been taken care of, but others have to be dealt with in later work. Future plans include enhancements of the lane changing and overtaking models as well as including models for merging at, for example, ramps on freeways. The future research plans also include development of methodology and methods for changing between stochastic simulated traffic and critical situations.

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