DEVELOPMENT OF A MICRO-SIMULATION MODEL TO PREDICT ROAD TRAFFIC SAFETY ON INTERSECTIONS WITH SURROGATE SAFETY MEASURES

Gerdien Klunder1*, Arshad Abdoelbasier2 and Ben Immers3

1TNO, Business Unit Mobility & Logistics, P.O. Box 6041 - 2600 JA Delft - The Netherlands, Tel: +31 (0)15 269 66 60 – Fax: +31 (0)15 269 68 54 – E-mail: gerdien.klunder@tno.nl
2TNO, Business Unit Mobility & Logistics, The Netherlands
3TNO, Business Unit Mobility & Logistics, The Netherlands

ABSTRACT

This paper describes an ongoing research project at TNO in the Netherlands for assessing the safety of road networks using micro-simulation techniques. A benefit of micro-simulation comes from the ability to evaluate the safety of new ITS systems, new infrastructure design, management strategies and different traffic compositions beforehand. The use of surrogate safety measures (SSMs) is crucial to this approach. Part of the research is the development of a new micro-simulation model for intersection traffic, which can generate accurate SSMs. The new model aims to represent driver behaviour on intersections more accurately than the current generation of micro-simulation models.

KEYWORDS

Surrogate Safety Measures, Micro-simulation

INTRODUCTION

Traffic safety is an important area in transportation engineering. Traffic accidents cause a lot of damage, both personal, in the form of injuries or casualties, and financial, in the form of material damage to vehicles and loss of productivity as the result of accidents, etc. The evaluation of road traffic safety measures is usually performed retrospectively by comparing the traffic situation before and after realization of a change in the system. The current generation of commercial micro-simulation models has proven itself inadequate for the use of modelling safety related behaviour, especially on intersections. Statistics have shown that about half of all accidents occur on intersections.

The safety aspect within micro-simulation modelling has received less attention than, for instance, roadway capacity calculations, environmental pollution impact studies and noise pollution. One of the reasons for this is that for the latter studies, simple models expressing “normative” behaviour suffice. The evaluation of safety, however, requires a far more complex model, which is able to express “less-than-perfect” features in order to simulate human error-causing variations in risk during interactions between road users [1]. Nowadays, with
the amount of computing power available, these more complex models are becoming feasible. As indicated in [2], adopting parameter values that represent the actual behaviour of drivers, even when this reflects unsafe behaviour, is necessary for the evaluation of infrastructural design with simulation models.

At TNO two models are being developed which will be used to evaluate traffic safety using micro-simulation. One is the ITS modeller, which is a modelling environment for cooperative road-vehicle systems and is coupled to an existing commercial micro-simulation model. The other is a new micro-simulation model specifically designed for the assessment of traffic safety on single intersections, with a high level of detail and calibrated with accurate real-world data.

RESEARCH APPROACH

In micro-simulation models, the relationship between microscopic traffic flow characteristics and accidents can be established using the concept of surrogate safety measures (SSMs). Surrogate safety measures rely on the idea that accidents evolve from conflicts, which are situations where the probability of a collision is high. Some of the most used SSMs are the Time to Collision and Post Encroachment Time.

Input parameters for the micro-simulation model can have a direct effect on the resulting SSMs from these simulations. In the case of the before mentioned measures, parameters for car-following and traffic gap acceptance models can have a big influence on the resulting measures. However, the relationship between the parameter settings of the micro-simulation model and the SSMs is not explicitly known, but rather follows from the simulation; it is not possible to deduct the SSMs directly from the input parameters, since the underlying traffic models are too complex and partly stochastic in nature. Also the processes governing the car-following and gap acceptance models might have to contend with other processes, which are needed for the vehicle control task, within the limited time and resources available to the driver.

For calibration and validation of the model, it is important that the parameter values are such that the vehicle and driver behaviour correspond with the real-world. In order to compare the micro-simulation output with the real-world, video footage and image processing is used. For this purpose, video footage has been recorded at a number of locations in the Netherlands over the period of at least one year. Analysis and evaluation of the years of video footage requires automatic image processing and interpretation of the safety-related traffic situations. Such an automated processing step provides a pre-selection of relevant video snapshots as input for traffic safety assessments. The findings will lead to a better insight in traffic safety and SSMs. This in turn can lead to improvements which can be made to the monitoring algorithms. An iterative learning process can be realized in which the micro-monitoring, modelling and simulations can be improved successively.

In figure 1 a schematic representation of this approach is shown. The literature review was performed and the results are being used during the development of the driver behaviour model. This paper concerns itself mainly with the model development. The video surveillance has already taken place, however at this point the image processing tools are not yet available. This means that the calibration of the simulation model can not be performed, since not all of the necessary data is available. Further stages of the research project are therefore on hold until all of the necessary data is available to continue.
SURROGATE SAFETY MEASURES

Surrogate Safety Measures reflect the safety of a facility or at least the increased probability of higher than average crash rates for a facility [3]. Important characteristics of these measures are:

- extractability from the simulation model,
- direct interrelation with accident risk,
- statistical efficiency (relatively frequent events).

A number of SSMs have been identified. These SSMs have been subdivided into measures indicative of accident probability and those indicative of accident severity. Furthermore, several SSMs have been identified for different types of traffic conflicts. In general, conflicts involving vehicles which travel in the same direction and on the same lane for a period of time are best measured using Time to Collision related indicators, while conflicts involving crossing vehicles are best measured related to the Encroachment Time.

The Time to Collision (TTC) is probably the most well known measure available. It is defined as the expected time for two vehicles to collide if they remain at their present speed and on the same path [3]. This measure is most effective in situations where vehicles travel along the same path for an extended period of time.
During conflicts where the vehicles paths cross each other for only a small period of time and the vehicles conversely do not travel in the same direction, the TTC is not very effective as a safety indicator. A better surrogate safety measure under these circumstances is the Post Encroachment Time (PET). This measure is defined as the time lapse between the end of encroachment of the infringing vehicle and the time that the vehicle with the right of way actually arrives at the potential point of collision [3]. This point, where the PET is measured, is of course located at the overlap of both vehicle’s trajectories.

THE INTERSECTION MICRO-SIMULATOR

The new micro-simulation tool for traffic on intersections is based on the MARS framework, which is also being developed at TNO but is also used for different research purposes. The Multi-Agent Real-time Simulator (MARS) [4] is a development framework for generic, high-fidelity simulation. It follows an “autonomous agents” approach to modelling and simulating complex dynamical systems. The MARS world is entity based. Some of these entities can act autonomously, based on input from sensors and actuators they possess. Other entities are static, e.g. roads and roadside objects.

The vehicles in the simulation were designed using dynamics models in Simulink. These models are highly detailed and calibrated to match the performance of real world vehicles. The control (i.e. the driver model) of these vehicles can be performed by a number of higher level controllers programmed in Java or another programming language. The optional visualisation of the simulation world is done using standard VRML models. The position and movement of the VRML models is controlled by the MARS.

The Intersection Micro-simulator, as the new simulation tool is called, is still in the early stages of development. The MARS framework which is being used as a development environment provides a ready made simulation world infrastructure and vehicle dynamics models. This allows us to focus on the development of the driver behaviour model, something which was not yet present in the MARS framework and which is critical to a detailed micro-simulation environment capable of generating accurate surrogate safety measures.

The driving task can be split up into three levels, namely control, guidance and navigation [5]. The navigation task consists more of long term processes such as route choice decisions on larger parts of a vehicle trip. Since the environment in the Intersection Micro-Simulator only consists of single intersections, only the first two levels are really applicable here. Therefore, the focus is on these two levels of the driving task:

- The control level of performance, which comprises of second-to-second information inputs and reactions (e.g. applying the right amount of gas or braking power). These actions are performed automatically or instinctively by drivers.
- The guidance level, which involves matters of short term importance such as maintaining a safe speed and proper path relative to the environment. This involves active and conscious decision making on the part of the driver (e.g. obeying the regulations indicated by signposts, and adapting to the traffic circumstances).

The vehicle dynamics models in Simulink accept pedal and steering wheel positions as their input from the driver model. The driver behaviour model in the Intersection Micro-simulator has a layered design. The upper layers are concerned with the (active) driver decision making
processes which are performed on the guidance level, while the lower layer translates these decisions into the appropriate vehicle control commands (gas/brake and steering).

At the current stage of development, we have focussed on implementing the minimal set of features into the model which are necessary to perform the basic behaviour of drivers on intersections. We decided to start with the modelling of unsignalized intersections. The features we have chosen are steering and speed control during turns, right of way determination when multiple vehicles arrive at the intersection at the same time and gap acceptance when other vehicles have the right of way. Of course it is also necessary to implement basic features such as car following and distance keeping in order to keep the vehicles from colliding with each other.

![Figure 2 - Left turn trajectories](image)

The steering heuristic in the driver model determines amount of steering necessary to arrive at the target lane after crossing the intersection. Figure 2 shows some resulting vehicle paths for left turning vehicles. The faster the vehicle drives, the wider the resulting turn will be. It is also possible to vary the starting point of the turn for different drivers in the simulation.

Figure 3 shows a simplified version of the driver decision model structure when approaching an intersection. During the simulation, each driver model instance can be initialized with a different set of parameters. It is possible to assign the drivers different preferences for speed during turns and straight road sections, minimum gap lengths which they are willing to accept when crossing or merging into traffic streams with a higher priority, and minimum following distances when in car following mode. These parameters could be set manually for different drivers or distributed stochastically over the entire set of drivers in the simulation.

Varying the minimum acceptable gap, also called the critical gap, for yielding vehicles can have an effect on the approaching vehicles with the right of way. The gap in the higher priority traffic stream is measured in seconds at a point shortly before the right-of-way vehicles reach the intersection. If the accepted gap is too small, the approaching right-of-way vehicle may need to take evasive action (slow down or move to another lane when possible) in order to avoid a collision.
INITIAL RESULTS

Two series of experiments were set up to measure the effect of smaller critical gap values. One set of experiments consisted of vehicles from two different traffic streams both merging into same destination lane at the intersection. During these experiments we measured the TTC for the next right of way vehicle when a vehicle from the minor traffic stream crossed the intersection. The right of way vehicles in these experiments drove straight through on the intersection at an average speed of 50 km/h. Of all the conflicts which occurred during the simulation, the smallest TTC was recorded for each different setting of the critical gap value. We also measured the corresponding speed decrease by the right of way vehicle, if any. The results are seen in the second and third column of table 1. The results show that as the critical gap value decreases, increasingly unsafe situations can occur at the intersection. TTC values below 1.5 seconds are generally deemed very unsafe, and we see at the critical gap setting of 3.5 seconds that at least one vehicle with the right of way had to decrease its speed significantly in order to avoid a collision.
### Table 1 - Surrogate safety measurements for decreasing critical gap time

<table>
<thead>
<tr>
<th>Critical Gap</th>
<th>Minimum measured TTC</th>
<th>Speed decrease by right-of-way vehicle</th>
<th>Minimum measured PET</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.0s</td>
<td>3.1s</td>
<td>0 km/h</td>
<td>2.1s</td>
</tr>
<tr>
<td>4.5s</td>
<td>2.2s</td>
<td>&lt;3 km/h</td>
<td>1.9s</td>
</tr>
<tr>
<td>4.0s</td>
<td>1.8s</td>
<td>7 km/h</td>
<td>1.2s</td>
</tr>
<tr>
<td>3.5s</td>
<td>0.7s</td>
<td>18 km/h</td>
<td>n/a</td>
</tr>
</tbody>
</table>

The other set of experiments was set up so the vehicles from the minor traffic stream crossed the major traffic stream. The PET was measured for these crossing events. Results from these simulation experiments are shown in the last column of table 1. We see a similar pattern to the TTC measurements in the other experiment series. Only here, at a critical gap time of 3.5 seconds sometimes a collision was unavoidable.

**FURTHER DEVELOPMENT**

It should be noted that the critical gap time implementation is still very static in the Intersection Micro-simulator. The critical gap can be different depending on whether the vehicle from the minor traffic stream is starting from a standstill, or if it is driving towards the intersection at a certain speed. The critical gap for an already moving vehicle could be smaller than for a vehicle which is standing still. This dynamic critical gap scheme will be added in a future revision of the gap acceptance model.

In the near future more features will be implemented in the driver behaviour model. At this time it only supports unsignalized intersections, but support for signalized intersections will be added too. We are also planning to add the possibility for the driver model to make errors in perception and/or control actions. With this feature, it will be possible to study the effects of distracted or inattentive drivers (e.g. because of using a mobile phone or some other device while driving) on the traffic safety level.

Currently, the Intersection Micro-simulator works on top of the MARS framework which limits the total amount of vehicles during a single simulation to a few dozen. The choice for the MARS was made because it allowed us great control over all aspects of the simulation, unlike if we were to use a closed source commercial micro-simulation model. The intention is to port the driver behaviour model onto other micro-simulation environments as well. A likely candidate for this is Quadstone Paramics, where the Intersection Micro-simulator can act as a more sophisticated controller for traffic on intersections. Paramics is a micro-simulation model capable of modelling very large urban and regional road networks. However the modelling of the traffic on intersections is a little rough and inaccurate and therefore is not suited for safety studies. With the coupling of Paramics or another large scale micro-simulation tool and the Intersection Micro-Simulator it should become possible to evaluate effects of safety related measures on the network level.

The Intersection Micro-simulator is still in the primary stages of development. Important next steps are to calibrate the sub models using real world data and extending the capabilities of the current model elements to represent a broader variance of driver behaviour on intersections in the simulations.
CONCLUSION

The research approach presented in this paper is very ambitious, taking into account the huge complexity of the accident process and all related matters, but the end result will mean a substantial improvement compared to the traditional safety assessment methods. Traditionally only average risk factors and traffic volumes are used for each type of road connected to the intersection. With the Intersection Micro-simulator we are trying to create a highly detailed and versatile micro-simulation environment which can be used to evaluate the effects of traffic management measures both at the level of detailed intersections as well as the network wide level.

The use of surrogate safety measures and conflicts is more directly connected to the cause of incidents than the traditional approach. Since every traffic situation is unique, it is questionable whether the application of average risk factors for different locations or times produces reliable results. Furthermore, the consequences of developments, like the introduction of new ITS systems like advanced driver support systems cannot be measured using the traditional approach. Especially under these circumstances it will be very useful to have a micro-simulation model which can combine vehicles both with and without such support systems in simulations studies and measure the effect of these new techniques on safety and other traffic characteristics on a networks scale with greater accuracy.

REFERENCES


