Lane changing and merging under congested conditions in traffic simulation models

P. Hidas
School of Civil and Environmental Engineering,
University of New South Wales, Australia

Abstract

This paper reports the findings of a study aimed at testing and evaluating the lane changing and merging abilities, especially under congested flow conditions, of four traffic simulators: AIMSUN, ARTEMiS, PARAMICS and VISSIM. Several hypothetical traffic scenarios that require a large proportion of vehicles to merge and/or change lanes are constructed. These scenarios are then implemented in each model and simulated under increasing traffic flow rates. The model outputs are compared and evaluated and conclusions are drawn on the quality of the simulators in terms of their ability to model lane changing and merging in congested conditions. This paper describes the test scenarios, briefly introduces the parameters related to lane changing available in each simulator, presents the results of the simulation runs, summarises the findings and formulates recommendations for further research and model development.

Keywords: traffic microsimulation, lane changing, merging, traffic modelling.

1 Introduction

Microscopic traffic simulation models are becoming increasingly important tools in modelling complex transport networks and evaluating various traffic management alternatives that cannot be studied by other analytical methods. Several traffic simulation tools are used in many countries, including AIMSUN, PARAMICS and VISSIM. While these packages are regarded as the state-of-the-art, several problems were also identified in practice. A topic of increasing concern is the validity of the microscopic sub-models, such as the car following and lane changing models. In a recent literature review and user opinion survey [1] several reports were found on lane changing and merging problems in congested flow conditions.
The aim of this study is to investigate, compare and evaluate the lane changing and merging abilities of some traffic simulators, especially under congested flow conditions. Four simulators are included in the study: AIMSUN (v4.2) [2], ARTEMiS (v1.50) [3, 4], PARAMICS (v4.2) [5, 6] and VISSIM (v3.70) [7]. Several hypothetical traffic scenarios that require a large proportion of vehicles to merge or change lanes are constructed, then implemented in each model and simulated under increasing traffic flow rates with various model parameter combinations. The model outputs are compared and evaluated and conclusions are drawn on the quality of the simulators in terms of their ability to model lane changing and merging in congested conditions.

This study is not aimed at calibrating the models to any particular real traffic scenario, but the aim is rather to discover the realistic range of output performance indicators, such as flow-speed relationships, that the models are able to produce in the tested scenarios, and to identify any limitations or irregularities in the models that require further research and development work.

2 The case study scenarios

Due to space constraints only two of the several traffic scenarios tested are reported here. The physical parameters and the demand flow levels for the three scenarios are as follows.

2.1 Weaving section

The weaving section network model consists of two input sections and two exit sections joining in a V-shape, and a common weaving section in the middle. Each road section is 150 m long, and the speed limit is 110 km/h. The input and exit sections each have 2 lanes, while the weaving section link has 4 lanes.

A period of 90 minutes was simulated, using increasing 15-minute demand flow rates (see Figure 2 below). The demand flow rate at the start was set to approximately 50% saturation level and gradually increased to full saturation. Both input sections had the same input flow rate, and the same proportion of weaving vehicles set to 40 percent. The demand flow composition is 95% cars and 5% trucks.

2.2 On-ramp terminal

The on-ramp terminal network consists of a 300 m long motorway section and a 150 m long on-ramp section, ending in a 100 m long ramp terminal (i.e. one acceleration lane along the motorway lanes). The motorway has 2 lanes and the speed limit is 110 km/h, while the ramp has one lane and an 80 km/h speed limit.

A period of 120 minutes was simulated, using increasing 15-minute demand flow rates, again starting at a low saturation level and going up to full saturation (see Figure 4 below). The ramp flow rate is always 30 percent of the total flow rate. The demand flow composition is 95% cars and 5% trucks.

A period of 90 minutes was simulated, using increasing 15-minute demand flow rates. Both input sections had the same input flow rate, and the same
proportion of weaving vehicles set to 50 percent. The demand flow composition is 95% cars and 5% trucks.

2.3 Model parameters used for testing

The following parameters were used to investigate the lane changing and merging abilities of the models.

In AIMSUN, two local parameters have the greatest influence on lane changing [2]: Distance Zone 1 which determines the distance from the next turning point where vehicles start trying to move into their required turning lane, and Distance Zone 2 (DZ2), where vehicles are forced to reach their turning lane and other vehicles may be forced to slow down to let them in. Besides, the Reaction Time (RT) global parameter also has a significant impact on the flow conditions, including lane changing.

ARTEMiS has a fixed 1 second simulation step time, but it uses several global parameters specific to lane changing [3]: Urgency Start and Max Urgency distance: these distances, measured backwards from the turning point, determine the rate of the accepted speed and deceleration parameters (defined as follows), increasing linearly as the vehicle approaches the turning point. Min/Max Speed Reduction (FSR): the speed values that a follower vehicle in the target lane is willing to slow down. Min/Max Foll and Own Deceleration Rate Factor (FDR/ODR): the deceleration rates, that a follower vehicle and a lane changing vehicle respectively are willing to use.

PARAMICS has no specific/local parameters related to lane changing. The factors tested in this study included the global variables Mean Headway, Reaction Time, and Timestep [5, 6], each having a significant impact on the basic traffic flow conditions.

VISSIM has two local distance parameters, Lane change and Emergency Stop, similar to those in ARTEMiS, and Maximum and Minimum Deceleration, and a reduction rate [7], for the lane changing and the follower vehicles, similar to those in ARTEMiS. The simulation step time was also tested in VISSIM to check its effects on the flow results.

All models except PARAMICS use some form of the concept of “lost vehicles”: if a vehicle is unable to get into the lane required to continue its route, it will either be destroyed or (in AIMSUN) it will continue travelling towards the wrong destination. The number of lost vehicles indicates the success of the simulation.

3 Results of the case studies

A large number of simulations were run in each model with varying model parameters in order to test the capabilities of the models. The simulators can produce a wide range of performance indicators in various time and space aggregation levels, but due to space constraints, only a brief summary of the results can be presented here.

In line with the stated objectives of this study, in the following sections we summarise the average flow and speed range achieved with different parameters.
in each model, and select one set of results from each, considered the “best” (i.e. most realistic, standard) results for comparison.

### 3.1 Weaving section case

Table 1 shows the minimum and maximum average flow and speed results obtained from the four simulators. These are the average flows and speeds of all vehicles on the weaving section link over the whole simulation period.

<table>
<thead>
<tr>
<th></th>
<th>AIMSUN</th>
<th>ARTEMIS</th>
<th>PARAMICS</th>
<th>VISSIM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flow</td>
<td>Speed</td>
<td>Flow</td>
<td>Speed</td>
</tr>
<tr>
<td>Minimum</td>
<td>1289</td>
<td>43.0</td>
<td>1262</td>
<td>40.8</td>
</tr>
<tr>
<td>Maximum</td>
<td>1699*</td>
<td>92.6*</td>
<td>1475</td>
<td>56.1</td>
</tr>
<tr>
<td>Best</td>
<td>1467</td>
<td>53.9</td>
<td>1475</td>
<td>52.8</td>
</tr>
</tbody>
</table>

Note: * unrealistic result

In AIMSUN, the results mostly depend on the Distance Zone 2 (DZ2) parameter, which needs to be calibrated for every local case. The Minimum results were achieved with DZ2= 3 sec and the Maximum values with DZ2= 1 sec. The results are also very sensitive to the Reaction Time (RT) and RT= 0.10 sec produced the Maximum results, however these results are unrealistic as a 0.1 sec reaction time is humanely impossible. The “Best” results are from DZ2= 1 sec with the standard RT= 0.75 sec.

In ARTEMiS, as expected, the flow and speed values increased in parallel with the level of cooperation between vehicles set by the accepted Speed and Deceleration parameters: the Maximum results reached with the highest accepted speed and deceleration values and the Minimum values with zero parameters. The “Best” results are achieved by the “maximum cooperation” option.

In PARAMICS, the results were most influenced by the Reaction Time (RT), the Minimum achieved with RT= 1.50 sec and the Maximum with RT= 0.60 sec. The “Best” results are taken at the standard RT= 1.0 sec.

In VISSIM, as in ARTEMiS, the results are related to the level of cooperation allowed by the accepted Deceleration parameters: Minimum results occurred at minimum or no cooperation (accepted deceleration = 0) and Maximum results at maximum cooperation (accepted deceleration = -3.0 m/s²). The simulation timestep had little effect on the results.

Table 1 shows that the average flow is in a similar range in 3 models, while it is significantly less in PARAMICS. In the average speeds, AIMSUN and ARTEMiS produced significantly higher values than the other two models.

Figure 1 shows the speed-flow curves of the “Best” results for the four simulators. There are significant differences between the models. AIMSUN shows the highest maximum throughput and the longest under-saturated period. The ARTEMiS curve has a similar shape with somewhat lower maximum flow, but higher speed range in the congested period. VISSIM shows a very different
picture with the lowest maximum throughput and most of the time in the low-speed fully congested conditions. PARAMICS shows an even higher level of fully congested scenario with the lowest maximum flows but slightly higher average speeds than the other models.

Figure 1: Speed-flow relationship for the Weaving case.

Figure 2: Flow and speed profile for the weaving case.
Figure 2 shows the 5-minute average flow and speed values over time from the “Best” results. AIMSUN has the highest maximum flow throughput for a short time but it drops down significantly as full congestion sets in. ARTEMiS and VISSIM have similar maximum throughputs, and PARAMICS maintained significantly lower throughput over the whole period. The speed comparison shows that full congestion occurred in each model, but at very different times and at very different average speeds. In AIMSUN, full congestion occurred only at the last third of the period, but at a very low speed. In ARTEMiS and VISSIM the speed drop happened after one third of the time, with ARTEMiS maintaining a slightly higher speed over the congested period. PARAMICS had a significantly lower average speed right from the beginning, which dropped further down almost immediately after the start, indicating a fully congested situation over the whole simulated period.

3.2 On-ramp terminal case

Table 2 shows the minimum and maximum average flow and speed results obtained for the ramp terminal case. These are the average flows and speeds of all vehicles on the ramp terminal link over the whole simulation period. In AIMSUN, the Two-lanes Car Following model (2LCF) and the Reaction Time (RT) can be used to calibrate the on-ramp model. The results are again very sensitive to the reaction time, while 2LCF did not have a significant effect. RT = 0.25 sec produced the Maximum results, however these results are again unrealistic. The “Best” results are from the standard RT = 0.75 sec.

In ARTEMiS, as expected, the flow and speed values increased in parallel with the level of cooperation between vehicles set by the accepted Speed and Deceleration parameters: the Maximum results reached with the highest accepted speed and deceleration values and the Minimum values with zero parameters. The “Best” results are achieved by the “maximum cooperation” option.

In PARAMICS, the Minimum results were achieved with Reaction Time RT = 1.5 sec and the Maximum with RT = 1.0 sec and Timestep = 8. However, this Maximum result also seems unrealistic, as the average speeds do not show the effects of congestion. The “Best” results are taken at the standard RT = 1.0 sec and timestep = 2.

Table 2: Overall results for the ramp terminal case.

<table>
<thead>
<tr>
<th></th>
<th>AIMSUN</th>
<th>ARTEMIS</th>
<th>PARAMICS</th>
<th>VISSIM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flow</td>
<td>Speed</td>
<td>Flow</td>
<td>Speed</td>
</tr>
<tr>
<td>Minimum</td>
<td>1431</td>
<td>52.7</td>
<td>1435</td>
<td>62.8</td>
</tr>
<tr>
<td>Maximum</td>
<td>1583*</td>
<td>80.6*</td>
<td>1508</td>
<td>78.0</td>
</tr>
<tr>
<td>Best</td>
<td>1505</td>
<td>59.7</td>
<td>1508</td>
<td>71.0</td>
</tr>
</tbody>
</table>

Note: * unrealistic results

In VISSIM, the effects of the simulation timestep and the trailing deceleration were investigated. Two experiments had significantly lower results: the 1.0
second time step and the zero accepted trailing deceleration case. It seems these parameters are beyond the satisfactory range for the model. Again, the results are related to the level of cooperation allowed by the accepted Deceleration parameters.

Table 2 shows that the average flows are in a similar range in all 4 models, while there are more differences in the average speeds: PARAMICS having the highest and AIMSUN the lowest, the other two models somewhere in between.

![Graph](image-url)  
**Figure 3:** Speed-flow relationship for the ramp terminal case.

Figure 3 presents the speed-flow relationships of the selected ‘best’ alternatives from the four models. The figure shows that the models produce similar maximum throughput values, but the shape of the curves are quite different. PARAMICS shows the highest speed values for most of the flow range. In VISSIM the curve suddenly drops to the fully congested conditions at the maximum flow with very low speed. ARTEMiS produces a fairly similar curve with slightly more continuous change between the unsaturated and saturated parts of the curve. AIMSUN predicts significantly lower speeds for the same mid-range flow rates than the other two models.

Figure 4 shows the 5-minute average flow and speed values over time from the “Best” results. The flow profiles of the four models are very similar, indicating that full saturation was reached in the last 25-30 minutes of the period. There are far more differences in the speed profiles. PARAMICS maintained a very high average speed, only dropping to a low level in the last half hour, but showing recovery towards the end. However, it must be noted, that due to the way on-ramps are modelled in PARAMICS, the average speed in this case does
not contain the speed of the vehicles entering through the ramp, therefore this speed is not fully comparable with those of the other models. VISSIM produced a similar speed profile, but in the last 20 minutes the speed dropped to a constant 20 km/h level. In ARTEMiS, the speed drop to the fully saturated level occurred 20 minutes earlier (at a lower demand flow level) than in the previous two models. AIMSUN had the lowest average speed during the unsaturated portion of the simulated period, and the speed drop showing the full saturation occurred at about 10 minutes earlier than in ARTEMiS, but it maintained a 15 km/h higher speed than ARTEMiS and VISSIM over the saturated period.

![Speed Flow Profiles](image)

**Figure 4**: Flow and speed profile for the ramp terminal case.

### 4 Conclusions

The following conclusions can be drawn from the case studies. While the aggregate, macroscopic performance indicators produced by the four models seem to be reasonably close to each other and realistic in most cases, there were some significant differences among the models worth noting. There are also important differences in the number and nature of model parameters available in each simulator that can be used to fine-tune the results to a particular set of observed data. For each simulator a number of weaknesses and model limitations were identified that require further investigation and development.

AIMSUN was found to be very sensitive to the value of ‘reaction time’ which is taken as the simulation time step. Values of ‘reaction time’ at and below 0.5 second are unrealistic and indeed, produce unrealistically high vehicle throughputs without congestion effects. It seems illogical to combine the reaction time with the simulation time step if its range goes beyond what is humanly possible. The local parameters related to lane changing and merging provide very good possibilities for calibration and validation.
ARTEMiS was found to produce satisfactory results with its fixed 1.0 second simulation time step. The number of lost vehicles was acceptable in most cases but high enough to require further model improvements. The parameters specific to lane changing can be used for calibration and validation. The on-ramp scenario indicated that the increasing willingness of the follower vehicles on the main road to cooperate did not result in any perceivable benefit in the system. This shows the need for a review of the lane changing cooperation algorithm.

PARAMICS has produced significantly lower flow and speed values than the other models in the weaving scenario, while it had the highest values in the on-ramp case. This indicates some weaknesses in the lane changing models. As PARAMICS does not have any specific parameters to lane changing, possibilities for calibration and validation are very limited in this simulator. This was also highlighted by the user opinion survey results [1], in which several users noted that they have developed special plug-in modules to eliminate local lane changing problems in PARAMICS.

VISSIM produced very consistent results in both scenarios. It was found that while the model works well with simulation time steps up to 0.5 seconds, at 1.0 second time step the results become unsatisfactory. In general, the model produced very few lost vehicles, but the circumstances in which the vehicles were lost are more serious than what is described in the user manual: it was found that some vehicles were removed when a collision occurred between lane changing vehicles or when a vehicle reached the end of the acceleration lane. While these occurrences are rare, they highlight the need for further improvements in the lane changing and merging algorithms. VISSIM also provides a number of parameters specific to lane changing that can be used for calibration and validation.

It is important to note that the comparisons presented in this study are purely relative and are not meant to indicate any qualitative evaluation of the models, because the scenarios used for testing do not represent ‘real’ situations and therefore the ‘true’ flow conditions that would occur in any similar real case are not known. However, the characteristic differences between the models in the outputs resulting from the same inputs are important to note.

Overall, this study has shown that there are significant inconsistencies between simulation models and the results need to be treated with caution, especially when modelling highly congested traffic scenarios. Further research and model development work is required to improve the lane changing and merging algorithms in each model.

This study was based on a few simple hypothetical traffic scenarios and a limited number of simulation experiments in order to investigate the basic lane changing and merging abilities of the three simulators. While a number of issues for further research were identified, more work is required to fully map out the capabilities and limitations of each model. Several simulation runs with different random seeds should be done to show the variance of the results from the same input data and model parameters. There are other model parameters and value combinations to be investigated in each model. There are other, more complex traffic scenarios to be tested, such as lane selection related to downstream short
lanes and multiple turning movements from the same lane. These experiments will be considered in the next phase of this research study.

Acknowledgements

The author is grateful to Martin Fellendorf (PTV AG) for providing a copy of the VISSIM simulator for research purposes, and to Hussein Dia at the University of Queensland for providing access to PARAMICS through the ITS Laboratory project in which UNSW is a partner.

References