Evaluation of traffic safety using microsimulation

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Abstract

Microsimulation is becoming a more useful and powerful tool in the field of ITS applications assessment. In the evaluation process, one of the most important steps is the safety analysis. Actually, classical microsimulation outputs give some helpful information for this purpose, but there aren't sufficient for an accurate and global analysis. Nevertheless, microsimulation allows the knowledge of the vehicles' position, speed and acceleration at any time. Microsimulation gives also appropriate outputs to calculate one or several safety indicators more relevant than those deducted from macroscopic values.

This paper explains the concept of a new safety indicator, which not only takes into account the probability but also the gravity of hypothetical collision. This indicator is particularly planned for highways assessments, limited to the linear collision. It gives no information on crossing trajectories conflicts like in junctions. The paper presents then a case study with the first results obtained.

Keywords

Safety indicator - microsimulation - rear-front collision – unsafety density

1. Context

The safety problems in transportation are now a major preoccupation in the studies and the research works, especially in road's domain. The VESIPO report [3] gives a good example of this fact, with its objective of a road's safety improvement in short, medium and long term. To achieve this goal, several policies are conceivable and envisaged: measures of the vehicle performance, the users' behaviour or the road infrastructure. The last-mentioned is the one where concrete human interventions can be made, notably at the "black points" located by a safety analysis. Actually, this analysis is generally conducted from a reactive point of view seeing that it is based on the number and the localisation of accidents. The development of safety indicators in relation with simulation could allow a preventive safety analysis. It could so help traffic engineers to design road infrastructures and implement management strategies, which could help to reduce the incident gravity and likelihood.

1.1 Microsimulation: a tool for traffic safety

Experience shows that ITS and microscopic traffic simulation are able to improve the knowledge of risks within a traffic flow. Thus, microsimulation can contribute to better road safety. In fact, microscopic traffic simulation helps to evaluate and optimise different routing strategies, without having to realise tests in the field. These tools are mainly used to estimate the performance level of road networks in terms of flow, speed or travel time. The possibilities offered by these software tools, in order to estimate the safety level, remain however limited.

Most of the currently existing microscopic traffic simulators are based on the family of car-following, lane changing and gap acceptance models to model the vehicle's behaviour. Microscopic traffic simulation is also a "perfect world". No incidents can occur, as far as the basic modelling hypothesis in the underlying car-following models is that vehicles should keep a "safety to stop distance". Hence, a decrease in safety doesn't imply a decrease in network performance as it must do. So, an analysis based only on performance indicators (like the travel time) isn't realist: in the reality, if the safety level of a network decreases, the number of accidents rises. The presence of new accidents creates congestions and thus a decrease in network performance. The hypothetical travel time saving calculated by microsimulation decreases to zero, seeing that safety and performance evaluations are directly linked, the first having an important influence on the second.

Nevertheless, the knowledge of the vehicle's position, speed and acceleration (positive or negative) at any time should allow calculating a more relevant safety indicator than those deduced from macroscopic values.

1.2 State of the art on safety indicators

Microsimulation is not widely used for evaluating the road safety. Nevertheless, there is several ongoing research's works on this topic, this since begin of the years 2000, period where the potential and the need of microsimulation for estimating the road safety has been showed.

"*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.* " [1]

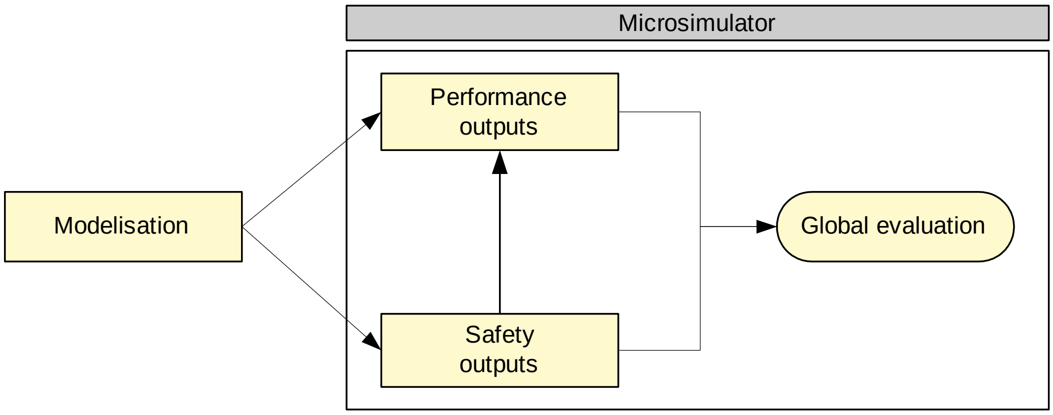
Several safety indicators are present in literature, with certain more or less compatible with the microsimulation possibilities. Without been exhaustive, the following indicators could be named: Deceleration to safety time (DTS) [Topp and al., 1996], Estimating incident probability (EIP) [Montero, Barcelo and Perarnau, 2002], Gap time, Initial deceleration rate (DR), Headway distribution, Number of shock waves [Von Arem and al., 1997], Possibly index for collision with urgent deceleration (PICUD) [Uno, Iida, Yasuhara and Suganuma, 2003], Post-enrochment time (PET), Potential time to collision (PTTC) [Wakabayashi and al., 2003], Required distance to stop (S) [Takashima, Koike and Morimoto, 2002], Severity of shock waves, Time exposed time to collision indicator (TIT), Time to accident (TTA) and Time to collision (TTC) [Minderhood and Bovy, 2001].

Most indicators express the safety in rear-front conflicts in distance, indeed time, till an hypothetical collision. More this distance (or time) near zero is, more the occurrence of an incident important is. These indicators are also indicators of accident probability more than safety indicators, seeing that the notion of accident gravity is missing. Well, the evaluation of this gravity is an indissociable element from the road safety analysis. The consequences of an accident can be tragic, on the contrary insignificant, according to the strength of the impact.

1.3 Justification and objectives

By listing and analysing various safety indicators present in the scientific literature, the degree of inadequacy and the limits of the existing indicators for microsimulation could be clearly seen. Even so, microsimulation gives appropriate outputs to calculate one or several safety indicators more relevant than those deducted from macroscopic values. Ideally integrated with the performance outputs, they would allow a global evaluation of the performance network.

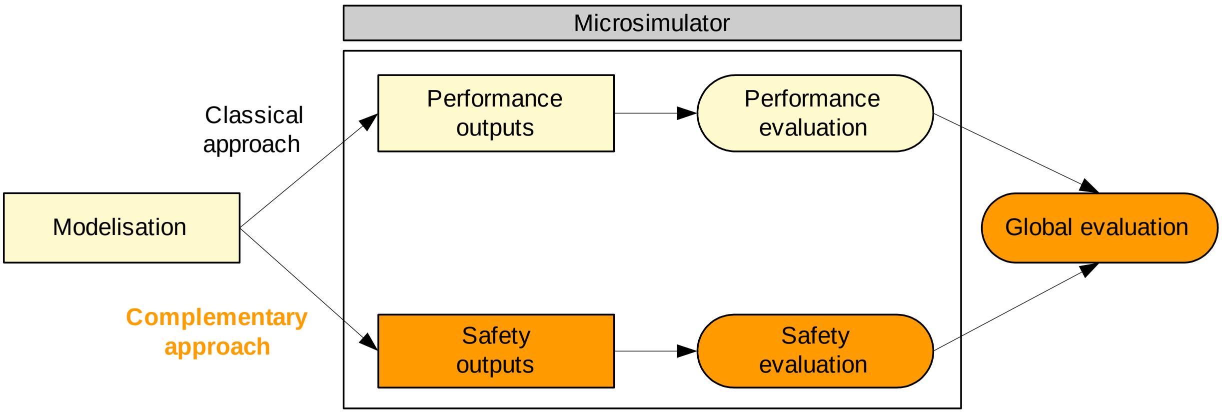
Figure 1 Ideally approach for safety analysis with microsimulation



The safety aspects would be part of the analysis and the risk of bad interpretation of the microsimulation outputs would be also limited. It would be no more necessary to balance between two parameters sometimes contradictory, as a situation where the network performances are improved, but where the user's safety is reduced.

This research proposes a first step of this ideal approach with a new output for microsimulation: the safety parameter, which not only takes into account the probability but also the gravity of accident (Figure 2). The research has been carried with the microscopic traffic simulator AIMSUN embedded in the GETRAM software environment for traffic modelling and analysis. It has been focused on the safety in linear conflicts.

Figure 2 Complementary approach for safety analysis with microsimulation



The present paper is structured as follows: a concept of a new safety indicator is proposed, with its application in a simulation process (Sect. 2). Then, this new parameter is tested on a site in a peripheral motorway (Sect. 3). The first results are commented and analysed (Sect. 4). Finally, the further researches and the conclusions are presented (Sect. 5 and 6).

2. New safety indicator

Microsimulation models prevent all collision between vehicles, notably with the car-following model in the particular case of linear conflicts. Microsimulation software has its own car-following model, for example the improved version evolved from the seminal Gipps model [4] in the case of AIMSUN. Nevertheless, all models are generally based on the same important behavioural parameter: the driver’s reaction time. Depending on the software, the reaction time can be a global parameter for all the vehicles (including their driver) or differentiated for each class of vehicles. Furthermore, it can be a deterministic value or a stochastic one, following a distribution rule. In ever case, the reaction time of a particular vehicle remains constant during the simulation. The car-following model controls the vehicles’ behaviour: its acceleration, its deceleration and consequently the headway of the follower vehicle that depends on its reaction time.

If this approach offers an excellent approximation of the traffic flows and the relative position of the vehicles, it doesn’t allow extracting potential real collision situations. The main reason is that, in the microsimulation, the headway between two vehicles is in accordance to the reaction time of the follower. The microsimulation is a “perfect world” where the less a vehicle’s reaction time is, the less its minimum acceptable headway is. In reality, the reaction time is always changing, because the driver’s concentration is permanently influenced (tiredness, dialog with other passengers, look in another direction, etc…).

Even so, the behaviour model approximates with a satisfactory accuracy the vehicle's movements. Reaction time, obtained after the calibration process, represents also the average of the reaction times of the vehicles in reality. Better said, it represents the average of the reaction times the drivers believe they have. Many standards fix limits or standard values for reaction time in the field of road transport, for example a reaction time of 2 seconds in the Swiss standards. Usually, a standard reaction time represents a maximum limit that only few drivers exceed. This is only during some limited moments of their journey.

2.1.1 The approach

The definition of the standard reaction time implies that the potential of collision becomes significant if the headway between two vehicles is below this value, provided that the speed and deceleration capacity of both vehicles are the same. This is rarely the case in reality.

The question which tries to answer the new concept of safety indicator is also to know what will happen, when the follower vehicle’s reaction time is equal to the standard time reaction and the leader vehicle breaks with its maximum deceleration capacity.

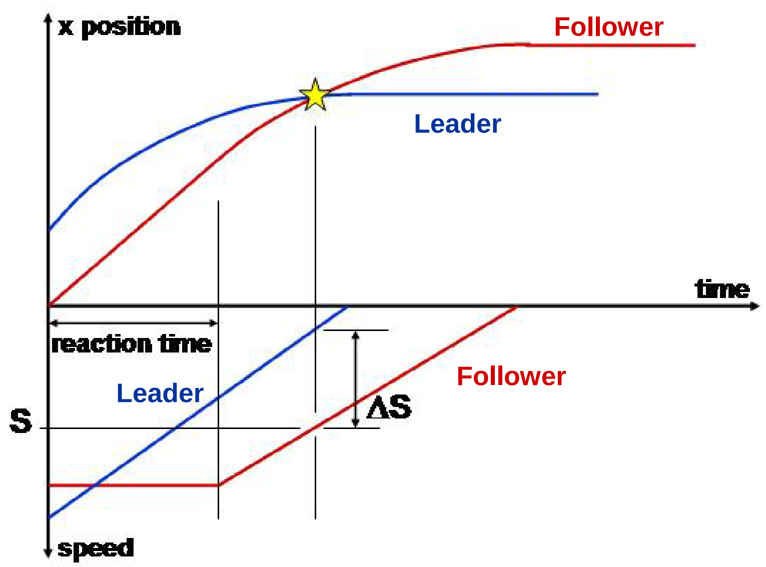
The general concept of a new safety indicator is based on a scenario with a hypothetical collision between a couple of vehicle (the leader and the follower). Thus introduces the notion of risk as the multiplication of probability and gravity, taking three parameters into account:

- the speed difference between two vehicles at collision time, giving an indication about the gravity of the first impact of the collision (collision's energy)
- the speed of the follower's vehicle at collision time, giving an indication about the gravity of the second impact of the incident (potential impacts with others cars or lateral obstacles after the first impact)
- the deceleration of the leader's vehicle, giving an indication about the presence of a risk situation

2.1.2 The unsafety density parameter

During each simulation step, position, speed and maximum breaking capacity of a particular vehicle can be known. The same parameters can also be obtained for its leader vehicle. With the hypothesis that the follower vehicle's reaction time is the standard reaction time and that the leader vehicle breaks with its maximum braking capacity, it's possible to say if a hypothetic crash will occur or not. If it occurs, the speed S of the follower vehicle and the speed difference ΔS between the two vehicles at collision time can be calculate by applying the basis dynamic rules, as shown in Figure 3 :

Figure 3 Determination on S and ΔS by applying the basic dynamic rules



As explained before, the importance of this hypothetical crash is proportional to S and ΔS. An "unsafety" parameter could then be defined as the multiplication of both parameters.

This value would represent the maximum importance of the hypothetical collision, with the leader supposed with its maximum deceleration. Such a deceleration is only theoretical. This maximum value must be multiplied by the ratio R_d between the deceleration of the leader vehicle and its maximum deceleration capacity. So, the importance of a hypothetical collision can be evaluated by the unsafety parameter, defined as:

$$\boxed{U = \Delta S \cdot S \cdot R_d} \quad [m^2/s^2]$$

With

U : unsafety parameter $[m^2/s^2]$

ΔS : speed difference between two vehicles at collision time [m/s]

S : speed of the follower's vehicle at collision time [m/s]

$R_d = \frac{R}{R_{max}}$: ratio between the deceleration of the leader vehicle and its maximum deceleration capacity [-]

This unsafety parameter determines the level of unsafety in the relation between two consecutive vehicles on the road, for a determined simulation step. If the hypothetical crash doesn't occur or the leader vehicle isn't breaking, the value of the unsafety parameter is zero.

But this parameter gives only local information about the safety in a particular section road. For having a global vision of the network, an unsafety density parameter must be calculated. It will be done for each link of the microsimulation model network and for each aggregation period, as follows:

$$\boxed{UD = \frac{\sum_{s=1}^{S_t} \sum_{v=1}^{V_t} U_{v,s} \cdot d}{T \cdot L}} \quad [m/s^2]$$

With

UD : unsafety density $[m/s^2]$

$U_{v,s}$: unsafety of vehicle v in simulation step s $[m^2/s^2]$

V_t : number of vehicles in the link [-]

S_t : number of simulation steps within aggregation period [-]

d : simulation step duration [s]

T : aggregation period duration [s]

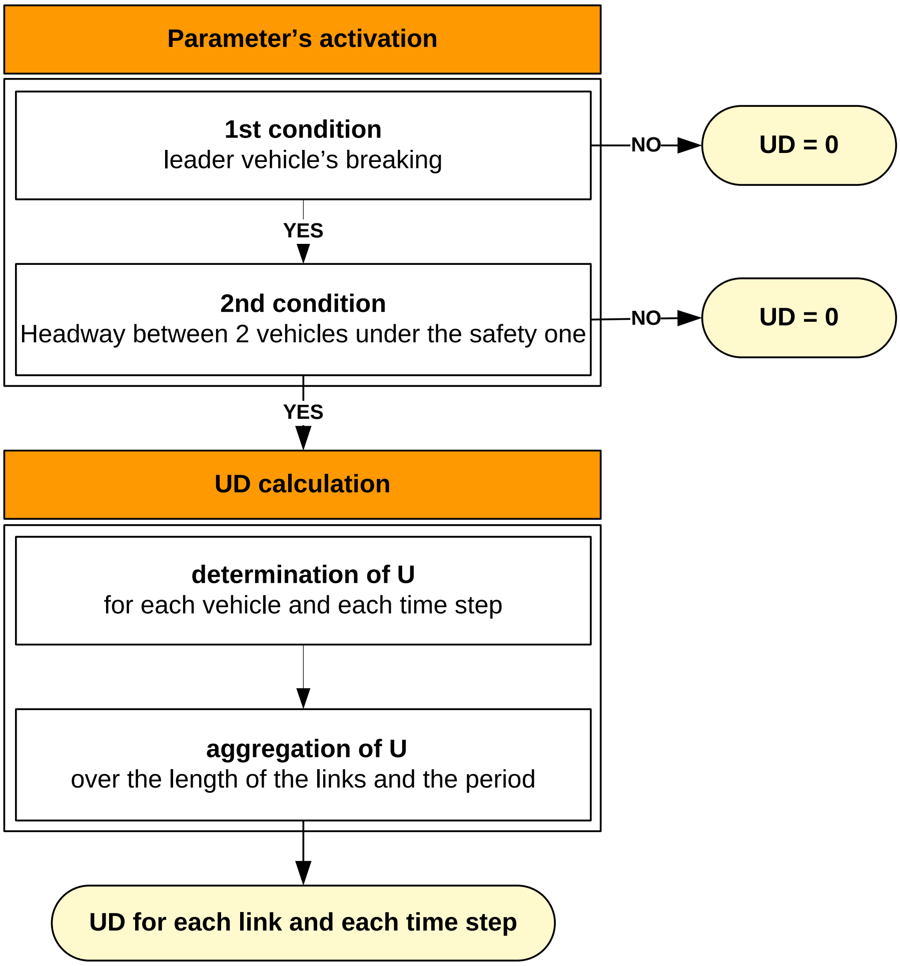
L : section length [m]

The values of unsafety density, calculated for each aggregation period, are qualitative. They allow to compare the safety level between different links of the network and to observe its evolution from one time period to another. But the most significant is that the unsafety density permits comparison between different simulation scenarios. Its can therefore be the principal indicator to use in a safety assessment process.

2.2 Unsafety parameter in microsimulation

The determination of the UD parameter with microsimulation needs several steps:

Figure 4 Approach for the determination of the UD parameter



1) Check of the first condition of UD parameter's activation : leader vehicle's braking

Microsimulation gives, within each time step, a "photography" of the network's state. We know the position, the speed and the deceleration of each vehicle. As said before, a risk situation appears only if the leader vehicle breaks. So we have to control, for each couple of vehicle, if the leader vehicle breaks or not. If yes, we have to go to the second step; if not, the process stops here for this simulation step and this couple of vehicles.

2) Check of the second condition of UD parameter's activation : real headway between two vehicles under the safety headway

When the headway between two vehicles is under those who allow a vehicle's safety progress, there is a potential crash situation and we need to calculate the UD parameter. The headway between a pair of vehicles is found with the simulation's outputs (vehicles' length, speed, position at each time). The safety headway is given by the situation where, after the leader vehicle's break, the follower breaks after a certain reaction time. The front of the follower touch the leader's back, the two vehicles having the same speed.

3) Unsafety calculation for each vehicle and each time step

The calculation of U needs three elements: the speed of the follower's vehicle S and the difference of speed ΔS at collision time, and finally the ratio R_d between the deceleration of the leader's vehicle and its maximum deceleration capacity. The last-mentioned is obtained with the microsimulation outputs at each time step. The speeds are calculated by applying the basic dynamic rules within several collisions' scenarios, defined in Figure 5:

Figure 5 Collision' scenarios

		Follower		
		Moving normally	Breaking, not yet stopped	Stopped
Leader	Breaking, not yet stopped	Case 1-1	Case 2-1	Case 3-1
	Stopped	Case 1-2	Case 2-2	

4) Determination of UD for each link and each time step

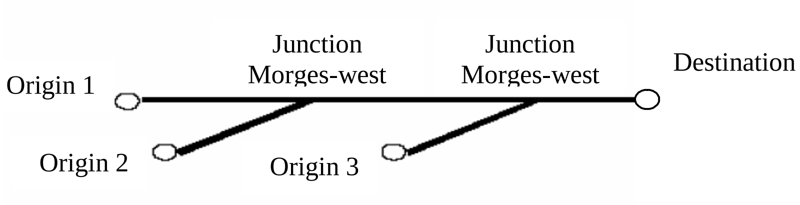
By aggregation of U over the length of the links and the period, the evolution of the UD on each link and each time step is obtained.

All these steps are taken into account within the creation on an extension's program of AIMSUN.

3. Case study

The new UD parameter is tested on a site, which was already studied within the framework of an evaluation study of a ramp metering implementation on a by-pass junction [8]. The modelled network corresponds to the south road of the motorway Geneva – Lausanne, with two by-pass junctions (Morges-west and Morges-east).

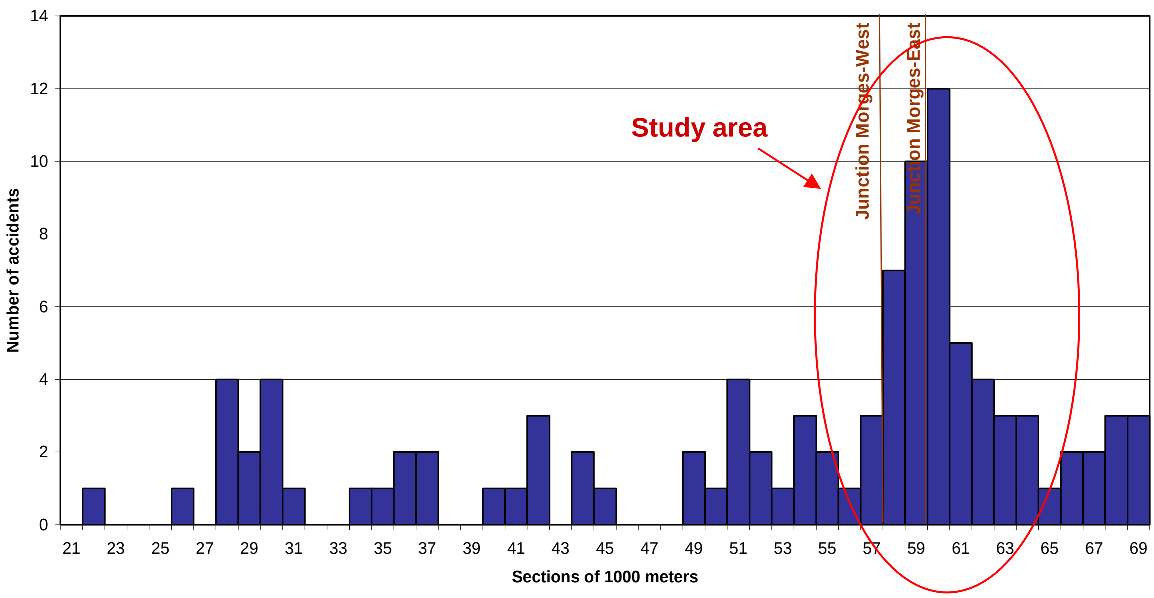
Figure 6 Schematic representation of the studied network



3.1 Accident' analysis

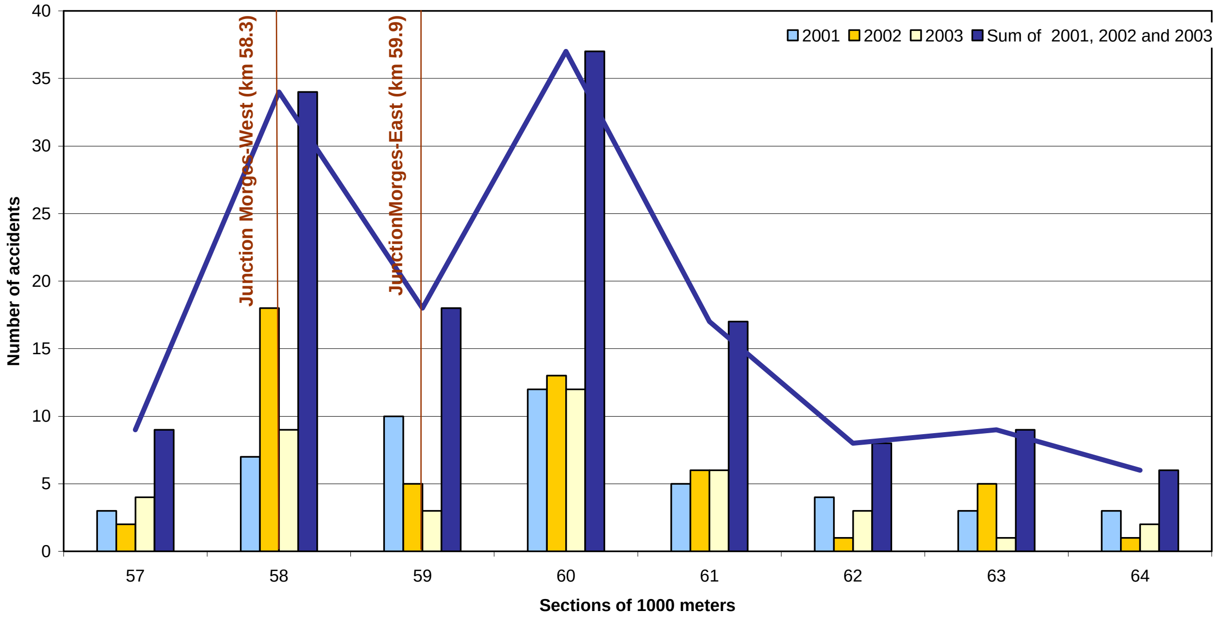
The UD gives information about the safety in linear conflicts. For its calibration, the corresponding accident' statistics are used, that is to say the front-rear collisions. The geographical distribution of the linear accidents in 2001 allow to justify the study area, from 57.0 [km] to 64.0 [km]. This section presents an important number of accidents.

Figure 7 Distribution of rear-front accidents (Motorway Geneva – Lausanne, south road, year 2001)



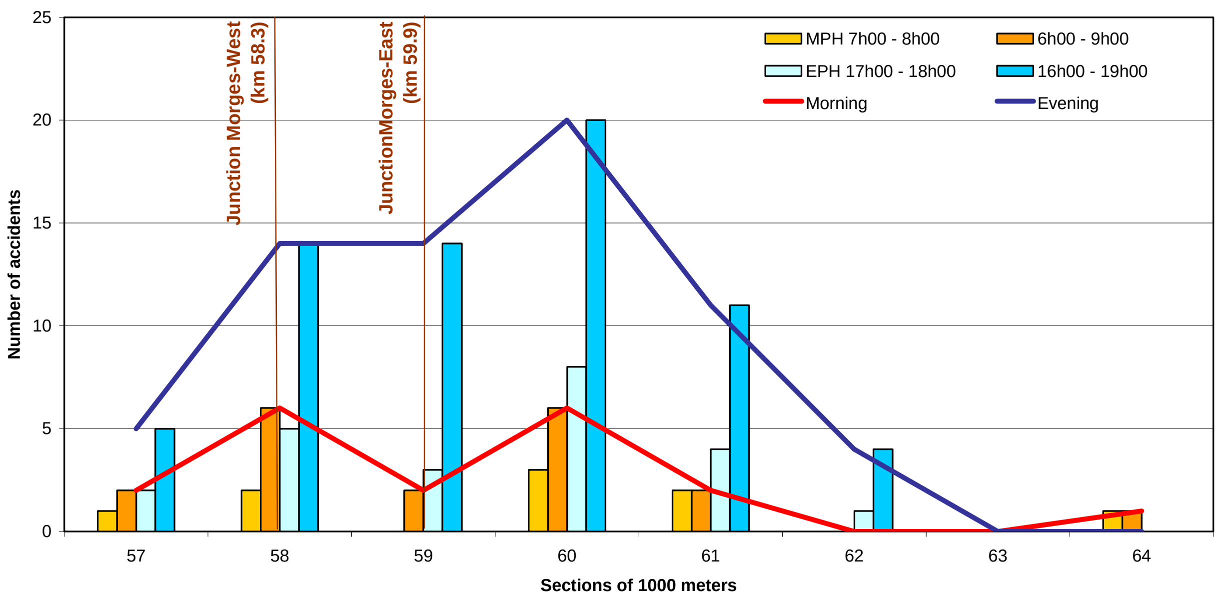
Even if there are more accidents in the study area, they are not enough for being representative. The work must be done with statistics of several years. So, the linear accidents from 2001 to 2003 (Figure 8) give the element to compare with the UD simulation's results.

Figure 8 Distribution of linear accidents (years 2001, 2002 and 2003)



The distribution of the accidents during the day shows that there are more linear accidents during the evening, as show in Figure 9.

Figure 9 Distribution of the accidents (sum of 2001, 2002 and 2003) during the day

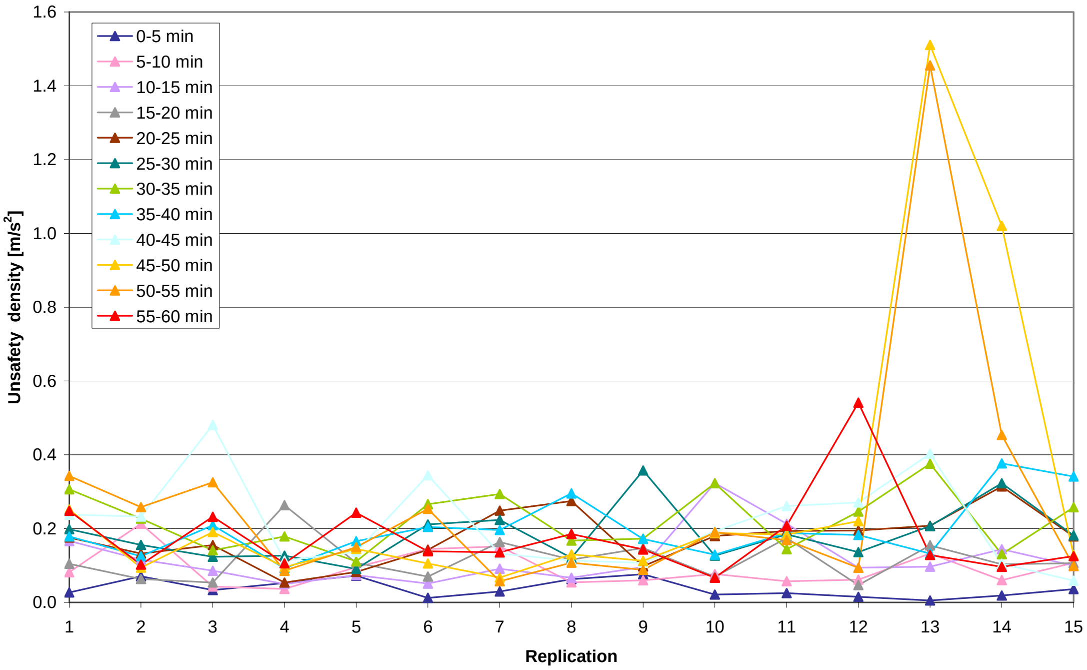


The number of accidents is more important during the evening. However, the global evolution of the number of linear accidents along the motorway is similar in the morning and in the evening, with two “peaks” located around 58.000 and 60.000 km. Studying the speeds and flows on this part of motorway, demonstrates that the morning and the evening present a similar structure, with a morning peak hour a little more compact. Consequently, it has been decided to work with the OD matrix from 7h00 to 8h00 and with the statistics of front rear accidents during all the day from the 2001 to 2003.

4. First results

The first results are obtained by simulating the morning peak hour (7h00 – 8h00). The microsimulation, combined with the safety extension, gives the UD parameter for each time step and each link. To take into account the stochastical behaviour of the microsimulation, several replications have been made for the analyses. The results show that 2 of 15 replications are irregular (see Figure 10), with a bigger coefficient of variability. The two irregular replications are also left and the study made on an average on 13 replications.

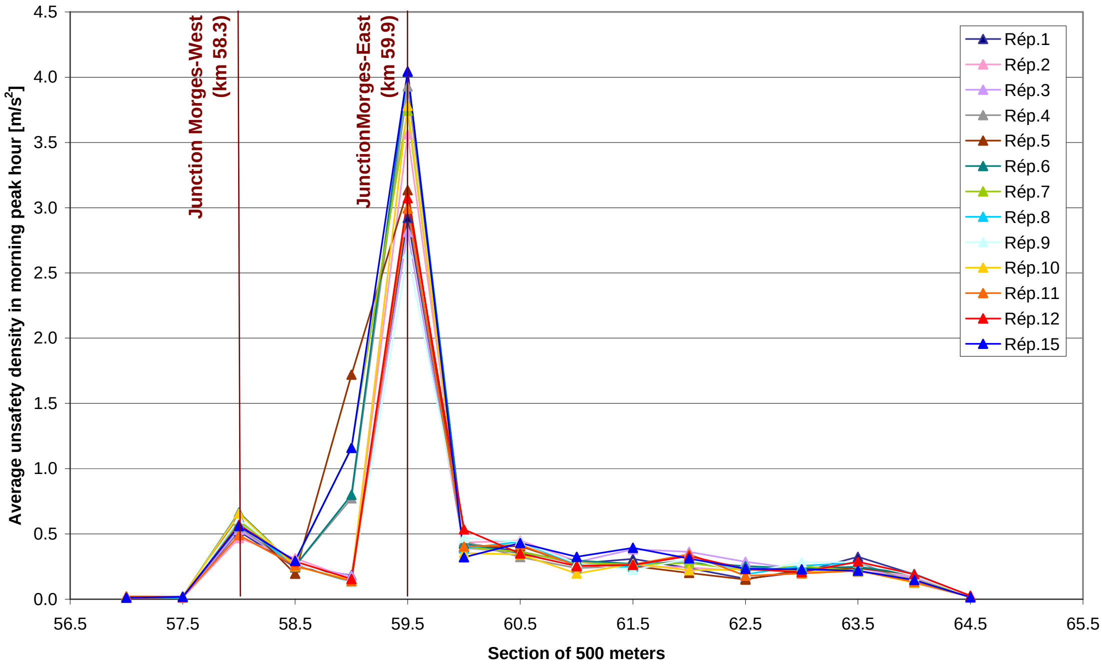
Figure 10 Microsimulation results in Section 18



The outputs allow knowing the evolution of the unsafety parameter on time and space. The value of UD can also be known along the all network, with a space determined aggregation. This information is very important, seeing that the UD is a qualitative parameter, which doesn't really have a sense in itself. The comparison between the evolution of UD along the network and the rear-front collision's statistic will also been a good validation parameter.

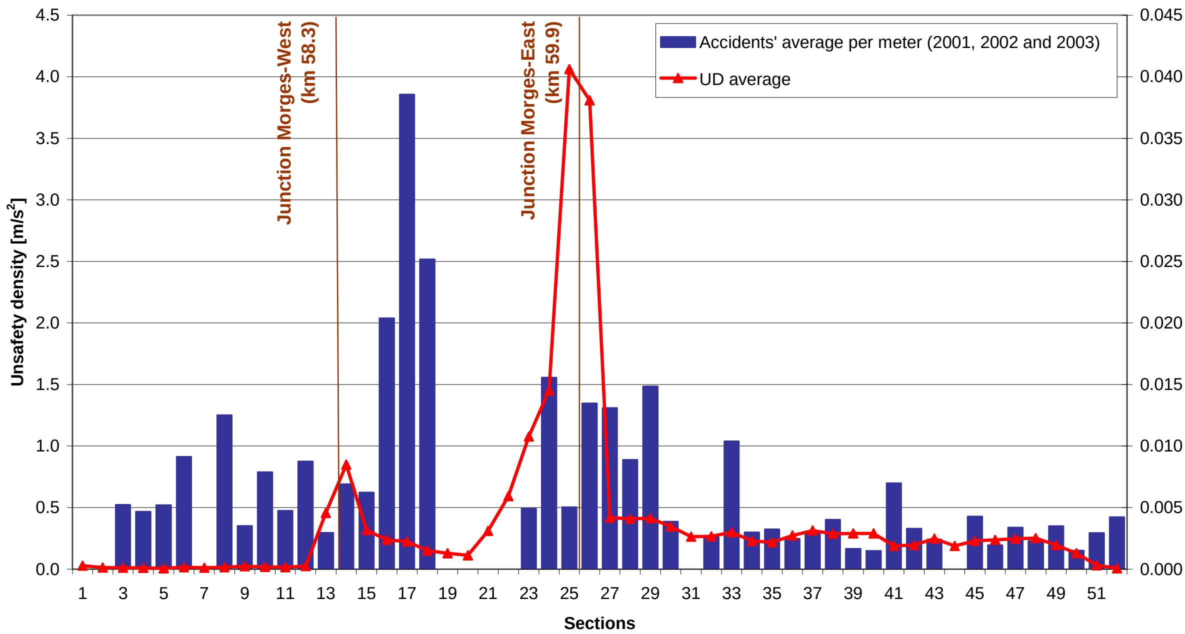
Several space aggregations are made for analysing the unsafety parameter evolution. With portions on 500 meters, the curve presents two peaks (a big one and a less important one). These peaks correspond twice with the entrance of the vehicles from Morges to the motorway, the second one (junction-Morges East) presented a peak about 8 times more important than the other.

Figure 11 Evolution of the unsafety density along the network



For been representative of the real front-rear collision risk, the curve should correspond to the repartition of the accidents along the motorway. Now, it is not so, the major number of rear-front accidents happened between the two junctions, that is to say in the 500 meters after the first junction Morges-West (Figure 12).

Figure 12 Comparison between the evolution of UD and the accidents



Thing amazing with a space aggregation considering the sections of the modelised network: by making a translation of 8 sections, the evolution of UD and the number of accidents correspond quite well.

The question is also to know if the problem comes from the concept of the UD parameter or from the microsimulation itself. So, this space shift prompts two questions:

1) Does the microsimulation well represent the traffic conditions, not only in terms of traffic flows but also in terms of individual drivers' behaviour?

2) Does the UD parameter well represent the sections dangerousness in term of rear-front collision?

5. Further researches

The present microsimulation can be considered as a good representation of the traffic conditions in terms of speeds and flows, seeing that its calibration has been based notably on the fundamental diagram [8]. Nevertheless, in the field of safety analysis, this is not sufficient. The individual behaviour of each vehicle must also correspond to reality.

A more accurate analyse of type of accidents, notably on the critical sections 16, 17 and 18, allow a better comprehension of the real system functioning. In the section 17 (that is to say one kilometre before the second junction), close on two thirds of the rear-front accidents implicate a stopped vehicle. It is so very likely that the augmentation of the rear-front unsafety comes principally from the back-propagation of the end of the queue, and not from the entry of the vehicles in the junction. .

The microsimulation must reproduce this fact. So, one of the problematic to be studied in the future is the driver's behaviour, in particular the lane-changing model and the on-ramp model as defined in AIMSUN.

Before this, it's imperative to control the independence from the place. Indeed, the utilisation of the UD parameter must be extended to another highway network, to separate the specific elements from the UD parameter itself and from the particular case study in Morges. Consequently, a second case study, which is the bypass of Lausanne, will be considered.

6. Conclusion

The concept of the unsafety parameter developed here is based on the direct interaction between couple of vehicles, which seem to be appropriate for treating safety problems. The UD parameter takes into account only potential for rear-end collision and is therefore particularly planned for highways network assessments.

Theoretically, the unsafety density parameter seems a good and important indicator for safety assessment, giving more accurate information than typical microsimulation outputs. Its value doesn’t really have a sense in itself and must be used only for comparison purposes. However, it allows, among other, to highlight the difference in safety level between a fluid and a congested traffic flow situation, which cannot be shown by using traditional macroscopic outputs like speed, flow or occupancy.

The first results are encouraging. They indicate a space evolution of UD, which allow the localisation of sections more unsafe than others, in term of linear conflicts. The first results show also a space shift between the UD parameter and the localisation of rear-front accidents. This must be explaining by further researches.

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