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State-of-the-art of micro-simulation models

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Executive Summary

Simulation tools that accurately model traffic are essential for highways scheme design. Without them we cannot predict the consequences of new proposals. Our impact assessment considerations should include safety, environment, journey time reliability, capacity enhancement and traveller comfort. The outcomes can be modelled and evaluated at two levels – the planned benefits for a specific element of the network and the whole network effect, which may be positive or negative.

This paper focuses on the tools available to us to model the outcomes that will result from ITS (Intelligent Transportation Systems) implementation. In particular it focuses on microsimulation tools as these are the type most able to make the predictions we need. ITS is arguably the most cost-effective means available to improve the highways network. These systems are aimed primarily at capacity enhancement, but safety, environmental, journey time reliability and comfort gains are also evident. ITS comes in many forms, from infrastructure-based schemes such as the variable speed limits on the M42 and matrix signage, to in-car devices and vehicle-to-vehicle controls. Many of these systems are innovative and some proposals offer step-changes in the way vehicles will use the highway. Where safety is affected we must, as a minimum, assess the effect of our proposals before they are implemented. Ideally we will understand their effect across the range of impacts even before the costs of development are committed.

Microsimulation tools model individual vehicles using ‘bottom up’ rules to determine each vehicle’s speed, acceleration, lane changing and so forth. The aggregation of vehicles models the overall performance of the highway. This is to be contrasted with macrosimulation tools which model the highway as a single entity and use parameters derived from periods of observation of overall behaviour. It can be seen that microsimulation tools are more able to adapt to new influences affecting vehicle behaviour; their downside is that many effects on the highway are complex and calibration of the tools is a problem. Macrosimulation is reliable as the tools are based on real aggregated speed-flow data and their speed makes them useful for real-time predictions. Their downside is that they are less able to predict the impacts of new interventions, and unable to address from first principles an influence that is localised. There is also a hybrid category, known as ‘mesoscopic’ models. Mesoscopic models combine the properties of both microscopic and macroscopic simulation models by simulating significant events affecting individual vehicles, but describing their interactions and network and environmental conditions based on aggregate (macroscopic) relationships. Mesoscopic models are not normally able to deal explicitly with stochastic and probabilistic effects, such as randomness in queuing and flow breakdown. Such effects can be accommodated in mesoscopic models only through the parameters of embedded functions.

An accurate microsimulation model is thus vital for predicting how a new scheme or technology will perform, allowing inexpensive comparisons to be made before big money is spent on infrastructure. Equally, microsimulation could play a highly significant role in predicting congestion in real time, thus allowing network operators to mitigate through speed control and route guidance. Microsimulation models are already widely used in assessing impacts on emissions, noise and fuel consumption.

The reader of this report will understand the range of techniques used to build the microsimulation engines that lie at the heart of the microsimulation tools, and the

accuracy of these techniques. The importance of accurately calibrating the individual vehicles within the microsimulation is highlighted – the predictions of key events such as flow breakdown on trunk roads are highly sensitive to calibration. The report reveals a wide range of approaches to simulation. The three market leading tools in Europe (AIMSUN, VISSIM and PARAMICS) are assessed in detail alongside SISTM, a product developed by TRL. In addition some 49 other tools (mostly developed for research purposes) are compared.

This report recommends that significant improvements can be made to most microscopic modelling projects through enhanced calibration using CCTV, MIDAS loops and other highways data. Such data would also facilitate improvements to lane changing algorithms, so that lane changing characteristics and use of lanes are modelled better. The combined effect would be more reliable prediction of the impact of highway schemes.

1 Introduction

Tools that can accurately model traffic are essential for scheme design and appraisal, environmental evaluations, testing of Intelligent Transport Systems (ITS), and congestion prediction and mitigation. Depending on the scale of the scheme or ITS intervention, a microscopic or macroscopic model may be most appropriate.

Microscopic models model individual vehicles using “bottom up” rules to determine their speed, acceleration and desire and ability to change lanes. Macroscopic models make use of flow-delay relations based on road type or junction type.

Microscopic models are useful for modelling microscopic interventions such as ramp metering, extending a slip road, urban traffic control systems, or testing the impact of inter-vehicle communication enabling cooperative merging or vehicle trains.

Macroscopic models are used for modelling strategic transport interventions, such as park-and-ride schemes, tolling, citywide route choices, or changes in public transport fares.

This paper focuses on microsimulation, as this is the tool that is most likely to assist in modelling ITS, which arguably is the most powerful tool available for capacity increase in the transport network of the future.

An accurate microsimulation model is vital for predicting how a new scheme or technology will perform, allowing inexpensive comparisons to be made before big money is spent on infrastructure. Equally, microsimulation could play a big role in predicting congestion, thus allowing mitigation through speed control or route guidance. Emissions, noise and fuel consumption models based on acceleration and speed rely on microsimulation models, and the better the model the more precise the prediction.

The reader of this report will understand the range of established techniques used to build a microsimulation engine and the accuracy of these techniques. The importance of calibrating the microsimulation to real world data will be highlighted. Three commercially mature models are discussed, and a flavour is given of the large number of other models developed and their availability.

The report focuses on motorway traffic simulation, assesses the sets of rules that are applied to the vehicles in different types of models, and draws comparisons between them.

2 The models that make up a microsimulation

There are three main components to a microsimulation:

- a car following model,
- a lane changing model, and
- a gap acceptance model.

The car following model describes how a vehicle interacts with the vehicle in front in the same lane. The lane changing model consists of a series of conditions for deciding when to change lane and the urgency of the lane change. The gap acceptance model, in motorway traffic, measures the gap that will be between the subject and the lead vehicle in the new lane and the subject and the following vehicle in the new lane and determines if it is safe enough. Gap acceptance models are usually based on the same calculation that is required for the car following model.

A few models also include calculations for the lateral position of a vehicle in its lane. However, these are not widespread and are not a prerequisite for accurately reproducing the primary features of highway traffic. Therefore these lateral position models have not been included in the literature review.

The review focuses on the different types of car following models, and then gives a sample of lane changing decision algorithms used in existing commercial models.

Microsimulation models are often linked with other features used for traffic analysis including:

- route choice algorithms – these establish the route through the network that each individual vehicle takes
- matrix generation algorithms – these establish the origin and destination of each vehicle
- traffic signal control systems – these determine the pattern of red and green signals at traffic lights, often using live data from the simulation.

However, this report does not assess the existence or otherwise of these features in modelling packages, nor of the relative merits of techniques in these areas.

2.1 Car following models

Car following models describe the longitudinal interaction among vehicles in a single stream of traffic. The main different types are as follows.

GHR model

The Gazis-Herman-Rothery (GHR) model, first proposed in 1958 at the General Motors research laboratory in Detroit (Chandler 1958), is based on an intuitive hypothesis that that drivers' acceleration was proportional to the difference in velocity and to the deviation from a set following distance. It was reviewed by Brackstone and McDonald (1999) and it was found that different studies came up with significantly different values for the calibration constants. This difficulty in calibrating has resulted in the model falling out of use.

Linear model

The Linear Model by Helly (1959) was based on the GHR model and included additional terms for the adaption of acceleration if the vehicle in front (or two in front) was braking. However, it had similar difficulties in calibration as the GHR model, and in addition did not work well at high speeds. Nevertheless, it is part of the SITRA-B model which is used for low speed urban simulations.

Collision Avoidance

In contrast, Collision Avoidance models are widely used in the present day. The most successful of these is the Gipps model (Gipps, 1981) which gives realistic behaviour for pairs of vehicles and platoons (a group of vehicles travelling bunched up together) based on calculating a safe following distance given driver reaction time and the relative speeds and distance between the vehicles. Its strongest feature is the ease with which it can be calibrated. Liu and Wang (2007) describe the method using inductive loop detector data which provide measurements of average traffic speed, flow, occupancy and vehicle composition at one-minute intervals. Thus they were able to find the optimum acceleration and reaction time values. They used a combination of Gipps (1981) and Brackstone (2002) which is a close-following model.

The main parameters that go into a Gipps (1981) model are described by Bonsall et al (2005). These are:

- desired speed (which should be affected by gradients and curvature)
- desired headway
- reaction time (which is often the simulation time step)
- normal acceleration (for relaxed following)
- maximum acceleration (for overtaking)
- normal deceleration (when approaching a known obstacle from a long distance)
- maximum deceleration (for emergency braking).

The paper lists values for these parameters which were found through observations or derived from theoretical calculations in various studies. For example, Gipps (1985) estimated that drivers' reaction times are 0.67 seconds, which is close to what was observed in some trials, including one by Olson et al (1984). Olson established two ranges of reaction times, one for young drivers (0.85 seconds to 1.6 seconds) and one for older drivers (0.57 seconds to 1.37 seconds). It is interesting that the older drivers had shorter reaction times. Other studies observed much higher reaction times, the highest being 2.74 seconds observed by McGee (1989).

AIMSUN, a popular microscopic traffic simulator developed in Spain is based on a variant of the Gipps model. Parameters are input with standard deviations so that ranges result. SISTM, TRL's motorway simulation model which is owned by the Highways Agency, also uses the Gipps model, as does DRACULA, built by the University of Leeds. These products will be covered more fully in the sections to follow.

Psychophysical or Action Point (AP)

Psychophysical or Action Point (AP) models rely on the definition of boundaries between different driving behaviours. These are defined in a graph plotting the speed difference versus the front to rear distance between the vehicles. There are two main models of this type, Fritzsche (1994) and Wiedemann (1974, 1991) and they form the basis of the commercial software packages PARAMICS and VISSIM respectively.

PARAMICS, see Figure 1, has five separate regions in the phase diagram, with the 'Danger' and 'Closing In' regions involving deceleration. However it is unknown to what extent the PARAMICS model follows from the original Fritzsche paper.

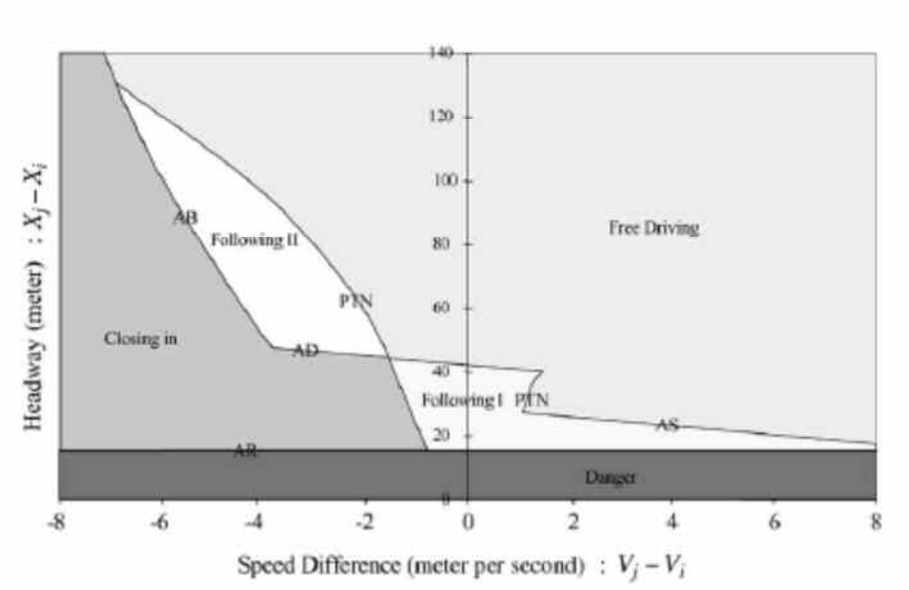


Figure 1: Fritzsche (1994) from Panwai and Dia (2005)

VISSIM, has four regions: free driving, approaching mode, following mode and braking mode. Figure 2 shows the interaction between two vehicles where the second vehicle is moving faster than, and approaching, the slower vehicle in front. It begins to consciously observe approaching a slower vehicle in front at the perception threshold, and decelerates until it reaches its individual threshold after which it follows at or below the speed of the vehicle in front. As the vehicle reaches the perceptual threshold for recognising small speed differences at short but increasing distances, labelled OPDV in Figure 2, the driver notices that it is travelling slower than the leading vehicle and starts to accelerate again.

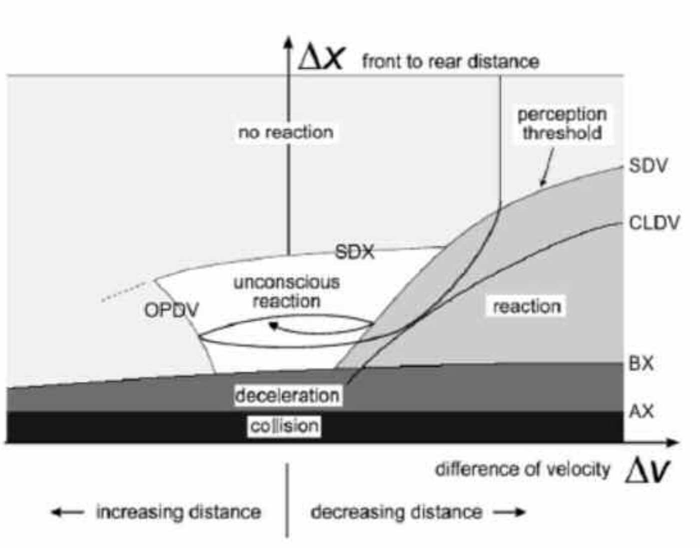


Figure 2: Wiedemann (1974) from Panwai and Dia (2005)

In Figure 2 the AX line marks the standstill distance between stopped cars, and BX is the safety distance at a given speed, which contains a random component. The 1999 model has not been published, but it is the one recommended for use on motorways. It contains nine main parameters including:

- standstill distance
- headway time

- standstill acceleration
- oscillation acceleration
- thresholds for entering following and speed differences allowed during following.
- a parameter that restricts the distance between coupled vehicles before acceleration is resumed.

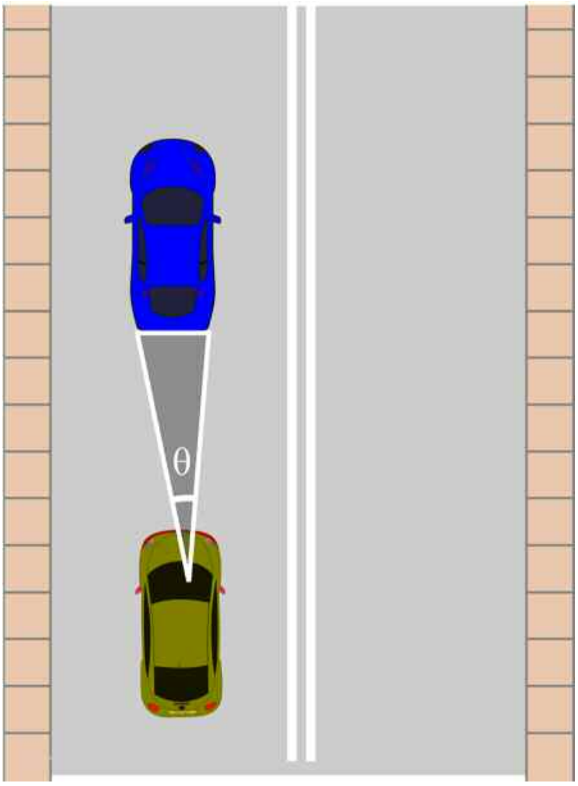


Figure 3

The Wiedemann 1974 model was also a kernel of a microsimulation model MISSION. The maths and experimental evidence for the action points are described fully in Wiedemann (1992). The point at which the driver perceives they are in a car following situation, for example, has been shown to be determined by the rate at which the horizontal angle subtended by the vehicle (as shown in Figure 3 by θ) is changing.

Whilst the elements of models which specify the driver perceptions are based on sound scientific studies, calibration of individual elements and thresholds has received little research, making the validity of models hard to prove or disprove.

Fuzzy Logic

In fuzzy logic-based models, variables such as headway are described by a mathematical tool called a “fuzzy set”. A fuzzy set is a range of parameters that describe a situation, for example ‘too close'. In classical set theory, parameters are either included in the set (are members of the set) or not. There is no middle ground. In contrast, fuzzy sets can have degrees of membership. Membership of the set lies somewhere between 0 and 1. The set 'too close' would contain a separation of 0.5 seconds with a membership of 1 while a separation of five seconds would not be too close and so would be given a membership of 0. A separation of one second would be considered too close by some drivers and not too close by others, and so would be given a membership of 0.5, for example.

Then rules are defined using the fuzzy sets, for example IF 'too close' THEN brake. However all the rules and memberships would have to be defined by hand, and could be viewed as very subjective.

Attempts have been made to "fuzzify" the GHR model (Kikuchi and Chakroborty, 1992) and MISSION model (Yikai, 1993), the latter of which formulated the microsimulation model MITRAM. However, no attempt was made to calibrate the fuzzy sets.

McDonald et al (1997) developed a fuzzy logic-based motorway simulation model where they investigated the membership sets using on road subjectivity tests.

Fuzzy simulation lends itself to the inexact nature of driving. One of the models investigated by The Smartest Project (1997) makes use of fuzzy logic: TRANSIMS (Davis, 1994). It has a cellular automata approach, which means that vehicles occupy discrete cells and follow rules based on the status of the neighbouring cells, but does not have the modelling details or accuracy to model intelligent transport systems such as ramp metering. Nor can it handle complex lane configurations (Zhang, 2002).

Comparison of Car-following Models with Empirical Data

A review of car following models carried out by Panwai and Dia (2005) used data from an instrumented vehicle travelling in stop-and-go urban traffic on a single lane in Stuttgart, Germany. The vehicle recorded its speed, headway to the vehicle in front, acceleration and deceleration. The authors repeated the study using three commercial software packages (AIMSUN v4.15, VISSIM v3.70 and PARAMICS v4.1) by programming in the lead vehicle and monitoring the behaviour of the following vehicle. Of the three, AIMSUN scored best in terms of its ability to mimic the movements of the instrumented vehicle in the original study (the logarithmic error metric was 2.55). VISSIM using Wiedemann 99 scored next best (4.50) followed by PARAMICS which scored 4.68. Wiedemann 74 scored 4.78. When the root mean square (RMS) error (which exaggerates errors in long distances) was used, PARAMICS was seen to be significantly worse than the other two.

A previous study using the same data from the instrumented vehicle scored a model known as T^3 Model even higher than AIMSUN (the logarithmic error metric was 2.4). The model is based on regression analysis of measurement data and is detailed in Bleile (1997).

Summary

The five types of models described above are summarised in the following table.

Model class	Advantages	Disadvantages
GHR	Intuitive assumptions	Very different results across calibration studies, needs microscopic data.
Linear	Uses data for two vehicles ahead, allows for vehicles not using optimum acceleration	Very different results across calibration studies, needs microscopic data
Collision avoidance	Easy to calibrate, only requires data such as maximum braking rates. Propagation of disturbances matches empirical studies	Safe headway does not take account of vehicles downstream
Psychophysical/action point	Perception thresholds are well-known in literature, behaviour appears realistic	difficult to calibrate, requiring “microscopic” data to calibrate trigger points, no account of vehicles downstream
Fuzzy logic	Behaviour appears realistic	no attempts have been made to calibrate the fuzzy logic sets, subjective

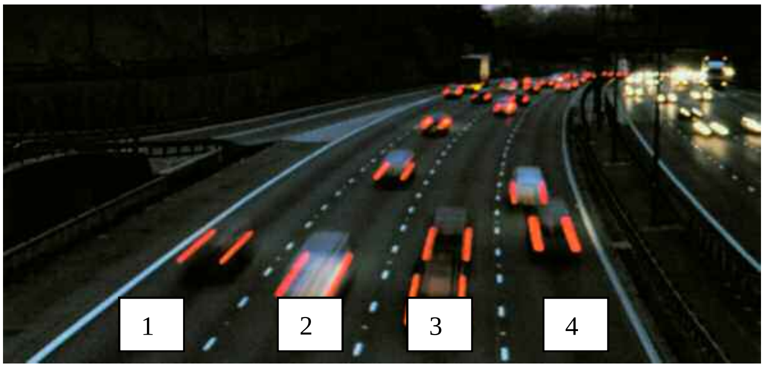
2.2 Lane Changing Algorithms and Gap Acceptance Models

Lane changing algorithms involve determination of intention to change lanes, and then the ability to change lanes is assessed using a gap acceptance model. Lane changing can be either mandatory or discretionary. Mandatory lane changes are due to needing to change lanes for a turning movement. Discretionary lane changes can be for speed advantage or to get out of the way of merging vehicles.

Unlike the car following models, there are not classes of lane changing algorithms. Each microsimulation package approaches the method of deciding whether to change lanes in a different manner. Therefore, it has been decided to compare and contrast four products. Three of these are market leaders in Europe (AIMSUN, VISSIM and PARAMICS) and a fourth is the microsimulation model SISTM built by TRL for the Highways Agency. While it is not commercially available, the algorithm is an interesting example as the calibration of it is known to the author.

AIMSUN

AIMSUN bases its lane changing algorithm on Gipps (1986), while the gap acceptance model used is based on the collision avoidance car following model described in Gipps



(1981). Each vehicle is set a preferred lane and a target lane as a function of its present lane. For example, if the present lane is lane 2, and the preferred lane is lane 3, the target lane will initially also be lane 3. However, if the move proves to be impossible or disadvantageous, the lane on the opposite side of the present lane (lane 1, in our example) is considered as a new target lane.

Three zones are defined in terms of distance to the next required turning point. In the farthest zone from the turning point lane changing is only considered in terms of desirability to reach the desired speed. In zone two the vehicle actively attempts to change lanes to meet the required turning movement, but does not interfere with the traffic in the lane it is moving into. In the third and final zone vehicles will slow down or even stop to wait for a gap and vehicles in the target lane may be forced to slow down to assist. Vehicles that have failed to change lanes in time for the turning movement, bearing in mind the maximum waiting time, continue on the wrong route. The zones are defined on a link by link basis and can extend beyond the link.

Using the car following equation, vehicles calculate the relative advantages of present and target lanes. Should the obstructions be level with each other or beyond the driver's horizon, the driver considers the next heavy vehicle in each lane as though it were the leading vehicle.

Vehicles are able to accept moves to lower speed lanes to ensure that vehicles move back after overtaking.

The model was designed for urban traffic. Nevertheless, it has been successfully validated and calibrated against flow and speed values provided by detectors on a freeway in Minneapolis, and in a different study using observed flows on Barcelona's ring roads. (The Smartest Project 2007).

VISSIM

VISSIM uses the car following, gap acceptance and lane changing algorithms set out by Wiedemann (1992). The car following model, described in section 2.1, is an Action Point model, relying on the point at which a driver perceives that he or she is following the vehicle in front. Similarly, the gap acceptance model relies on the drivers' perception of the speed and distance between the vehicles the driver intends to move between.

A hierarchy of questions determine if a vehicle will change lane:

1. Is there a desire to change lane?
2. Is the present driving situation in the neighbouring lane favourable?
3. Is the movement to a neighbouring lane possible?

The desire to change to a faster lane results from avoiding obstructions in the form of slower vehicles, while changes to slower lanes are due to the rules of the road. VISSIM lets the user select whether the rules reflect free lane selection as in America, or overtaking on the right as in the UK, or on the left as in Europe. If the latter two, vehicles return to slower lanes after overtaking. The considerations of vehicles differ depending on whether it is a movement to a faster or a slower lane.

Parameters include a minimum headway (front/rear) for lane changing in standstill conditions and acceptable deceleration rates for the lane changing vehicle and for the trailing vehicle in the new lane. As in the car following model, the perceptions of speed differences are important. The model allows for differences in perceiving vehicles behind through the rearview mirror.

As in AIMSUN there is a maximum waiting time for mandatory lane changes, but in VISSIM the vehicles are removed rather than rerouted.

A VISSIM model of a section of UK motorway, which TRL audited, demonstrated that VISSIM mostly failed to predict flow breakdown, although on some sections it was correct.

PARAMICS

PARAMICS is also an Action Point model, based on the work of Fritzsche (1994), although how much the original paper is followed is unknown.

PARAMICS has a separate model for on ramps where vehicles in the mainline traffic becomes aware of a vehicle on an approaching ramp and will attempt to change lanes in order to create a gap for the emerging vehicle. Within the program, the user must specify the first point at which drivers become aware of the need to change lanes, and also the point where the least aware drivers would become aware of the need to change lanes. Rather than defining specific parameters, the user defines types of driver.

SISTM

SISTM is the microsimulation model developed by TRL for the Highways Agency Although the model is not commercially available, the lane changing algorithm has undergone changes and subsequent recalibration, and is of interest to the reader in that it demonstrates the complexities and subtleties that are involved in producing an accurate and reliable lane changing algorithm. It is included here in detail because, of all the aspects of existing microsimulations, lane changing algorithms are the weakest component. The algorithm in SISTM is not perfect either, but the improvements to it are visible to the author and serve as a good example of how small changes to the logic can make a difference to the accuracy of the resulting model. Further work in this area would definitely be of benefit to the industry.

SISTM's lane changing algorithm was originally as follows:

(1) Lane Change Desire

- (a) Is the vehicle in front travelling too slowly?
  - (i) Desired speed of driver
  - (ii) Speed of vehicle in front
- (b) Am I in my preferred lane?
  - (i) Preferred lane
  - (ii) Current lane
- (b) Am I near to my desired exit and not in the correct lane?

(i) Desired exit

(ii) Required lane

(iii) Current lane

(c) Is a vehicle on an inside lane trying to merge?

(i) Intention of vehicle on inside lane

(2) Lane Change Availability

(a) Is it safe to change lanes?

(i) Size of gap in target lane

(ii) Speed of gap in target lane

(iii) Rate of change of size of gap in target lane

(iv) Current speed

(3) Lane Change Mechanics

(a) How do I physically change lane?

(i) Steering profile

(b) After making the decision to change lane, when do I start changing lane?

(i) Delay

In order to enhance the accuracy of the modelling lane changing behaviour, the model was improved as follows:

- The lane changes last for a finite duration with the vehicle occupying both lanes during the process.
- The preferred lane is correlated with "aggressiveness", one of the program's variables used to define the type of driver, rather than all vehicles returning to lane 1. In other words, more "aggressive" drivers will have preferred lane of 2 or 3 rather than lane 1 as in the original model.
- Calculation of acceptable gaps includes a calculation of whether the next gap would be better.
- The attainable speed in each lane is based on the current speed of up to 4 vehicles downstream in each lane.
- Aggressive vehicles will apply pressure to the vehicle in front (by gradually getting closer) if the speed difference between current speed and desired speed is high and the vehicle in front can move left.
- Undertaking, previously only performed by aggressive drivers, now will also occur if the speed in the right-hand lane is below the input threshold.

It was also attempted to introduce forced lane changes to reduce the number of vehicles missing the exit. In order to make the exit, the vehicle adjusted its speed to make the gap acceptable. Smaller gaps are accepted if the desire to change lanes is high. However, in practice these changes resulted in flow breakdown at relatively low flows due to vehicles in lane four trying to make the exit at the very last minute. Therefore forced lane changes were excluded from the improvements.

Testing the SISTM lane changing algorithm

The old and new versions of the SISTM lane changing algorithm were compared against real traffic data. Data on the frequency of lane changes and lane utilisation obtained from CCTV cameras were plotted against model outputs.

The new model was a significant improvement on the old model on the open motorway in terms of the number of lane changes as it accurately reproduced the data from CCTV cameras, whereas the old model over-predicted lane changes. However, both models still over-predict lane changes near the merges and diverges, although the new algorithm over-predicts to a lesser extent. Both models predict increasing lane changes with increasing flow, but the CCTV data does not show this.

Both models predict lane utilisation well in a three lane motorway (the new model a slight improvement). However, in a four lane motorway, both over-predict the usage of lane one. While the old model reasonably predicts lane two, the new model over-predicts. The new model improves on the old model for lane three, but it under-predicts the utilisation of lane four.

Discussion

In the literature such comparisons with real-life lane changing frequencies and lane occupations are rare. Macroscopic data such as overall flow can hide the cancelling out effects of errors. For example, commercially available products do not consider several gaps in the way that SISTM does, and arguably most drivers do this when choosing an exit. There is much work still to do in this area, particularly for four lane motorways, in accurately mimicking lane changing near exits and merges.

3 Overview of microsimulation packages

There are many microsimulation models in the literature. Some are purely for research purposes within university departments and are not available commercially. Others have little evidence of validation against real traffic data. The Appendix contains a list of microsimulation models, indicating use of credible theories, real-world tests, use with ITS and whether or not the model is publicly available. It is not a comprehensive list, but it gives a flavour of what is being worked on. Some of the products, for example CORSIM, are popular in the USA but little-known in Europe. AIMSUN, VISSIM and PARAMICS are the market leaders in Europe. They all have links with traffic signals software. AIMSUN and VISSIM allow the user to define their own vehicle behaviour algorithms. VISSIM has a module for simulating vehicle to vehicle and vehicle to infrastructure communications.

DRACULA has links with the macrosimulation model called SATURN, and is based on well-established Gipps equations. It provides the best of both worlds, using the convergence methods of macrosimulation to establish the routes of the vehicles but the performance of individual junctions can be monitored on a microscopic level.

MITSIM and SUMO are both open source microsimulations, and both are based on publicly available PhD theses. MITSIM's car following model includes calculations based on the density of traffic ahead of the vehicle in front and there are a publicly available real-world tests. SUMO is for right-hand driving only.

OLSIM is used in Germany as the microsimulation engine for a website to provide live traffic data and predictions of future traffic to travellers.

Some of the packages, including PARAMICS, have been developed to make use of parallel computers. VISSIM can make use of multiple cores on normal PCs. However, the speed of simulations is generally not an issue unless multiple scenarios need to be run over a short period of time in order to give near-instantaneous advice based on live data.

Details of all of these models are in the Appendix.

4 Conclusions

Many motorway simulations to date have lacked accuracy in terms of predicting occurrences of flow breakdown and therefore overall capacity of the network. It is recommended that this should be addressed by creating a microsimulation of motorways that could accurately reproduce flow breakdown; this would be a powerful tool for evaluating ITS interventions such as managed motorways, ramp metering and route guidance. To achieve this, the following suggestions are made:

1. The microsimulation should use the Gipps car following and Gipps lane changing models. The lane changing model should be modified so that the decision tree represents driving behaviour accurately. The model should be calibrated using MIDAS and/or CCTV data.

2. The two open source models SUMO and MITSIM should be reviewed. Both of these are based on the Gipps model and have their car following and lane changing algorithms well documented in PhD studies which are available on the internet. The PhD studies should first be studied in detail and the model tested against real MIDAS and CCTV data to see if these models (SUMO or MITSIM) provide a good base for further development.

3. AIMSUM is adept at allowing the model user to define characteristics specific to each vehicle in the model. This could be used to develop a test platform for various lane changing algorithms calibrated using MIDAS and CCTV data, and possibly also data from TRL's driving simulation facility.

4. In addition to modelling motorway networks populated with driver-controlled vehicles, the microsimulation model can be used to assess effects with automated vehicle control. The advantages and risks of driving at short headway (or in 'platoons', where vehicles are controlled to drive at headway of a metre or less) can be assessed in addition.

The recommendations above relate to simulating motorway traffic. Simulations of urban areas suffer from similar inaccuracies in terms of calculating capacity. Urban simulations could be improved upon by considering the following:

- vehicle interactions at give way junctions
- vehicle interactions at roundabouts
- emulating or linking with adaptive traffic signal control systems
- emulating vehicle actuated traffic signals, including pedestrian crossings
- obtaining the signal plans of any fixed time signalised junctions

Unless these elements of an urban microsimulation are accurate, the benefits of using a microsimulation are diminished. This is one of the reasons why large-scale projects are often undertaken using a macrosimulation, where only simple relations between flow and delay are required. The accuracy of unsignalised junctions can be improved through careful calibration. As well as checking that the delays are accurate at current flow levels, it is possible to check that the junctions respond realistically to changes in flow by comparing the results against empirical models such as ARCADY and PICADY for roundabouts and give way junctions respectively.

For accurate representation of signalised junctions, the signal control mechanism must be accurately reproduced, and also the saturation flow (maximum queue discharge as standing queue) must match that seen on street or predicted through empirical relations.

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Appendix A Register of Microsimulation Models

The following table summarises the findings of Boxill and Yu (2000). Each model they looked into was measured against five criteria:

1. Credible theories used in the model
2. The model has been tested for real-world applications.
3. The ability to output measures of performance such as travel times and speeds.
4. Documentation has indicated incorporation of at least one ITS feature
5. Model is obtainable by the public

This table has been partially updated to reflect current status of the more prominent commercial modelling tools and some models that have been developed since the original survey.

Model	Criteria				
	Credible theories	Real-world tests	Performance measures	Incorporates ITS	Publicly available
AIMSUN	yes (Gipps)	yes	yes	yes	yes
AUTOBAHN	yes (psycho-physiological)			yes	no, Benz Consult GMBH in Germany

Model	Criteria				
	Credible theories	Real-world tests	Performance measures	Incorporates ITS	Publicly available
AVENUE	yes (does not seem to be microsimulation)		yes		no, University of Tokyo
CARSIM (USA)	yes (Gipps)	yes		yes (vehicle steering control)	yes
CORSIM (USA) (integrates NETSIM and FRESIM)	yes		yes	yes	yes
DRACULA (UK)	yes (Gipps)		yes	yes (chains of vehicles)	yes
FLEXYT II (Netherlands)	yes		yes	yes	yes
FOSIM (USA)					
FREEVU (USA) (based on INTRAS)	yes (collision avoidance)				yes
FRESIM (USA) (based on INTRAS)	yes			yes	yes
HUTSIM	yes		yes	yes	yes
ICARUS					no, Elsevier Company in Amsterdam

Model	Criteria				
	Credible theories	Real-world tests	Performance measures	Incorporates ITS	Publicly available
INTEGRATION	yes (also tracks lateral movements, their car following algorithm is a kinematics model that calculates the individual vehicle speeds based on the macroscopic parameters of the free flow speed, speed and capacity and jam density)	yes (no references given by Boxill and Yu, presumably validated on American roads)	yes	yes (including ramp metering)	yes
INTRAS	yes		yes (can count total number of lane changes)		Available as FRESIM
MELROSE	yes		yes	yes	no, Mitsubishi Electric Corporation
MICROSIM	yes (cellular automata)	yes		yes	no, centre of parallel computing (ZPR), University of Cologne
MICSTRAN				yes (for evaluating traffic signal control algorithms)	no, National research Institute of police science in Japan
MIMIC	yes		yes		no, University of Chalmers School of technology

Model	Criteria				
	Credible theories	Real-world tests	Performance measures	Incorporates ITS	Publicly available
MISSION	yes (Wiedemann)	yes	yes		Now the engine of VISSIM, PTV
MITRAM	yes (fuzzified Wiedemann)	yes			
MITSIM	yes (car following model takes into account the density of traffic ahead of the vehicle in front http://web.mit.edu/its/papers/DRIVIN.PDF)	yes (http://web.mit.edu/its/papers/CALIBR2.PDF)	yes	yes (mimics ITS detectors and accepts traffic control data)	yes (open source http://mit.edu/its/MITSIMLabOSnew.html)
MIXIC	yes		yes	yes (intelligent cruise control)	no, Centre for regional transportation infrastructure Delft
NEMIS				yes (traffic signals, route guidance, VMS)	
NETSIM			yes	yes (traffic signals)	
OLSIM	yes (cellular automata Chrobok (2003))	yes (takes live traffic data and predicts delays www.autobahn.nrw.de)	yes		
PADSIM	yes	yes (in an urban network using SCOOT data)			no, Nottingham Trent University computing Department
PARAMICS	yes	yes	yes	yes	yes

Model	Criteria				
	Credible theories	Real-world tests	Performance measures	Incorporates ITS	Publicly available
PELOPS (German)	yes (Wiedemann car following, vehicle model providing acceleration)	yes (within 4.2% travel time in an urban road, Neunzig (2000))	yes	yes (adaptive cruise control)	yes
PHAROS/Ulysses	yes			yes (it is a driving program to control a robot van)	no, School of computer science, Carnegie Mellon University, Pittsburgh
PLANSIM-T	yes		yes		no, Centre for parallel computing at the University of Cologne
ROADSIM	only two way rural roads				Federal Highway Administration
SHIVA	yes			yes (for design of intelligent vehicles)	no, Robotics Institute Carnegie Mellon University, Pittsburgh
SIGSIM	yes		yes	yes (signal control)	Centre for transport studies, University of London
SIMCO2				yes (for simulating V-V and V-I communication protocols)	no, technical University of Aachen

Model	Criteria				
	Credible theories	Real-world tests	Performance measures	Incorporates ITS	Publicly available
SIMDAC	yes	yes (using equipped cars to calibrate maximum deceleration and drivers reaction times)	yes		no, ONERA-CERT, France
SIMNET	no, simple queueing model			Yes, traffic signals	no technical University in Berlin
SIMTRAFFIC	yes		yes	yes, traffic signals	yes
SISTM	yes (Gipps)	yes	yes	yes (CODIA, corporative systems including congestion warning, collision warning)	no, Highways Agency developed at TRL
SITRA-B+	yes (Helly)	yes, travel times	yes	yes (traffic signals, route guidance)	no, CERT
SITRAS	yes (linear relationship between headway and speed)	yes, in terms of reduction in speed due to incidents	yes	yes (incident management systems, route guidance)	no, University of New South Wales in Australia
SOUND	mesoscopic, using packets of flow	yes			University of Tokyo, Japan
SPEACS	yes	yes	yes		
STEER, part of RONETS				Yes, traffic signals	University of York
STREETSIM	yes		yes	yes, traffic signals	

Model	Criteria				
	Credible theories	Real-world tests	Performance measures	Incorporates ITS	Publicly available
SUMO	yes (car following based on Gipps, stochastic lane changing). Right-hand drive only		yes	yes	Open source, http://sourceforge.net/apps/mediawiki/sumo/index.php?title=Main_Page
THOREAU	yes	yes		Yes	
TRAFFICQ	yes				MVA
TRANSIMS	yes (cellular automata)	yes	yes	yes	Los Alamos National laboratory, New Mexico
TRANSMODELER				yes	yes, http://www.caliper.com/transmodeler/Simulation.htm
VEDENS	driver decision algorithm				Yes, AEA technology
VISSIM	yes (Wiedemann)	yes	yes	yes	yes (PTV)
WATSIM (based on NETSIM)	yes	yes	yes	yes	yes
WEAVSIM	yes	yes (American "weaving" sections)			No, FHWA