VALIDATION OF THE SSAM TECHNIQUE FOR THE ASSESSMENT
OF INTERSECTIONS SAFETY

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ABSTRACT

The Surrogate Safety Analysis Module (SSAM) is a software application that reads trajectory files generated by microscopic simulation programs and calculates surrogate measures of safety. This approach eliminates the subjectivity associated with the conventional conflict analysis technique and allows assessment of the safety of a facility under a controlled environment before the occurrence of accidents. The specific goal of this research is to validate SSAM as a tool for accident prediction at urban intersections. Two methods are used: the first compares the simulated number of conflicts using SSAM and the predicted number of injury accidents using analytic models in three reference intersections layouts (4-leg intersection, 4-leg staggered intersection and single-lane roundabout); the second compares SSAM results with conflicts observed on site in four real intersections, two priority ones and two roundabouts. The results indicate that despite some limitations related to the nature of current traffic microsimulation models, SSAM analysis is a very promising approach to assessing the safety of new facilities or innovative layouts.
INTRODUCTION

In urban areas traffic accidents are usually concentrated at intersections. Traditional approaches to estimating the potential traffic accident risk of intersections, based on historical crash data, include before-and-after analyses and accident prediction models. Both approaches have important limitations related to the complexity of the safety factors and the poor quality of data, thus: (i) compared to other traffic events, accidents are quite exceptional in that they result from a series of unhappy improbable actions and situations; (ii) accidents are rare events, so it is troublesome to base traffic safety analyses at individual sites on accidents alone; (iii) not all accidents are reported and the level of underreporting depends on the accident’s severity and types of road users involved; (iv) information on the circumstances preceding the accident is seldom available. Additionally, the fact that accidents must take place before one can determine the risk of locations is, from an ethical point of view, a disadvantage. Therefore, specific evaluation techniques are required to take into account changes in traffic regulations or in the geometrical design of infrastructure, in order to estimate the true effects of safety improvements. Moreover, regression models may not be transferable because they implicitly reflect road users' behavior, the vehicle fleet and driving rules which vary from country to country and even from site to site.

The traffic conflict technique is an approach that overcomes the lack of good and reliable accident records, relying instead on observations of conflicts. A conflict is defined as a situation in which two or more road users approach each other in time and space such that there is risk of collision if their movements remain unchanged. The necessary evasive action is usually braking, but may also be swerving or acceleration, or a combination of them. In other words, conflicts are events that would result in an accident if one of the drivers was not able to make an evasive maneuver in due time, since both vehicles were in course to occupy the same space at the same time. Conflicts are far more frequent than accidents and they are observable in real time at the site, allowing safety assessments without the occurrence of accidents. While interest in the conflict technique has been considerable, its practical use has been limited due to questions of subjectivity in the registration process and the costs of data collection. Automatic tracing of trajectories from video recordings is a recent and promising technology that addresses these questions but the problem of predicting the safety benefit of a new geometry or circulation scheme remains. Some functions linking simulated conflicts and crash predictions were obtained, but the connection between surrogates and crashes is still relatively unknown.

Microscopic simulation models are seen as promising tools to evaluate road safety levels of existing and new infrastructures. The core of this new approach is the software developed by the FHWA (Surrogate Safety Assessment Model - SSAM) that automates conflict analysis by processing the vehicle trajectories produced during the simulation (vehicle's position, speed and acceleration profiles). This approach has all the generic advantages of simulation (possibility of assessing the safety of new facilities before the occurrence of accidents, controlled environment, etc.) but also has some limitations: common microscopic simulation models are developed for traffic-flow analyses and lack
some operational sub-models that are essential for safety analyses. Some authors have proposed specific procedures to calibrate simulation models for safety assessment (10; 11) but this is still an ongoing research field.

Practical experience with SSAM is limited and the results are not consensual. Gettman et al. (6) found a significant correlation between simulated conflicts and crashes reported at 83 four-leg signalized intersections. Kim and Sul (12) tested the effect of changing the speed limit of an arterial road in Sungnam, Korea and concluded that VISSIM microsimulation represents speeds and flows well but is insufficiently detailed in terms of safety analysis. Dijkstra et al. (13) modeled a 300 km² road network in PARAMICS and concluded that there was a significant relationship between the observed crashes and the simulated conflicts. Huang et al. (14) compared observed and simulated conflicts at ten signalized intersections in the Nanjing area in China. Their results show a reasonable goodness-of-fit between simulated and recorded rear-end conflicts but they also found that the simulated conflicts are not good indicators for traffic conflicts generated by unexpected driving maneuvers, such as illegal lane-changes.

The specific goal of this research is to validate SSAM as a tool for accident prediction in urban intersections. Two methods are used. The first compares the simulated number of conflicts using SSAM and the predicted number of accidents using analytic models in three fictitious intersections – one 4-leg priority intersection, one staggered 4-leg intersection, and one single lane roundabout – with simple geometry and idealized traffic demand distributions. The second method compares the observed conflicts in four selected intersections and the simulated conflicts using SSAM, emulating (as much as possible) the real conditions observed at the different locations.

THE SSAM APPROACH

SSAM operates by processing data describing the trajectories of vehicles driving through a traffic facility and identifying conflicts. For each vehicle-to-vehicle interaction SSAM calculates surrogate measures of safety and determines whether or not that interaction satisfies the criteria to be deemed a conflict. In the present analysis the research team used time to collision (TTC) as a threshold to establish whether a given vehicle interaction is a conflict and the relative speed (DeltaS) as a proxy for the accident severity. Their definition is (6):

• TTC is the minimum time to collision value observed during the interaction of two vehicles on collision course. If at any time step the TTC drops below a given threshold (1.5 s in this work, as suggested for urban areas (15)), the interaction is tagged as a conflict;

• DeltaS is the difference in vehicle speeds as observed at the instant of minimum TTC. More precisely, this value is mathematically defined as the norm of the velocity vector of each vehicle, thus accounting for the differences in the vehicles’ absolute speeds and headings. For example, if the speeds of two vehicles at the instant of minimum TTC were 50 km/h and 30 km/h, then DeltaS would be 20 km/h if they were following the same direction (rear-end accident), 80 km/h if they were driving in opposite
directions and 58.3 km/h if there were in following perpendicular directions (law of cosines).

Aimsun (16) was the simulator used in this work. With the exception of the parameters that control the drivers’ desired speed on links, most parameters kept their default values and a single vehicle type (car) was considered. To increase the accuracy of the surrogate measures (and specifically, for each vehicle conflict, the value of the minimum TTC and the vehicles’ speeds at that instant) the simulation step was set to 0.25 seconds and drivers’ reaction time was set to 0.75 seconds. Further details about alternative surrogate measures can be found elsewhere (1; 17).

CONCEPTUAL VALIDATION

Evaluation framework

The SSAM would ideally be validated against accident records. However, as accidents are very rare, it would be very difficult to obtain enough data from a single site under controlled external variables such as weather or traffic conditions to define a reference scenario. As an alternative, conventional accident prediction models (APMs) were taken as reference. These models are usually based on a large number of accident records and rely on advanced statistical techniques to identify the significant variables and calibrate the respective coefficients. A simple evaluation framework was designed to assess the performance of SSAM: it consists of comparing the SSAM outputs against accident estimates from the APMs for a set of layouts under the same traffic demand (see Figure 1). It starts with a 4-leg yield-controlled intersection with a typical traffic demand (70% traffic in the major E-W direction, 30% in the minor (N-S); at each entry, 30% turn right, 50% move through and 20% turn left, Figure 1-a). We were interested in seeing if the safety models can replicate the safety improvements arising from a left-right staggering (reconfiguration of crossroads as two T-junctions, Figure 1-b) and with the conversion to a single-lane roundabout (Figure 1-c).

The three layouts have standard geometric characteristics for urban conditions. The 4-leg intersection has left-turn lanes in the major direction and short right-turn lanes from the minor direction. A conventional single-lane roundabout with four legs was also considered, designed according to the Portuguese Roundabout Design Guidelines (18). It has the following main geometric characteristics: inscribed circle diameter (ICD) – 40 m, carriageway width (between lane markings) – 6.5 m, approach lane width – 3.5 m, entry width – 4.5 m, entry radius – 30 m. The roundabout is symmetrical in both the N-S and E-W directions. A 50km/h speed limit was assumed for all layouts.

These layouts were chosen because, first, there are several directly applicable APMs (presented in the next section) and, second, their effects on safety are well documented through a large number of studies. With respect to the staggering, according to Elvik et al. (19), junctions with four approaches (32 conflict points) make greater demands on road user alertness and behavior than junctions with three approaches (9 conflict points). The effects of staggered junctions depend on the proportion of minor road traffic at the crossroads before staggering and on the staggering side. For the
conditions presented on Figure 1-b (left-right staggering, heavy minor road traffic) one can expect a 33% reduction in injury accidents and 10% reduction in property damage accidents (19). Converting a crossroads to a single-lane roundabout is also a well-recognized way to improve safety. Several factors contribute to this: i) the number of conflict points is reduced from 32 to 20; ii) all drivers must give way to circulating traffic and are thus forced to watch traffic at the roundabout more carefully; iii) all traffic comes from one direction, which facilitates finding a suitable gap to enter the roundabout; iv) roundabouts make users drive around a circular traffic island located in the middle of the intersection. This reduces the entry and circulating speeds, and the potential impact angle. A meta-analysis of several studies indicates that the total number of severe accidents is significantly lower on roundabouts (46% reduction for injury accidents) but property damage accidents increase (+10%) (19). A recent before-and-after study in Denmark reports decreases of 47% for injury and 16% and property-damage-only accidents (20).

For simulation purposes the daily traffic demand was split into 24 O/D matrices based on a typical distribution throughout one day. Traffic demand assumed only cars.

![Figure 1 - Conceptual validation - geometric layouts: a) 4-leg priority intersection, b) staggered 4-leg-intersection (modeled as two 3-leg intersections), c) single-lane roundabout](image-url)
Accident Prediction Models

At least two different models were used for each layout analyzed. The accidents in the priority intersections (3-leg and 4-leg, see Table 1) were estimated using models developed in the United States (21), United Kingdom (22) and Portugal (23). Each of these models gives the predicted number of total intersection-related injury accidents per year, excluding pedestrians. The data samples vary considerably between studies: the US models are based on a sample of 324 four-leg STOP-controlled intersections and 382 three-leg STOP-controlled intersections in Minnesota and they include 5 years of accident data (1985-1989) for each intersection. The UK model was based on data for 3800 km of highway in the UK including more than 5000 minor junctions. The Portuguese dataset included 44 locations for the 3-legged intersections and 50 locations for 4-legged intersections, located in Lisbon.

Table 1 – Accident prediction models for 3-leg and 4-leg priority intersections

<table>
<thead>
<tr>
<th>Model type</th>
<th>Origin</th>
<th>Expression</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-leg priority</td>
<td>USA: Harwood and Council (21)</td>
<td>[ A = AMF_1 AMF_2 AMF_3 AMF_4 e^{-10.9 + 0.79 \ln ADT + 0.49 \ln ADT_2} ]</td>
</tr>
<tr>
<td>4-leg priority</td>
<td>UK: Maher and Summersgill (22)</td>
<td>[ A = 0.049 \left( \frac{IF_1}{1000} \right)^{0.80} \left( \frac{IF_2}{1000} \right)^{0.36} ]</td>
</tr>
<tr>
<td></td>
<td>PORTUGAL: Vieira Gomes (23)</td>
<td>[ A = 4.7078 \times 10^{-6} IF^{1.167} ]</td>
</tr>
<tr>
<td></td>
<td>USA: Harwood and Council (21)</td>
<td>[ A = AMF_1 AMF_2 AMF_3 AMF_4 e^{-9.34 + 0.69 \ln ADT + 0.61 \ln ADT_2} ]</td>
</tr>
<tr>
<td></td>
<td>PORTUGAL: Vieira Gomes (23)</td>
<td>[ A = 3.8765 \times 10^{-5} IF^{3.167} ]</td>
</tr>
</tbody>
</table>

Where: \( A \) is the predicted number of total intersection-related accidents per year. USA - AMF_1 is the accident modification factor for there being a left-turn lane on major road (0.78 for one major-road approach, 0.58 for both major-road approaches), AMF_2 is the accident modification factor for there being a right-turn lane (0.95 for a right-turn lane on one major-road approach, 0.90 for right-turn lanes on both major-road approaches), AMF_3 is the accident modification factor for the sight restrictions, AMF_4 the accident modification factor for the conversion from minor road to all-way stop-control, ADT_1 is the annual average daily traffic on the major road, ADT_2 is the annual average daily traffic on the minor road. Portugal and UK: \( IF, IF_1 \) and \( IF_2 \) – total inflow in the intersection, major direction and minor direction, respectively (veh/day, annual average).

The accidents in the roundabout were estimated using models developed in the United Kingdom (24), Australia (25) and Portugal (23) (see Table 2). The British model is based on accidents that occurred over a six-year period on 84 roundabouts in the UK. Some of the sub-models obtained were excluded because they refer to causes that are beyond the scope of the SSAM methodology (namely the sub-model \( A_3 \) – single-vehicle accidents and sub-model \( A_5 \) – accidents involving a pedestrian casualty). Arndt (26) analyzed one hundred Queensland (Australia) roundabouts, where 492 major accidents were recorded, generally over a five-year analysis period. The main objective of that study was to determine the effect of roundabout geometry on accident rates. Models were developed for single vehicle accidents, approaching rear-end accidents and...
entering/circulating vehicle accidents. For the reasons stated in the previous point, the first type was excluded from the current analysis. Vieira Gomes (23), using data from 15 roundabouts in Lisbon, Portugal, developed models to estimate the frequency of accidents with injuries on urban road networks.

Table 2 – Accident prediction models for roundabouts

<table>
<thead>
<tr>
<th>Origin</th>
<th>Conflict type</th>
<th>Expression</th>
</tr>
</thead>
<tbody>
<tr>
<td>UK: Maycock and Hall (24)</td>
<td>Entry-circ.</td>
<td>[ A_1 = 0.052Q_e \theta \exp \left( -40C_e + 0.14e - 0.007ev - \frac{1}{1 + \exp(4R - 7)} + 0.2P_m - 0.01\theta \right) ]</td>
</tr>
<tr>
<td></td>
<td>Approach</td>
<td>[ A_2 = 0.0057Q_e^2 \exp(20C_e - 0.1e) ]</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>[ A_3 = 0.0026Q_e^2 \exp(0.2P_e) ]</td>
</tr>
<tr>
<td>Australia: Arndt (25)</td>
<td>Rear-end</td>
<td>[ A_4 = 9.62 \times 10^{-11} Q_e Q_v S^2 ]</td>
</tr>
<tr>
<td>Portugal: Silva (23)</td>
<td>Entry-circ.</td>
<td>[ A_5 = 3.45 \times 10^{-12} Q_v \sum (Q_{e,v} S_i^2) ]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[ A = 2.3845 \times 10^{-8} FT^{1.5084 - 0.5248 \times \text{LEG}} e^{A} ]</td>
</tr>
</tbody>
</table>

Where: UK - \( A_1 \) are personal injury accidents (including fatalities) per year per roundabout approach; \( A_2 \) entering-circulating accidents; \( A_3 \) approaching accidents (mostly rear-ends, but also changing lane accidents, \( A_4 \) other accidents (variety of non-pedestrian accidents)); \( Q_e \) and \( Q_v \) are the entering and circulating flow, respectively (1000s of veh/day), \( C_e \) is the is entry curvature (\( C_e = 1/Re \) and \( Re \) is the entry path radius for the shortest vehicle path (m)), \( e \) is the entry width (m), \( v \) is the approach width, \( R \) is the radius of the inscribed circle diameter, \( P_m \) is the proportion of motorcycles (\%), and \( \theta \) is the angle to next leg measured centerline to centerline (degrees, °). Australia - \( A_2 / A_3 \) are, respectively, rear-end and entering/circulating accidents per year (over $1000 property damage and/or personal injury), \( Q_v \) is the average annual daily traffic on the approach, i.e., one-way traffic only (veh/d), \( Q_{e,v} \) are the various average annual daily traffic flows on the circulating carriageway adjacent to the approach, i.e., one-way traffic only (veh/d). Si are the various relative 85th percentile speed between vehicles on the approach curve and vehicles on the circulating carriageway from each direction (km/h). Portugal - \( A \) is the estimated number of accidents with injuries per year in the roundabout, \( FT \) is total entering traffic flow in vehicles per day (AADT), \( \text{LEG} \) is the number of legs of the roundabout.

Results

The purpose of this first test was to compare the SSAM and APM results for uniform traffic growth, when the total AADT (entering traffic) varies from 0 to 20000 veh./day in the three layouts.

Figure 2 shows the results for both the simulated conflicts and predicted accidents in all three types of intersections. We can infer that although the regression models relate to different countries and are based on different assumptions, they still provide consistent estimates. The SSAM conflict-flow points are almost perfectly fitted by a convex curve, similar to the accident-flow curves from the regression models, although with a more pronounced curvature, which suggests a good correlation between simulation conflicts and actual accidents.

All APMs predict a reduction in the number of injury accidents with the staggering of the 4-leg intersection and a further reduction following the conversion to a roundabout, which agrees with expectations and with international experience. The SSAM method
predicts a reduction in the number of conflicts in the staggered intersection (sum of the two T-intersections), as expected, but it also predicts an increase on the roundabout. To assess the severity level of the simulated conflicts, the average speed differential (DeltaS), was calculated for each intersection and the following values were obtained: 4-leg intersection - 6.46 m/s, staggered junctions - 6.19 m/s, roundabout – 4.40 m/s. SSAM predicts a large number of low severity conflicts at roundabouts. This agrees with the above mentioned typical significant reduction of injury accidents at roundabouts, associated with an increase of minor accidents.

Figure 2 – Accident – Flow relationships from analytic regression models and Conflict – Flow relationship from the SSAM technique
The graphs show that the relation between conflicts and accidents is not linear, as it varies with the entry flow, the intersection type and with the APM in question. Nevertheless, it is possible to obtain some approximate figures that may be useful to narrow down the uncertainty in this research area. For example, for a 12000 vehicles/day entry flow, depending on the APM we can expect to find a conflict/accident ratio of 25000 – 30000 in a 4-leg intersection, 15000 – 60000 in the staggered 4-leg intersection and 180000 – 500000 on the roundabout. These ratios increase with the demand flow, as expected, due to the increasing difficulty of maintaining high speeds, which leads to lower probability of a conflict resulting in an accident with injuries.

FIELD VALIDATION

The objective of this section was to understand how conflicts predicted by the Aimsun-SSAM approach correlate with real conflicts observed in urban intersections. Four intersections were selected within the city of Coimbra, Portugal: one three-leg stop controlled intersection, one four-leg stop controlled intersection, one four-leg single-lane roundabout, and one five-leg two-lane roundabout. The main geometric and traffic characteristics of these intersections are presented in the next section.

Observation of conflicts

The conflict observation followed the guidelines presented in the FHWA Traffic Conflict Observers Manual (27), with minor adjustments aiming at comparability with the simulation outputs. Therefore, only vehicle-vehicle interactions were considered. Pedestrians were not regarded as road users but could be a cause of a conflict, particularly rear-end conflicts between two vehicles forced to stop for a pedestrian in a crosswalk. The severity of conflicts was not assessed, meaning that there was no limit on time-to-collision or post-encroachment time for a conflict to be registered. As such, observers were expected to register a conflict every time a road user with the right of way was forced to modify their behavior, either by braking or swerving.

Each observer was responsible for a certain direction of vehicles with the right of way (e.g.: one observer would only register conflicts involving northbound vehicles in the major road while the other was responsible for the southbound vehicles). This meant that conflicts in minor roads and after the intersection (from each observer’s point of view) were ignored. In roundabouts, each observer was responsible for a quarter of the circulatory carriageway. Rear-end conflicts in the approaches were disregarded. Because of the methodology used for conflict observation on site and in order to properly compare the number of observed and simulated conflicts, only the conflicts that took place in the intersection itself or in the major road immediately before the intersection were considered. In the case of roundabouts, only the conflicts taking place in the circulatory carriageway were counted.

There was a trial period during which we tested this method and made sure that every observer was on the same page, so that the results were as similar as possible. At least one of the authors was permanently on the field accompanying the sessions and helping observers to decide on the less clear cases.
The observations were taken for nine hours per location, each on a different day, divided into three periods: the morning period from 7:30 am to 10:30 am, the noon period from 12:00 pm to 15:00 pm, and afternoon period from 16:00 pm to 19:00 pm. These periods cover different traffic demand levels and directional splits. The total workload was 108 person\times hours.

Development of the microscopic models

Other observers were responsible for collecting the data required for the microsimulation modeling: traffic volumes per movement, pedestrian movements in crosswalks, bus stop frequency (if needed), and vehicle approach speeds using a laser gun (LIDAR). The parameters that control the speed of vehicles under free-flow conditions (desired speeds and levels of compliance with speed limits) were adjusted in the model to correspond to field measurements.

Pedestrians are traditionally simulated in Aimsun by using an embedded pedestrian simulator engine (a plugin provided by Legion, a company specializing in the field of pedestrian simulation). Unfortunately, SSAM is unable to assess pedestrian-pedestrian and vehicle-pedestrian interactions, so we decided to emulate pedestrian crossing events using Aimsun’s “periodic section incidents” feature. This feature allows a specified segment of a road (the crosswalk) to be blocked to vehicles during short time intervals, with a duration and frequency typical of the observed crossings.

The default values of the remaining parameters that control the car-following and gap-acceptance behavior were not changed. A comprehensive calibration was not deemed necessary as the main objective of this analysis was to compare alternative layouts, so the absolute values are not of significant importance. Furthermore, keeping default values facilitates future comparisons with similar studies.

Locations

Three-leg intersection

The chosen intersection is located on an arterial road within an urban environment. The main street is north-south oriented and has an estimated total entering AADT of 14483 vehicles per day, with evenly balanced flows for most of the day, but mainly northbound in the morning peak hour. The street is approximately 7 meters wide and has one lane each way. No left-turn lane is provided on the major road. The minor street approaches the main one from west and has a considerable entering AADT of 8245 vehicles per day, with most of the movements being northbound. The street is approximately 12 meters wide and has one lane for the westbound traffic and two lanes for the eastbound traffic, thus allowing segregated right and left turns. There is also a one way street approaching the main road from the east, just a few meters to the south of the intersection, which was disregarded due to its low traffic volume. Additionally, there is one bus stop on each side of the major street, located approximately 60 meters to the north
of the intersection. This is a very significant factor for the traffic flow, both southbound and northbound, since there is no bay and the buses have to stop in the main road. Other constraints are a couple of crosswalks immediately to the west and south of the intersection. Both have residual pedestrian traffic, crossing every other 10 or 15 minutes. The average free flow speed while approaching the intersection was 46.0 km/h with a standard deviation of 5.4 km/h.

*Four-leg intersection*

The chosen intersection is located in the heart of a residential district, where most of the neighborhood’s commerce can be found. The main street is north-south oriented and has an estimated entering AADT of 5135 vehicles per day, mainly northbound, particularly in the morning peak hour. The street is approximately 9 meters wide, with one lane each way, and parallel parking is allowed in both ways. The minor street is east-west oriented and has an estimated entering AADT of 1924 vehicles per day. The street is approximately 8 meters wide, with one lane each way, allowing parallel parking for the eastbound vehicles on the eastern approach and diagonal parking for both ways on the western approach. Perpendicular parking is allowed within the intersection in the northeast and southeast corners. This fact was ignored during the traffic conflict observations since it was very difficult to emulate in the microsimulation software. There are crosswalks in all of the four approaches. Since it is a residential area pedestrian traffic is a significant factor. As such, we have registered the pedestrian crossing frequency for each crosswalk. The average free flow speed while approaching the intersection was 39.6 km/h with a standard deviation of 4.9 km/h.

*One-lane roundabout*

The chosen roundabout is located in one of the most densely populated areas of the city. This node connects three arterial streets and one local street. The roundabout has a diameter of 36 meters and a 6 meters wide circulatory lane. The total estimated AADT is 22938 vehicles per day. There are crosswalks in all of the four approaches. Nevertheless, even though it is located in a central area, there is not much pedestrian movement in this intersection. Given that, crosswalks were not considered in the model. The average free flow speed while approaching the roundabout was 46.4 km/h with a standard deviation of 6.7 km/h.

*Two-lane roundabout*

The chosen roundabout is located in one of the most densely populated areas of the city. This node connects three very important arterial streets and two local streets, one of which is a one way street towards the intersection. This intersection is within Coimbra’s ring road and there is a considerable amount of heavy vehicle traffic. Based on a partial observation, it was assumed that heavy vehicles represented 5% of the total traffic. The total estimated AADT is 33625 vehicles per day. There are crosswalks in all of the four approaches, however, for the abovementioned reasons, crosswalks were not considered
in the model. The average free flow speed for cars while approaching the roundabout was 60.0 km/h with a standard deviation of 7.8 km/h.

Results

The SSAM analysis produced the results illustrated in Figure 3 for the noon period. The graphical display of conflicts agrees reasonably with observations: i) most approach legs have low severity rear-end conflicts. These occur at peak periods when, for several reasons, priority drivers slow down and delay upstream vehicles; ii) at the 4-leg intersection the model predicts a high-percentage of severe conflicts, which actually occur and are related to perpendicular trajectories and to sudden stops in response to pedestrians at crosswalks; iii) at the roundabouts, the model predicts entering-circulating and weaving conflicts where they actually occur.

Figure 3 - SSAM results (noon period): graphical display of conflicts, colored by relative speed (proxy for the accident severity)
The comparison between observed and simulated conflicts is presented in Figure 4. As noted above, only the conflicts that take place in the priority links are registered (major direction links in the priority intersections, circulatory lanes on the roundabouts). SSAM presents a systematic underestimation trend, probably related to the TTC threshold adopted, but in global terms it is able to replicate the pattern of real conflicts in the four intersection types and for the different demand periods. The least satisfactory results were obtained at the single-lane roundabout and are related to a pedestrian crossing in the south leg, not included in the model, which was sometimes responsible for upstream queues that reached the circulatory lane.

![Comparison of observed and simulated total conflicts at the four sites](image)

**Figure 4 - Comparison of observed and simulated total conflicts at the four sites**

**SUMMARY AND CONCLUSIONS**

Safety assessment based on conventional accident prediction models raises questions about the availability and quality of crash data to serve as reference for model development, and it is not feasible for studying new layouts or facilities operating outside the models’ calibration domain. Recently, efforts have been made to expand the use of microscopic simulation models to safety assessment problems. Our study evaluated the potential of the SSAM approach to assess urban intersections’ safety levels. A conceptual validation, based on conventional accident prediction models (APMs), showed a strong
relation between accidents predicted by the regression models and conflicts predicted by simulation models. Conflict/accident ratios were found to vary according to the intersection type, the entry flow and the APM in question. For a moderate traffic flow (entering AADT = 12000 vehicles/day) that ratio is about 25000-30000:1 in a 4-leg intersection and 180000-500000:1 on a single-lane roundabout.

A field validation compared simulated and observed conflicts in four types of intersection. Despite a systematic underestimation trend, SSAM was able to replicate the hourly evolution of conflicts and to identify the hazardous areas of each intersection. The sub-optimal results at the single-lane roundabout indicate that this safety approach is quite sensitive to inaccurate modeling. Nevertheless, it can be concluded that SSAM analysis is a very promising approach to assessing the safety of new facilities, of innovative layouts (e.g. turbo-roundabouts (28)) or of traffic regulation schemes (e.g. limiting the driving degree of freedom on freeways(8)).

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