The idea of using micro-simulation modelling for road traffic safety assessment is still a controversial issue in the traffic research community. A recent investigation sponsored by the European Union’s 4th Framework Program revealed that there is an implicit and substantiated need for the development of micro-simulation systems designed for the assessment of traffic safety. Despite this recognised need, there appears to be a number of considerable practical and conceptual problems that have prolonged the introduction of such systems despite advances in computer power and capacity, modelling techniques, and data-collection methods. In particular, the typical simplified “normative” model of driver behaviour that is sufficient for the study of traffic system efficiency, must be revised to allow representative levels of variance in road-user communication and interaction. It is conceivable that behavioural variance can be introduced through a naturalistic modelling of perception, decision-making and action-taking processes, thereby allowing “less-than-perfect” behaviour and the possibility for various types of typical driver errors to occur. A second main issue concerns the identification of safety indicators that can be used to create a comparable and situation specific safety assessment profile. The safety profile emanating from a real-world situation must be reproduced from the microscopic behaviour of road-users in the logical simulator environment given the bounds of normal statistical error variance. This paper describes current work on the SINDI-project at the Centre for Traffic Simulation Research, Stockholm, which aims to break new ground in the use of micro-simulation for traffic safety assessment through the development of a detailed “nanoscopic” model of driver behaviour, and the establishment of a safety profile based on identified safety indicators. The project focuses primarily on safety related to the interactions of different types of road-users at urban intersections, and the possibilities to improve traffic safety through the use of intelligent transport systems.

INTRODUCTION

The existing traffic safety problem within the European OECD countries is unacceptable by modern standards. During 1997, around 45 000 fatalities and 1.3 million injuries were reported to be the direct cause of road traffic accidents. The estimated costs of these accidents within the European Union amounted to around 160 billion ECU, thereby far exceeding the total annual budget for the EU for this year. Perhaps not surprisingly, traffic research related to the traffic safety problem indicates that the majority of accidents are directly attributable to the inept behaviour of individual road-users.

In order to improve the traffic safety situation, it is therefore appropriate to argue for the use of predictive methods such as micro-simulation, where the impact of various safety measures on the traffic system can be estimated at an early stage on the basis of the behaviour and interactions of road-users at the microscopic level. In traffic engineering, micro-simulation has proved to be a particularly useful tool for studying the traffic system, enabling new and sometimes controversial measures to be tested without disrupting existing traffic networks, or putting people at risk. Through the ability to indicate the potential of alternative system
designs at an early point in time, micro-simulation can also provide a useful and cost-effective platform for establishing a balance between the different and often opposing system objectives of efficiency, safety, and environmental concerns.

A recent state-of-the-art review of existing road transport related micro-simulation models was undertaken as part of the SMARTTEST project funded by the European Union’s 4th Framework Program (Algers, et.al., 1997). The report from SMARTTEST indicated the existence of some 58 different micro-simulators. The majority of these were designed specifically for system efficiency evaluation, usually related to the impact and sensitivity of different roadway design strategies. Other objectives included evaluating the effects of various Intelligent Transport Systems, and different traffic management and travel information systems. One of the primary objectives of SMARTTEST was to identify “gaps” in existing micro-simulation models, i.e. important traffic related issues for which little or no support was provided, but where an implicit and substantiated need had been recognised. Distinct gaps were identified in relation to: safety evaluation modelling, levels of detail, standards of calibration and validation, standard performance indicators for output evaluation, and inclusion of pedestrians and cyclists.

One of the main reasons attributable to the lack of micro-simulators designed for safety assessment, is related to the fact that detailed modelling of road-user behaviour in relation to the traffic system requires in-depth knowledge of a far more diverse and multi-disciplinary nature than is usually anticipated. While simple car-following and gap-acceptance driver sub-models are sufficient to provide “normative” behaviour for traffic system capacity assessment, the evaluation of safety demands a more complex driver model that incorporates a representative degree of behavioural variance. The level of variance required should allow errors to occur as the result of “less-than-perfect” perception, decision-making, and action, thereby causing different levels of risk in the interactions between road-users and the environment. Furthermore, the study of safety at isolated traffic sites is hindered by the fact that accidents, the most tangible and accepted measure of traffic safety, occur very seldomly. Therefore the study of safety requires the identification of a number of useful and relevant safety indicators that, as proxy measures, have a validated relationship to accidents and provide some indication of their outcome in terms of severity.

In the past micro-simulation systems were limited by computer power and capacity, programming and modelling techniques, and the type of data that could be collected given the resources available. More recently there has been significant technological developments in these areas. Vastly improved computer power and capacity, in combination with new and innovative modelling techniques, has opened the door for a new era of high fidelity micro-simulation modelling. In addition, new technology has also led to improvements in data-collection techniques, providing a new found wealth of detailed empirical data to promote more substantiated model design and development, and ease the burden of validation and calibration. Given these practical advancements and the fact that there is a noticeable shift in the academic world toward the integration of knowledge from different scientific disciplines, it now seems an appropriate moment in time to attempt the development of a micro-simulation system for safety assessment purposes.

THE SINDI-PROJECT

The SINDI-project (SINDI is an acronym for Safety INDIcators) approaches many of the problems associated with developing and adapting a micro-simulation system for safety assessment purposes. More specifically, SINDI focuses on the safety problems of different road-user groups (including pedestrians and cyclists) at different types of urban intersections (e.g. three-way or two-way intersections and roundabouts) where it is also possible to have different forms of traffic control (e.g. yield or stop-signs, traffic-lights). The urban traffic environment was chosen on account of the fact that accidents, specially those involving vulnerable road users, appear to be far more common in this areas. Also, urban driving
places higher demands on road-users and calls for a greater degree of interaction and communication, a systems approach such as that offered by micro-simulation is therefore highly motivated.

Urban traffic safety statistics show that roughly one-third of all fatal accidents, and more than two-thirds of all reported injury accidents, tend to occur in this environment mainly at intersections and often involving vulnerable users (Archer & Vogel, 2000). A number of interesting studies have been conducted with a view to finding the causes of urban accidents. One of the most comprehensive studies covered 1254 injury accidents over a one-year period in northern England (Carsten, et.al., 1989). Findings suggested that road-users were often unable to, or failed to, anticipate other road-users actions, and often failed to yield. These errors were found to be due to perceptual and cognitive factors such as failing to look, failing to see, and a lack of judgement.

The long-term goal of the SINDI-project is to be able to evaluate the potential of different safety countermeasures such as those that fall under the “umbrella-term” Intelligent Transport Systems (ITS). Intelligent Speed Adaptation (ISA) is of particular interest due to its high safety potential and suitability to the urban environment (Várhelyi, 1996). In SINDI the two most important issues that are critical to the success of the project concern the establishment of a representative model of road-user behaviour that allows for a sufficient degree of variance in road-user perception, decision-making, and action and identifying suitable and relevant safety indicators that can be used as a foundation for safety assessment (preferably by panel of safety experts).

In the following sections of this paper the establishment of a representative model of road-user behaviour, and the identification of suitable and relevant safety indicators are discussed in conjunction with the current work on the development of a micro-simulation system for safety assessment. Some preliminary work has been carried out using the HUTSIM micro-simulation system that allows quite a high level of detail in the geometric design of road networks, and has been designed primarily for use with the testing of traffic control systems and strategies (see Kosonen, 1999). HUTSIM has also introduced a degree of variance in the representation of driver behaviour, although the actual behaviour of interacting vehicles is largely controlled by logical signal objects in the system.

**MODELLING DRIVER BEHAVIOUR**

For safety assessment related micro-simulation, the key to success is related to the ability to model road-user behaviour with a high degree of representivity, accuracy, and detail. In a typical micro-simulation model where efficiency evaluation is the main concern, the behaviour of the driver is usually represented by a number of fundamental sub-models that describe behaviour such as car-following, lane-changing, gap-acceptance, and obstacle detection. A degree of variance between (but rarely within) individual drivers is introduced by the inclusion of distributions that are sampled by randomisation functions. This adds slightly more realism in the movement of vehicles but is generally arbitrary and has only a limited value. Accidents and near-accidents are very rarely possible in micro-simulation owing to the deterministic rule-base that governs specifically how vehicles may or may not interact with one another in a given traffic situation.

For safety assessment purposes the relatively strict deterministic rule-base that governs this type of simplified driver behaviour needs to be “loosened” in order to allow for a realistic amount of behavioural variance, and the possibility for errors to occur. For this purpose, it is essential to know something of the factors that, in a given situation, can increase or reduce the risk for accident involvement. The consensus among the traffic safety community is that road-user behaviour lies behind the majority of traffic accidents, although the drivers themselves are often not prepared to accept their own shortcomings, and often tend to consider themselves as more proficient than the average driver (Risser, 1985; Rumar, 1985).
The individual factors that increase or reduce risk for accident involvement are very difficult to identify and model. The driving task itself can be regarded as a continual adaptation process that is steered by the demands of a dynamic and complex environment. Some idea of the demands and limitations of the driver can be derived from the information presented by Hämäläinen and Luoma (1991) based on data from Finland and the United States (see table 1). There are many different types of theoretical driver behaviour models, each with different advantages and limitations, but very few that are sufficiently comprehensive to form the basis for simulation modelling, and even fewer that have been verified by objective empirical enquiry (see e.g. Michon, 1985).

### Table 1. Events of an average driver in traffic based on an average speed of 60 kph/h and annual mileage of 200,000 km

<table>
<thead>
<tr>
<th>Event</th>
<th>Event per time-unit</th>
<th>Event per kilometre</th>
</tr>
</thead>
<tbody>
<tr>
<td>pieces of traffic inform.</td>
<td>5 in 1 sec</td>
<td>300 per Km</td>
</tr>
<tr>
<td>driver observations</td>
<td>2 in 1 sec</td>
<td>120 per Km</td>
</tr>
<tr>
<td>driver decisions</td>
<td>40 in 1 min</td>
<td>40 per Km</td>
</tr>
<tr>
<td>driver actions</td>
<td>30 in 1 min</td>
<td>30 per Km</td>
</tr>
<tr>
<td>driver errors</td>
<td>1 in 2 min</td>
<td>1 per 2 km</td>
</tr>
<tr>
<td>risky situations</td>
<td>1 in 2 hrs</td>
<td>1 per 120 km</td>
</tr>
<tr>
<td>near accidents</td>
<td>1 in 1 mon</td>
<td>1 per 2000 km</td>
</tr>
<tr>
<td>accidents</td>
<td>1 in 7.5 years</td>
<td>1 per 150,000 km</td>
</tr>
<tr>
<td>injury accidents</td>
<td>1 in 100 years</td>
<td>1 per 2 million km</td>
</tr>
<tr>
<td>fatal accidents</td>
<td>1 in 2000 yrs</td>
<td>1 per 40 million km</td>
</tr>
</tbody>
</table>

One way to approach the problem of modelling driver behaviour is to look at the types of errors that lead to an increase in traffic safety risk. Risser (1985) has systematically studied different types of errors in driving behaviour that were related to conflicting situations in traffic. He concluded that most errors were the result of a lack or misunderstanding of communication in the interactions between different road-users. Among the behaviours that were found to be related to conflict probability among drivers were: risky passing manoeuvres, badly adapted speed, following too closely, unlawful behaviour at traffic lights, hesitant or risky lane-changing, cutting corners, insisting on or taking others right of way, jerky steering, inadequate lateral distance, and lack of precaution at intersections.

A comprehensive model of driver behaviour that has found support in a number of empirical studies has been suggested by Rumar (1985). The model of driver information processing suggested by Rumar (see figure 1), describes how decisions are made on the basis of the driver's comprehension of the actual traffic situation, and how decisions are influenced by attention factors, motivation, previous experience, and expectations. Perceptual and cognitive filters are also included to show how information can be lost during different stages of the decision-making process. Rumar's model provides a useful theoretical foundation for the modelling of road-user behaviour in SINDI. This can also be regarded as an information-processing model that incorporates important elements related to the perception of the environment, the information quantity and quality available to drivers for making decisions, and the types of actions that are decided upon and enforced.
THE SINDI MICRO-SIMULATION MODEL OF DRIVER BEHAVIOUR

It should be mentioned that the implementation of driver behaviour in many of the existing micro-simulation systems, even those that claim to be high-fidelity, is often significantly limited in ways which make the adaptation for safety evaluation purposes very difficult. Limitations tend to appear when these systems are considered for purposes other than those for which they were originally designed. Many systems were originally intended for use with large or medium size traffic networks, where the number of dynamic objects can be high, thereby placing higher demands on computer power and capacity and calling for a higher level of optimisation and rationalisation in driving behaviour. Typical limitations in micro-simulation systems other than the oversimplification of general driving behaviour principles that make the study of traffic safety less than ideal include: one-dimensional and non-lateral movement in accordance with a fixed path, combining the driver and vehicle object, allowing interaction to be controlled by objects other than the vehicles or drivers, and an over-standardisation of vehicle objects and their accompanying dynamics.

Figure 2. Possible movement paths based on guidance points for a vehicle approaching an intersection
In the SINDI-project, the area that is modelled for micro-simulation includes only one specific intersection (or roundabout) rather than a complete traffic network, thereby allowing for increased capacity in the modelling of the driver by reducing the number of dynamic objects. The emphasis is placed on detail, and the physical real-world environment that has been studied beforehand, must be accurately mapped into a suitable logical representation so that any effects related to intersection geometry are not lost. The general simulation model of an intersection requires a great deal of standard input information that is based on empirical studies. Movement in the model is more two dimensional, based on a coordinate system where drivers determine a path or trajectory on link roads and at intersections based on guidance points (see figure 2). This corresponds roughly to the way drivers plan their movement, keeping to the centre of the lane while driving forwards towards a new target point.

As with Rumar’s information processing model, the SINDI model on which behaviour is based focuses specifically on the perception, decision-making, and action-taking processes (see figure 3). A number of driver-specific characteristics are assigned individually to drivers in order to form particular patterns of behaviour that have been recognised and quantified in the real-world. Drivers are separated from the characteristics of their vehicles, although it is important to recognise the fact that there is a strong relationship between the two. For example, the braking and acceleration capacity that is actually used by a driver given the vehicle’s actual potential. Vehicle characteristics and dynamics must be modelled in detail (i.e. type, length, width, acceleration capacity, braking capacity, and extra equipment).

![Figure 3](image_url)  The theoretical model of driving behaviour that is currently used as a platform for development in SINDI

**Perception**

Normally, the environment of a driver is sampled at regular intervals to gain useful perceptual information in order to make decisions about the type of action that is required. This perceptual process is included in the SINDI behavioural model. In simplified form this perceptual sampling will follow a pattern, for example, straight ahead in the intersection, to the right of the intersection and to the left of the intersection and then vice versa when an approach is made (see figure 4 below). Visual samples are known to take different amounts of time depending on the complexity or amount of information that is available. When one area is sampled the information from other sampled areas cannot be observed and must be remembered. The use of a memory function also implies that information is subject to fading, distortion, and even loss of information. Each visual sample in a particular direction in **Figure**
4. Visual sampling on approach to an intersection, each sample is collected at different time cycles.

the model is used to estimate the position, speed and distance of dynamic objects, and the position of important static objects. Estimated speed and distance is in itself prone to varying degrees of distortion. Slower speeds tend to be underestimated, while the opposite is true for higher speeds.

The visual sampling process is also subject to a number of limitations. Static objects such as buildings can restrict the field of view, and larger dynamic objects can hide smaller objects (typically pedestrians are hidden by vehicles). Perceptual errors are also possible as a result of incorrect perceptual sampling (e.g. failing to sample a particular area in accordance with the visual sampling pattern) caused perhaps by distraction, or perceptual fixation on other events. Most significantly, errors are introduced through the incorrect subjective estimations of speed and distance due to factors such as inexperience or fatigue. These types of errors can be incorporated into the model through probability factors that are assigned to drivers on the basis of existing empirical data.

**Decision-Making**

Drivers make decisions about which actions to take, or not to take, based on the perceptual information that is available to them. Driving experience governs the amount and quality of information that is required relative to the actual decision that needs to be made. Personal preferences with regard to gaps in traffic that are considered acceptable, for example for turning manoeuvres or lane changing, are randomly assigned to drivers from a suitable distribution based on empirical data. Preferences for what constitutes a safe driving distance in a car-following situation, and preferred speed given the prevailing speed limit, should also be assigned in a similar way. There are many similar characteristic preferences which guide the decisions made by individual drivers. The decisions that are eventually made concern the ability to adapt to situational demands and how to interact with other road users.

Errors are possible in the decision-making process as the direct result of a perceptual failures, but also as the result of mistakes that emanate from expectations concerning other driver's behaviour. This is particularly evident when, for example, indicator lights are misused. Communication between vehicles based on the visibility of indicators will be incorporated into the model with a random factor for misuse assigned to each driver and each manoeuvre taken. Another important factor that can result in incorrect decisions is situational complexity. Complexity not only prolongs the process of extracting information, but also causes existing information held in memory to be distorted or forgotten. Another
important factors is fatigue, causing a lapse of awareness in situations where drivers receive little or no perceptual stimulation over a period of time. For modelling purposes this could be represented by a slowing down of the perceptual sampling process.

An aggressive driving style is another important factor that must be incorporated into the driver behaviour model.

Aggressive driving is usually represented by higher speed preferences, shorter gaps in car-following situations, and the acceptance of shorter gaps when yielding or driving from a stop or yield-sign after stopping. Taking others right-of-way and causing vehicles on primary roads to slow down, and lack of conformity/compliance is common. For modelling purposes it is necessary to identify the relationships between manifest variables such as: speed, headway, gap-acceptance, and probability of non-compliance/conformity, that are associated with aggressive behaviour. Multivariate analyses can be helpful for describing different behavioural profiles.

**Action**

The last part of the process concerns the resulting action that is decided upon by the driver. One of the following actions is normally being performed by the driver either in a free-flow or car-following situation:

- Continuing straight ahead on link-road
- Continuing straight ahead on primary road through junction
- Continuing straight ahead from secondary road with yield sign without stopping
- Turning right without yielding at junction from primary road
- Turning left without yielding at junction from primary road
- Turning left with yielding for oncoming traffic at junction from primary road
- Turning right at junction from secondary road (following stop at a yield, stop-sign, or a traffic light when 1st in queue)
- Turning left at junction from secondary road (following stop at a yield, stop-sign, or a traffic light when 1st in queue)
- Turning right at junction from secondary road with yield-sign without stopping
- Turning left at junction from secondary road with yield-sign without stopping
- Waiting at stop-sign/yield-sign on a secondary road (1st in queue)
- Waiting for a traffic light at junction (1st in queue)
- Waiting for pedestrians/cyclists at pedestrian crossing (1st in queue)
- Waiting in queue behind other vehicles
- Approaching (slowing for) stop-sign/traffic light on a secondary road
- Approaching (slowing for) yield-sign on a secondary road (stop not essential)
- Approaching (slowing for) a pedestrian crossing
- Approaching (slowing for) a queue of other vehicles
- Changing to outside lane on link
• Changing to inside lane on link
• Emergency collision avoidance action

Actions can be revoked by new decisions at any time on the basis of new perceptual information. There is also the possibility to take incorrect actions, for example, driving straight ahead instead of making a correct approach to a pedestrian crossing when it is occupied, this type of action should be the result of an incorrect decision based on incorrect or missing perceptual information.

An important part of the driver’s perception, decision-making, and action cycle concerns the time-delay from receiving the perceptual information to the actual onset of action. This is usually in the region of half-a-second to two seconds, and is often represented in models through the use of a reaction time distribution from which random values are drawn. In the model proposed, reaction time takes into account the time taken for perceptual processing and decision-making, and a smaller random time element that represents the time between making a decision and actually implementing it (between zero and approximately half-a-second). Thus, reaction times are influenced by situational complexity and other factors which can slow down the decision-making process.

Perception, decision-making, and action-taking are undoubtedly concurrent processes, the information that is passed from one to another is not immediately available at precisely the same moment, but is subject to time-delay as mentioned above. The three basic processes can therefore be said to be working in parallel even though the information they use as input is always from the past rather than the present (see figure 5). This can be achieved practically through the use of a “memory” function that preserves information between cycles and also provides the possibility to filter or loose information, and to make old information fade in terms of accuracy. The result is a differentiated and more realistic representation of total information processing cycle.

**Figure 5.** Temporal parallel processing in the vehicle driver model.

At present, work is continuing with the development of the driver behaviour model at a level which is essentially “nanoscopic”. The behavioural model will be difficult to calibrate and validate exactly, and is dependent on previous research findings and a variety of different studies that involve the collection of different empirical data related to driving behaviour. In the SINDI-project traditional observational traffic data is complemented by that from obtained from instrumented vehicle studies in order to obtain useful behavioural data both within and between subjects. Also, the use of a driving simulator with pre-programmed interactive scenarios is planned at a later point in time. Work related to establishing models of pedestrian and cyclist behaviour is also planned.
ASSESSING TRAFFIC SAFETY

Traditionally, the objective safety level of the traffic system is measured by the number of police reported accidents and the severity of their outcomes in terms of personal injuries and fatalities. As previously mentioned, the collection of accident data relative to a particular urban intersection is most often impractical and has only a limited value for safety research (Risser, 1985).

A far better approach, from an empirical enquiry point of view, is to focus on measures of the quantity and quality of road-user behaviour, communication, and interaction in order to obtain an indication of prevailing traffic safety levels in any given intersection (Risser, 1985; Hydén, 1987). Svensson (1998) states that for proxy measures or indicators of safety to be useful they must:

a) complement accident data, and be more frequent than accidents
b) have a statistical and causal relationship to accidents
c) have the characteristics of “near-accidents” in a hierarchical continuum that describes the severity levels of road-user interactions, in which accidents are placed at the highest level and very safe passages with a minimum of interaction are found at the lowest level

Most significantly, these preconditions can be found in the Swedish Traffic Conflict Technique developed at Lund University (Hydén, 1987). The term “conflict” is generally defined as an observed situation in which two or more road-users approach each other on a collision course, and where an accident is imminent if neither takes evasive action. Conflicts are described by the estimated “time-to-accident” (TA) value derived from the difference between the point in time at which one of the road-users takes evasive action, and the estimated time of the collision had it taken place. The TA measure also provides a measure of severity related to the interactions of road-users if speed is considered.

Recently, Svensson (1998) has extended the use of the TA-Speed relationship, to describe the “shape of the severity hierarchy” for a particular intersection by including all interactions between road-users and not just those that are considered as severe or Figure 6.

Graph showing the different frequencies of interactions with different levels of severity in two intersections, intersection B shows a larger proportion of severe interactions serious (i.e. traffic conflicts). The frequencies of interactions in relation to different levels of severity can be used to represent the safety-related behaviour of road-users at specific intersections (see figure 6). Furthermore, the interaction-frequency - severity-level distributions can be disaggregated to focus on, for example, different road-user types, or specific manoeuvre types.
Another useful approach is found in the Dutch conflict technique DOCTOR, which includes both “time-to-collision” (TTC) and “post encroachment time” (PET). TTC represents the smallest time-gap between two vehicles on a collision course at any moment in the duration of a conflict relative to a spatial point, while PET represents the time-gap between the passage of two vehicles on a near-collision course to pass over a common spatial point (van der Horst & Kraay, 1986). Research has shown that TTC’s less than 1.5 seconds, and PET’s less than 1 second are critical for safety in urban areas.

There are also a number of other safety indicators with an established level of validity in relation to accident risk in the traffic system. The most important and well-researched of these is speed. The speed profile of an intersection should include, not only the average free-flow speeds of drivers on their approach, but also average turning speeds, levels of speed adaptation, and speed variance among drivers. The relationship between speed and safety in terms of accidents and their outcomes has been established by a vast amount of international research (e.g. Baruya & Finch, 1994, Várhelyi, 1996). Other important safety relevant variables are:

a) the average headway distances or time-gaps for vehicles in car-following mode (Grayson, 1984)

b) the traffic flow, where high levels of traffic flow imply the need for more frequent interaction, and therefore increased accident risk potential. It has been found that the traffic flow and interaction-severity relationship is not entirely straight-forward (Ekman, 1996)

c) the manoeuvre patterns and proportional numbers of different manoeuvre types (Svensson, 1998)

d) the traffic engineering design and type of control that is imposed, which consequently has an effect on such safety aspects as driver visibility but also defines the possibilities and limitations for road-user interaction (O’Cinnéide & Murphy, 1994)

In the final assessment of the proxy safety indicators, it is also useful to obtain as much information as possible related to the actual police reported accident data during earlier years to get an indication of the general characteristics and level of safety at the intersection. The conflict technique provides the possibility to estimate the expected number of accidents within levels of error variance, and therefore provides a useful means of verifying the empirical conflict studies.

THE SINDI MICRO-SIMULATION MODEL SAFETY ASSESSMENT OUTPUT

Using micro-simulation for the safety assessment of specific urban intersections implies the collection of a great deal of empirical data in order to determine standard input data for validation and calibration purposes including: traffic-flow data, speed and headway distributions, time-gap acceptance distributions for yielding and turning vehicles, vehicle type distributions, manoeuvre patterns, pedestrian and cyclist relevant information, etc. For safety assessment purposes data must also be collected for safety indicators of the type previously described.

The main source of safety data comes from the direct on-site recording of more severe road-user interactions (i.e. conflicts) and video-recording that enables the subsequent study of less severe interactions, post encroachment times, TTC’s, and the behaviour characteristics of different types of road-users. As mentioned previously, SINDI also makes use of additional behavioural data that is collected from instrumented vehicle and simulator studies.
During the micro-simulation of an intersection, brief safety output is generated at run-time in relation to the occurrence of severe conflicts, PET’s, and accidents together with the composition and numbers of road-user types, traffic flows, and average free-flow speeds (see figure 7).

**Figure 7.** The run-time safety output generated from the simulation of an intersection.

More detailed information concerning the exact nature of road-user interactions and other safety relevant information from the micro-simulation is also written to specially prepared output files for further safety analysis. Depending on the accuracy and validity of the existing behavioural model that determines road-user behaviour, the output data from the road-user interactions (and more specifically interactions categorised as serious traffic conflicts), should match that obtained from the corresponding empirical studies, given acceptable predetermined statistical error variance margins.

The aim of SINDI is to generate useful output data that is of sufficient quality and quantity to used for safety assessment, preferably by a panel of traffic safety experts. Providing it is possible to generate a suitable safety profile, the impact of various safety countermeasures such as those commonly used in traffic engineering or different ITS applications, can be estimated directly from the emergent complex and dynamic microscopic behaviour of simulated road-user behaviour in a specific logical urban intersection environment.

**CONCLUSIONS**

Without any doubt, the micro-simulation of specific traffic situations for safety evaluation offers great potential. The realisation of this potential is dependent on the possibilities to model representative road-user behaviour at a sufficient level of detail. The use of “nanoscopic” modelling of the type described here, offers an interesting research platform for testing many different hypotheses related to driver behaviour, both at the microscopic and macroscopic traffic system level. For safety assessment purposes the use of indicators related to the frequency and severity of interactions (bearing in mind traffic flow...
measurements, movement patterns, and intersection geometry), offers a useful foundation for creating comparable safety profiles both between and among real-world situations and their corresponding logical representations in the micro-simulator.

There is a considerable amount of work remaining in relation to the validation and calibration of the model of road-user behaviour, and the safety output that is generated for assessment and analysis. The eventual validation of the model of road-user behaviour and the micro-simulation model in general, together with the use of specific calibrated traffic scenarios, should yield a wealth of interesting and significant safety relevant data for expert assessment. Most importantly this data should provide an indication of the safety relevant changes that are brought about in driving behaviour as a result of different types of Intelligent Transportation Systems and other types of traffic safety countermeasures in the urban environment.

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