DSC North America 2003 Proceedings, Dearborn, Michigan, October 8-10, 2003 (ISSN 1546-5071).

TRAFFIC GENERATION FOR THE VTI DRIVING SIMULATOR

Johan Janson Olstam
PhD student
Swedish National Road and Transport Research Institute, VTI
SE-581 95
Linköping, Sweden
ITN – Department of Science and Technology
Campus Norrköping, Linköpings Universitet
SE-601 74
Norrköping, Sweden
Tel: +46 13 – 20 41 82
Fax: +46 13 – 14 14 36
johan.janson.olstam@vti.se

Submitted July 7, 2003.

ABSTRACT

Driving simulators are often used in a type of experiments where the result may depend on traffic conditions. One example is the evaluation of cellular phones and how they affect driving behavior. It is clear that the ability to use phones during driving depends on the amount of traffic, and that realistic experiments in driving simulators therefore must include surrounding traffic.

This paper describes an ongoing project on the development of a micro simulation model for generation of stochastic traffic for the driving simulator at the Swedish National Road and Transport Research Institute (VTI). The goal is to generate a traffic stream, corresponding to a given target flow, and simulate realistic interactions in the neighborhood of the driving simulator vehicle.

The model is built upon established techniques for time-driven micro simulation of traffic, where driver behavior is described by a set of fundamental sub-models for car-following, speed adaptation, lane changing etc. In this respect the model is similar to ordinary traffic simulation models, like AIMSUN (1), MITSIM (2) and VISSIM (3). A fundamental difference is, however, that we in the new model only have to consider the closest neighborhood of the driving simulator vehicle. The neighborhood can be interpreted as a window that consequently moves with the speed of the simulator vehicle.

The basic purpose, and motivation for the model, is traffic generation of vehicles within sight distance of the simulator vehicle. To make this traffic realistic and to allow for speed changes of the simulator, a much wider window must be considered. The size of the window has, on the other hand, an impact on the computational time. A compromise is obtained by dividing the window into one inner and two outer regions. Close to the simulator vehicle (inner region) the “full” micro simulation model is used, while a simplified and less time consuming model is used in the two outer regions. In the latter model, vehicles are simply assumed to travel at their desired speeds.

In experiments using driving simulators, a key issue is to minimize statistical variations of the result by giving all the subjects of the experiment the same conditions. With stochastic traffic different drivers will, on a micro level, experience different situations. They will soon come into new situations and interact with other traffic in a unique way. We have to accept these differences and the uncertainty that it implies, and instead say that conditions are comparable, but at a higher level. That is, each driver “feels” the same traffic flow and, in the long run, meets the same type of traffic.

The first version is able to simulate traffic on a motorway with two lanes in each direction and without ramps. We are currently working on a rural road model, with possible overtakes and conflicts with oncoming traffic.

INTRODUCTION

Driving simulators are widely used for experiments concerning driver behavior, vehicle characteristics, road design, etc. Two of the main advantages are that it is possible to accomplish safe experiments with equal conditions for all test drivers. The driving simulator at the Swedish National Road and Transport Research Institute (VTI) utilizes a real vehicle cab with an advanced motion system. The surroundings, the road and the vehicles, are presented for the simulator driver on three screens. A new, more advanced, simulator is under construction. The new simulator will offer, among others, higher accelerations and smoother movements. The old simulator has been used for many different types of experiments, for example experiments concerning road design, the use of cellular phones during driving, vehicle characteristics, and human-machine interfaces. (4)

Since the idea with experiments in driving simulators is to create an environment that resembles driving in a real traffic system as close as possible, it is obvious that trustworthy ambient traffic is needed. But is simulation of ambient traffic always desirable? Simulation of ambient traffic increases the statistical variation of the results due to different conditions between the test drivers. Drivers will, on a micro level, experience different situations. If it is important that all drivers experience exactly the same situations before a test event, the experiment should not include stochastic simulation of ambient traffic. This can, for example, be in experiments concerning reaction times, where the reaction time may differ within one driver, depending on the situations that he or she has experienced before the event. If, for example, one driver has been overtaken by several vehicles, before the point in time where the reaction time measurement take place, and another driver has been able to travel unconstrained with respect to ambient traffic, their conditions differs. It can then be hard to observe whether the difference in reaction time depends on the test drivers or on their different test conditions.

Simulation of ambient traffic is, however, needed in studies where the amount of traffic has a large influence on the driver's ability to drive the vehicle. When performing experiments about the use of cellular phones during car driving, the need of ambient traffic is obvious. It is a lot easier to drive a vehicle and use a cellular phone if there is no surrounding traffic. The same holds for applications in the area of Intelligent Transportation Systems (ITS), for example different kinds of route guidance systems. Ambient traffic is also an important ingredient in experiments related to collision warning systems and design and placing of road signs. As mentioned above different drivers will indeed experience different situations but will in the end "feel" the same traffic load and meet the same type of traffic. In these types of experiments we have to accept the increase in statistical variation and instead say that the drivers test conditions are comparable at a more aggregated level.

Traffic simulation is a useful and popular tool in studies of traffic systems. On the basis of a road network description, an Origin-Destination matrix (OD-matrix) and information about driver characteristics like desired speed and desired acceleration, a traffic system can be simulated and the user can get information about average speeds and traffic flows on different road sections. The vehicles' state variables are updated continuously, with short time steps, less than one second between updates. The simulation is done at a microscopic level, which implies detailed modeling of vehicle characteristics and driver behavior. The output is often macroscopic measurements like average flow, speed and density. Calibration and validation are usually done at a macroscopic level, that is against traffic flows, queue lengths, average speeds etc.

A simulation model uses different sub-models to model driver behavior in different situations. One essential behavioral model is the car-following model. This model describes a driver's behavior when following another vehicle. The basic idea is to conclude when a vehicle is free and when it is following another vehicle and what actions the driver applies in each case. Several car-following models have been developed through the years. The research in this area started in the fifties, see *Car-following: a historical review* (5) for an overview of car-following models. When simulating traffic on multilane roads, a lane-changing model is needed. This model is used to decide whether a vehicle should change lane or not. This is often done in several steps, for example first deciding whether it is desirable to change lane and then concluding if it possible and safe to do so. To be able to model roads with oncoming traffic, an overtaking model is necessary. This model cannot only concern the actual lane change to the oncoming lane. Instead, the whole overtake process must be considered, starting with deciding whether the driver is willing to execute an overtaking at the available sight distance. A simulation model also has to include models for calculation of desired speeds at different road sections and models for calculation of vehicles' route choices through the network.

The aim of this project is to develop a traffic generator that in real time and in a statistical and trustworthy way can generate and simulate ambient traffic on motorways and rural roads. The model is limited to only dealing with roads without intersections and ramps. The Swedish National Road Administration (SNRA) (4), finances the project, which will run until the end of 2004. A feasibility study, concerning generation and simulation of ambient traffic on motorways, was made in 2002 (6). The aim was to investigate the previous research in this area and to start to develop a traffic generation framework. The study ended in a traffic generator named Intelligent Traffic Generator (INTRAG), which now is the project's working name.

There are several driving simulators around the world. In order to distinguish how many simulators that include stochastic ambient traffic, a survey, included in the feasibility study, has been done. Totally 38 institutes, universities, and companies were contacted and 21 answers were received. We found that at least ten driving simulators include some kind of model for stochastic generation and simulation of ambient traffic (6). The ten included the car manufacture Renault (7), the French research institute Institut National de Recherche sur les Transports et leur Securite (INRETS) (8), and the United States National Highway Traffic Safety Administration (NHTSA) (9). Several of the ten models are protected commercial products, which makes it hard to find interesting information about those. The main part of the models is poorly documented, regarding the utilized traffic generation frameworks. The available documentation mainly focuses at the models' possibilities and at their utilized behavioral models. Almost no information about calibration and validation of the models are to be found. The models developed by GlobalSim (10) and NHTSA (9) only generates and simulates vehicles in the closest area around the driving simulator, whether that is the case or not in the other models is unknown.

A TRAFFIC GENERATION FRAMEWORK

It is very important that the behavior of the ambient vehicles is trustworthy. This can be achieved by using good models for describing driving behavior. However, that's not enough to ensure that the generated traffic corresponds to the specified traffic flow and composition. Generation of new vehicles must be done in a statistically correct way. This can only be achieved by using a reliable traffic generation framework.

In ordinary traffic simulation models, the whole geographic area of interest, often a part of a city or a highway, is simulated. In this case, simulating traffic for a driving simulator, the area of interest is the closest neighborhood of the driving simulator. This area consequently moves with the same speed as the driving simulator and can be interpreted as a moving window, which is centered on the driving simulator. The vehicle movements that are visible for the simulator driver are the relative movements between the simulator vehicle and the ambient vehicles. The differences between ordinary traffic simulation and traffic simulation for a driving simulator is illustrated in figure 1 and figure 2, the black vehicle symbolizes the driving simulator. Vehicles traveling slower or faster than the simulator will increase the distance to the simulator and they are deleted when the distance becomes too large. This is not the case in ordinary traffic simulation, where vehicles are deleted only when they have reached their final destination.

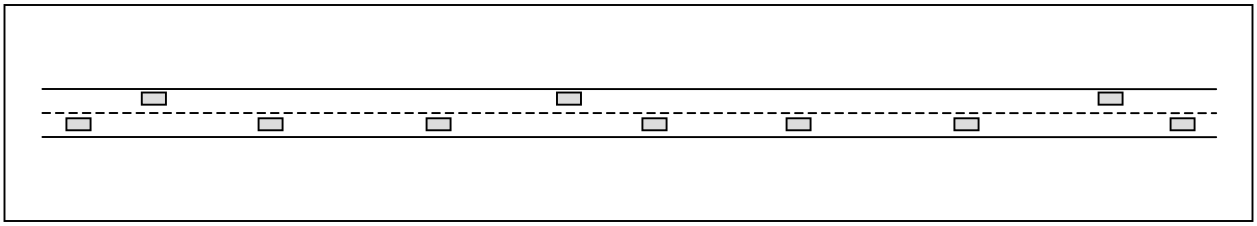

FIGURE 1 Ordinary traffic simulation

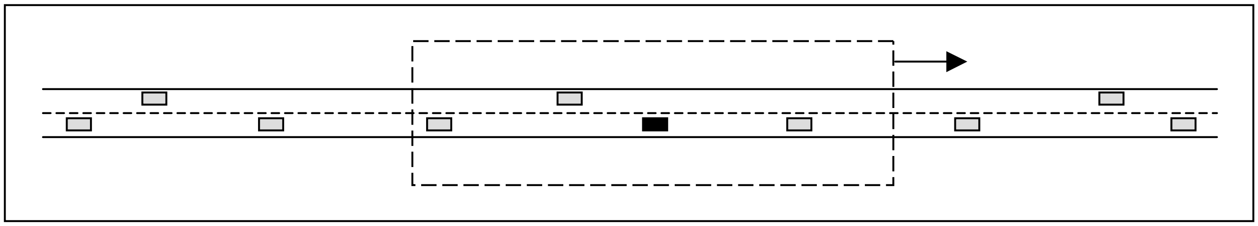

FIGURE 2 Traffic simulation with the moving window

The traffic generator should be able to generate and simulate ambient traffic in real time. To fulfill this the model must be very efficient. Simulating vehicles several miles ahead or behind the driving simulator is not very efficient. Vehicles that are so far away do not affect the driving simulator. Therefore only vehicles in the neighborhood of the simulator are simulated. However, this area cannot be too small. Firstly, the size of the window is constrained by the sight distance. The length of the window must at least be as long as the sight distance, so that vehicles don't "pop up" in front of the driving simulator. Secondly, the window must be large enough to make the traffic realistic and to allow speed changes of the simulator. If the simulator driver change its speed often and rather rapidly, there is a risk that there will become a lack of vehicles in front of, or behind, the simulator if the length of the window is too short. That is, if the vehicles in front of, or behind, the simulator have passed out of the window and the generation of new vehicles hasn't yet been affected by the changed conditions before the simulator changes its speed again. A compromise, between computational time and window length restrictions, is obtained by dividing the window into an inner and two outer regions. It is very important that the vehicles in the closest neighborhood of the driving simulator behave like real drivers. Vehicles traveling in the inner region are therefore simulated according to advanced behavioral models for car-following, lane changing and speed adaptation etc. The inner area is therefore called the simulated area.

The behavior of vehicles traveling fairly far away from the simulator is less important. These vehicles, traveling in the outer regions, are simulated according to a very simple model that is less time consuming. When getting closer to the simulated area, these vehicles become candidates to move into the simulated area. The outer regions are therefore called candidate areas and vehicles traveling in these areas are consequently called candidate vehicles.

The simulated area

Vehicles traveling in the simulated area, the inner region, are simulated according to established techniques for time-driven micro simulation of traffic. The vehicles are updated frequently, about ten times per second. Different behavioral models are used to create real driving behavior. To test the traffic generation framework, behavioral models from the model *Traffic Performance on Major Arterials (TPMA-model)* (11) and the *VTI rural road model* (12) have been used.

The simulation model used treats drivers and vehicles as vehicle-driver units. Each unit is assigned different driver and vehicle characteristics. Every vehicle is assigned a length, a width, a normal deceleration rate, a desired time gap (to a vehicle ahead), a power/weight ratio and a basic desired speed. Typical average values of the normal deceleration rate and the desired time gap are 3 m/s^2 and 1 – 1.5 s. The power/weight ratio is the ratio between a vehicle's power, available at the wheels, and its mass. The average power/weight ratio for passenger cars is typical about 19 W/kg. The basic desired speed is the speed that the driver wishes to travel at on a straight and plain road with no speed restriction and without surrounding traffic. The basic desired speed is reduced with respect to road width, horizontal curves and speed limits to a desired speed for each road section. The speed reduction is computed according to the reduction model utilized in the VTI rural road model (12). The test model concerns motorways, which are assumed to be wide and without tight curves. Reduction with respect to horizontal curves and road width has therefore been ignored. The reduction is done by shifting the basic desired speed distribution curve and rotating it about its median. A vehicle's reduced desired speed, v_{1i}, at a specific road section is calculated as

$$v_{1i} = \left(v_{0i}^{Q} - v_{0}^{Q} + v_{1}^{Q} \right)^{\frac{1}{Q}},$$

where v_{0i} is the vehicle's basic desired speed and v_0 and v_1 are the median desired speed before and after reduction, respective. The parameter Q is a transformation measure, currently with value 0.2. For $Q = 1$, the desired speed distribution curve is obtained by a parallel shift of the basic desired speed distribution curve. For $Q < 1$, the basic desired speed distribution curve is also rotated anticlockwise about its median value, which implies that vehicles with high basic desired speeds reduce their speeds more than vehicles with low basic desired speeds. Both the vehicle's basic desired speed, v_{0i}, and the median basic desired speed, v_0, is known. Thus the only unknown variable is the reduced median desired speed, v_1, which is calculated as

$$v_1 = \frac{v_0}{1 + c \cdot d^{z^2}},$$

where z is the ratio between the speed limit and v_0, d is an calibration constant, currently 0.05, and c is a calibration constant calculated as

$$c = \begin{cases} 1.3 - \left|3.6 \cdot v_g - 70\right| \cdot 0.015 & \text{if } v_g < 30.56 \text{ m/s (110 km/h)} \\ 0 & \text{if } v_g \geq 30.56 \text{ m/s (110 km/h)} \end{cases},$$

where v_g is the speed limit.

The car-following model is built upon the car-following model utilized in the TPMA-model. A vehicle can either be in the free-, stable- or forbidden area. The different areas are defined by headways. A space headway is defined as the front-to-front space distance between two vehicles while a time headway is defined as the time it takes for the vehicle furthers back to travel the space headway. The front-to-back distance is referred to as the space- or time gap, if it is measured in space or time, respectively. The forbidden area is defined by a headway that depends on the speed of both the follower and the leader. It consists of an estimation of the brake distance needed for a deceleration from the follower's speed down to the leader's speed with a normal deceleration rate. The forbidden headway is calculated as

$$d_{forbidden} = v_n \cdot t_{\min} + l_n + \frac{v_{n-1}^2 - v_n^2}{2 \cdot a_{normal}},$$

where v_n and v_{n-1} are the speed of the follower and the leader, respectively, $t_{\min}$ is a min time gap, currently equal to the follower's desired time gap, l_n is the length of the follower vehicle, and a_{normal} is the normal deceleration rate. To avoid very short forbidden headways at low speeds, the forbidden headway is limited to values larger than the vehicle's effective length. The effective length is the sum of the vehicle's length and the min distance between stationary vehicles, which is approximately 0.5 – 1 m.

The stable area is defined as the sum of the forbidden time headway and a time headway constant, currently 0.2 seconds. When traveling at larger headways than this, the vehicle is free and accelerates to obtain its desired speed. The acceleration is calculated according to the acceleration model used in the VTI rural road model. The calculation is based on Newton's force equation and looks like

$$a = \frac{p}{v} - g \cdot i,$$

where p and v is the vehicle's power/weigh ratio and speed, respectively, and i is the inclination in radians. The parameter g is the gravitational acceleration in m/s^2. The acceleration is then reduced with regard to air and rolling resistance.

When traveling in the stable area the vehicle is following the vehicle in front and is not allowed to accelerate. If the vehicle travels faster than its leader and passes the forbidden time headway, the vehicle enters the forbidden area and has to decelerate to avoid a collision and to reenter the stable area. The deceleration rate that's being used depends on the ratio between the actual space gap and the forbidden distance (the forbidden headway – the vehicle length). The deceleration rate increases with decreasing ratio.

The output from the car-following model is the acceleration, or deceleration, that the vehicle uses in the time step. This acceleration is used to calculate the vehicle's speed and finally its position at the end of the time step. The new position is determined by integrating the vehicle's speed. Thus, the new position is calculated as

$$x(t+T) = x(t) + v(t) \cdot T,$$

where $x(t)$ and $v(t)$ is the position and speed at time *t,* respectively, and T is the time step.

In the test model, The TPMA lane-changing model has been used to model lane-changing behavior. The model uses a pressure measure to describe the psychological pressure that a driver experience from a vehicle in behind. The pressure is an approximation of the deceleration rate that is necessary to avoid a collision and is calculated as

$$P = \frac{\left(v_{desired} - v_{obstacle}\right)}{2 \cdot \Delta x},$$

where $v_{desired}$ and $v_{obstacle}$ is the back vehicle's desired speed and the obstacle's speed, respectively, and Δx is the distance between them. The pressure is used to determine the driver's will to execute a lane change. When considering a lane change to the left, the driver is willing to execute the lane change if the pressure to the vehicle in front is larger than the pressure to the front vehicle in the left lane, see figure 3, and if the vehicle's desired speed is larger than the front vehicle's speed. Correspondingly, a vehicle is willing to change lane to the right if the pressure from the vehicle in behind is larger than the pressure to the front vehicle in the right lane. Two calibration parameters c_l and c_r are used to control the sensitivity in lane changes, see figure 3. Parameter values close to one result in lane changes even at very small difference in pressure. No lane changes at all will take place if the parameters are set to zero. Calibration made within the TPMA project stated that $c_l \approx 0.5$ and $c_r \approx 0.9$ gives a good fit with measures from Swedish and Finnish roads (11). Vehicles traveling in the left lane will also change lane to the right if there are "no" vehicles ahead, currently within a time headway of 5 seconds.

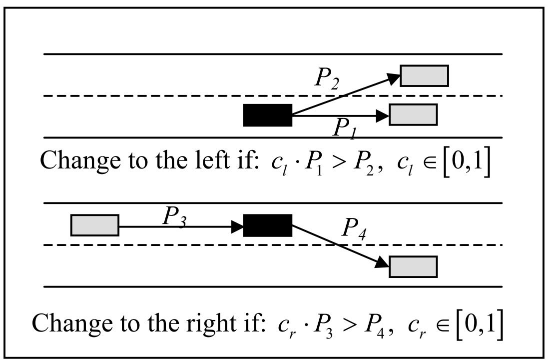

FIGURE 3 Illustration of the TPMA lane changing model

The next step in the lane-changing model is to conclude whether it is possible and safe, with respect to the ambient vehicles, to execute the lane change. There must be a sufficient space in the target lane, enough distance between the vehicle in front and behind in the target lane. To deduce whether the available gap is sufficient or not, a gap-acceptance model is used. The used gap-acceptance model is very simple. It simply assumes that the distance to the vehicle in front, such well as the distance to the vehicle in behind, must be at least as large as the vehicle's desired time gap. It should be desirable to use a more advanced gap-acceptance model. One possible enhancement is to use different gap-parameters to the vehicle in front and behind, respectively. Another possibility is to use different parameters for different kinds of lane changing, for example different parameters for normal and merging situations.

Whether the behavioral models used in the test version will be used in the final version is not yet decided. The traffic generation framework will be that general that, in principle, any types of behavioral models can be used to simulate the ambient vehicles. The framework may in the end be used to test and compare different driver behavioral models.

Vehicles traveling in the closest area around the driving simulator, at least vehicles within sight distance, are updated more frequently, about 50 times per second or more, than the other vehicles in the simulated area. Information about these vehicles is sent to the computer that handles the simulator's graphical system, where it is used to display the ambient vehicles at the simulator screen, hence these vehicles are the ones that the simulator driver sees and it is therefore very important that information about these vehicles is up to date. The test version used User Datagram Protocols (UDP) over an intranet to send information between the traffic generator and the graphic computer. The reason why the UDP protocol was chosen instead of the Transmission Control Protocol (TCP) is that transmissions with UDP are faster. UDP is therefore often used in real time applications as Internet radio and telephony. One disadvantage with UDP is however that there is no guarantee that the IP-packages will arrive to the receiver.

In ordinary traffic simulation there is no need for simulating occurrences like the use of turn signals or brake lights, all vehicle actions are known within the model. When simulating traffic for a driving simulator it is important to model both turn signals and brake lights, otherwise such signals will not be visible for the simulator driver. It is also important to model the variation in usage of, for example, turn signals. The usage of turn signals varies both between drivers and traffic situation. The usage, for example, at lane changing and at intersections turns differs. Traffic flow may also influence the usage. The need of telling other vehicles about my intentions is significant lower in the middle of the night, when there are almost no ambient vehicles, than during rush hour.

The candidate areas

As mentioned above, the behavior of vehicles traveling several miles away from the driving simulator is less important. These vehicles' actions don't affect the driving simulator, since the distance between them is too great. That is, the simulator driver is not affected by their actions at normal conditions. However, it may be affected if there, for example, are an accident or a roadwork, which bring long queues, a couple of miles ahead. The idea with the candidate area is to keep the computational time as low as possible, but at the same time get a wider window.

Vehicles traveling in the candidate area are assumed to travel unconstrained with respect to ambient traffic, hence traveling at their desired speeds. When closing up another vehicle, they are always able to overtake the caught up vehicle without any delay in travel time. In principle, every vehicle is traveling in an own lane, see figure 4.

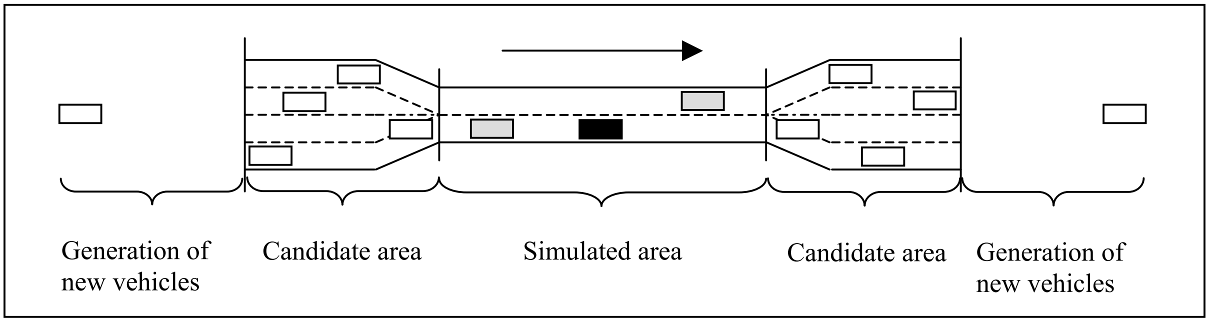

FIGURE 4 The different areas

The candidate vehicles are seldom updated, one time per second or less seldom. The vehicles travel at their desired speeds and with no acceleration. The only necessary updating of these vehicles are therefore to update the vehicles' posisitions, which is done in the same way as in the simulated area, see page 5. Thus, the new position is determined by integrating the vehicle's speed.

A candidate vehicle that reaches the the back edge of the simulated area is only allowed to travel into the simulated area if there is a sufficient space in one of the lanes. If there is no sufficient space in any of the lanes, the vehicle is placed at the edge between the candidate area and the simulated area. The vehicle gets a new opportunity to pass into the simulated area in the next time step. Candidate vehicles reaching the front edge of the simulated regime is only allowed to travel into the right lane in the simulated area. This restriction prevents incoming candidate vehicles from stopping faster simulated vehicles from passing in the left lane. The described procedure for passing into the simulated area is used on multi-lane roads. Since the rural road model is not yet finished there is no corrresponding procedure for that kind of roads. One idea is to, except allowing candidate vehicles to pass into the normal lane, give the candidate vehicles the possibility to begin an overtake, thus pass into the simulated area in the oncoming lane. This should of course only be an avaialble choice for candidate vehicles that catches up with the edge between the candidate area and the simulated area. Candidate vehicles that are caught up by the edge, videlecet vehicles driving in the same direction as the simulator and passes the edge in front of the simulator, have no vehicles to overtake, thus they passes into the simulated area because they drive slower than the simulator.

Generation of new vehicles

Vehicles traveling much slower or faster than the simulator will travel out of the simulated area, in to the candidate areas and finally out of the system, thus the system will become empty if no new vehicles are generated. The generation of new vehicles are done at the edges of the window, see figure 4 above. Since the edges consequently moves with the speed of the simulator, generation of new vehicles cannot be done in the same way as in ordinary traffic simulation models, where new vehicles are generated at the geographical points that define an origin in the simulated network.

When generating new vehicles at the edge behind the driving simulator it is only interesting to generate vehicles traveling faster than the driving simulator. Vehicles driving slower than the simulator will never catch up with the edge between the candidate area and the simulated area. It is therefore meaningless to generate new vehicles, at the window edge behind the simulator, which travels slower than the driving simulator. The opposite holds for the edge in front of the simulator, where it is no need to generate vehicles that drive faster than the simulator.

When only generating vehicles with higher, or lower, desired speeds than the simulator, the calculation of their arrival times becomes important. In ordinary traffic simulation models the average time headway between arriving vehicles is calculated as the inverse of the traffic flow (measured in vehicles/hour). As mentioned above, it's only meaningful to generate vehicles driving faster than the simulator at the edge behind the simulator, but the arrival distance between these vehicles cannot be shorter than in the case where both faster and slower vehicles is generated. Otherwise, the frequency of faster vehicles will be higher compared to the reality, which results in a traffic composition that differs from the chosen one. To avoid this, the following algorithm is used to estimate the time to arrival for a new vehicle, see figure 5 for an illustration.

1. Generate a new vehicle with a desired speed and time headway to the vehicle in front.

2. If the desired speed is lower than the driving simulator's present speed: go to step 1.

3. Calculate the time to arrival as

   $$\Delta T = \frac{\sum_{i=1}^{n} \Delta t_i \cdot v_i}{|v_n - v_{DS}|}, \text{ where}$$

   Δt_i is the generated time headway for vehicle i, [s]

   v_i is the desired speed of vehicle i, [m/s]

   v_{DS} is the present speed of driving simulator, [m/s]

4. Discard all vehicles except the last generated.

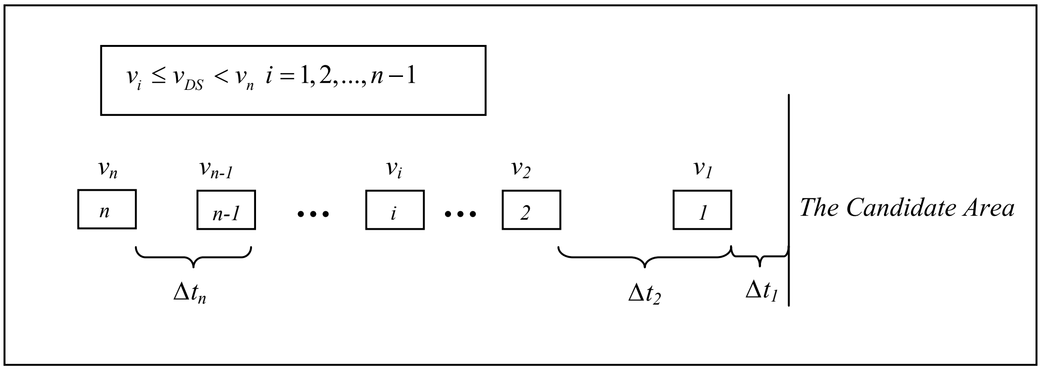

FIGURE 5 Algorithm for generation of new vehicles

The algorithm generates, in principle a number of slower vehicles and one faster vehicle, and in practice only one faster vehicle, thus every slower vehicle is discarded. At the edge in front of the simulator, new vehicles are generated according to a corresponding algorithm. The stop criterion is then, of course, a desired speed lower than the simulator's present speed.

FUTURE RESEARCH

The existing test model is only able to generate and simulate traffic on plain and strait motorways without ramps. The test model is also restricted to two lanes in each direction, but enhancement to three or more lanes is not a big issue. At the end of this project the model will manage motorways and rural roads, not necessary straight and plain but without ramps and intersections. This implies, among others, a model for overtakes on rural roads.

Further research in this area depends very much on the expected usage of the driving simulator. To get a more complete modeling of rural roads and motorways the model should include intersections and ramps. The next natural enhancement would be to model urban roads with signalized intersections, pedestrians, cyclist, etc. It may also be interesting to improve the model with the possibility to simulate different ITS applications, such as Variable Message Signs (VMS) and static or dynamic route guidance.

Another interesting enhancement would be to improve the model to be able to simulate different weather and road conditions. When running for example experiments on winter roads the ambient traffic must also be affected by the changed road conditions, otherwise they will drive as if the conditions were unchanged, thus probably faster and without getting into skids. It is also important that the ambient vehicles react to events that the simulator driver is exposed to. If, for example, a child or a moose runs up on the road, the vehicles closest to the obstacle must react, thus decelerate and/or steer to avoid a collision. Using stochastic simulated vehicles in this type of situations increases indeed the statistical variation in conditions between the test drivers. To avoid this in such situations, it may be better to use deterministic vehicles with predefined movements, rather than stochastic simulated vehicles.

CONCLUSIONS

The traffic generation framework has, unfortunately, not yet been tested within the VTI driving simulator, due to the development of the new simulator. The framework has instead been tested using a computer program that simulates the driving simulator. It seems like the framework is able to generate and simulate surrounding traffic corresponding to the specified flow and composition. The division into several regions, the candidate areas and the simulated area, works as intended, that is the computational time is lower and the window can be longer compared to only using one long simulated area. Even when using rather large flows, about 3500 vehicle/h, and wide lengths of the different regimes, totally about 40 – 50 km, the computational time for one time step is not especially high on a modern PC, in average less than 1 ms on a computer with a 2.0 GHz processor.

The model has not yet been properly calibrated and validated. The calibration of this type of model must be done at a microscopic level, since it is the behavior of the ambient vehicles that is noticed by the driver. Calibration at a macroscopic level is less important. In the end it is not the mathematical calibration that's most important. The most important thing is that the ambient traffic "feels" like real traffic and in a perfect system, the simulator driver cannot conclude whether an ambient vehicle is driven by another human or by a computer.

Development of a traffic generation framework for driving simulators not only makes it possible to run new experiments in driving simulators, it also creates possibilities to enhance or develop new traffic simulation models. Statistics concerning all movements, including the driving simulator's movements, can be gathered. This data can then be used to study for example car-following-, lane changing-, and overtaking behavior. It can also be used for calibration of traffic simulation models on a microscopic level, for example calibration of acceleration and deceleration parameters.

REFERENCES

1. AIMSUN, by Transport Simulation Systems (TSS), http://www.aimsun.com/, 2003.

2. MITSIMLab, by MIT, http://web.mit.edu/its/papers/MITSIM2001.pdf, 2003.

3. VISSIM, by PTV, http://www.ptvag.com/cgi-bin/produkte/vissim.pl, 2003.

4. Swedish National Road and Transport Research Institute (VTI). Research Resources - Driving Simulator, http://www.vti.se/info/foresurs/edetalj.asp?RecID=646. Accessed Jun. 27, 2003.

5. Brackstone, M. and M. McDonald, Car-following: a historical review. Transportation Research F, Vol. 2, 1998, pp. 181-196.

6. Janson Olstam, J. and J. Simonsson, Simulated Traffic for the VTI Driving Simulator - a feasibility study (in Swedish), VTI-Notat 32-2003. Swedish National Road and Transport Research Institute, VTI, Linköping, Sweden, 2002, http://www.vti.se/PDF/reports/N32-2003.pdf.

7. Renault. Simulation Toolkit SCANeR II, http://www.experts.renault.com/kemeny/projects/scaner2/. Accessed Jun. 25, 2003.

8. INRETS. SIM2 - Open, low cost and modular architecture, http://www.inrets.fr/ur/simus/imasime.htm. Accessed Jun. 25, 2003.

9. NHTSA. National Advanced Driving Simulator (NADS), http://www-nrd.nhtsa.dot.gov/departments/nrd-12/NADS/. Accessed Jun. 25, 2003.

10. GlobalSim. Research simulators, http://www.drivesafety.com/research_simulators.html. Accessed Jun. 25, 2003.

11. Davidsson, F., et al., TPMA Model-1 final report, KTH, Stockholm, Sweden, 2002, http://www.infra.kth.se/ctr/projekt/tpma/tpma_en.htm.

12. Carlsson, A. and A. Brodin, The VTI traffic simulation model, VTI meddelande 321A. VTI, Linköping, Sweden, 1986,