Safety analysis of turbo-roundabouts using the SSAM technique

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The Surrogate Safety Analysis Module (SSAM) is a software application that reads trajectories files generated by microscopic simulation programs and calculates surrogate measures of safety corresponding to each vehicle-to-vehicle interaction. This approach eliminates the subjectivity associated with the conventional conflict analysis technique and allows assessing the safety of a facility under a controlled environment, before the occurrence of accidents. This study has two main parts: the first addresses the conceptual validation of SSAM by comparing its outputs against well-established accident prediction models; in the second part SSAM is used to evaluate the safety benefits of three roundabout layouts – single-lane, two-lane and turbo-roundabout. This work allows two main conclusions: despite some limitation related to the nature of current traffic microsimulation models, SSAM analysis is a very promising approach to access the safety of new facilities or innovative layouts; based on a limited conceptual validation, it was found that the safety performance of a turbo-roundabout is similar to a single-lane, but with the advantage of offering much higher capacity levels.

Keywords: Safety; Crash; SSAM; Conflict; Simulation; Aimsun

1 Introduction

In urban areas traffic accidents are usually concentrated at intersections (Elvik et al., 2009). Traditional approaches to estimate potential traffic accident risk of intersections, based on actual 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: (i) compared to other events in traffic, accidents are very exceptional in the sense that they are the results of a series of unhappy realizations of many small probabilities; (ii) accidents are rare events, making it troublesome to base traffic safety analyses at individual sites on accidents only; (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 behavioral aspects preceding the accident is seldom available (Laureshyn et al., 2010). Therefore, specific evaluation techniques are required to account for changes in traffic regulations or infrastructure geometrical design, in order to estimate the true effects of safety improvements. Moreover, regression models may not be transferable because they implicitly reflect road users’ behavior which varies from country to country.

The traffic conflict technique is an approach that overcomes the lack of good and reliable accident records, relying instead on observations of conflicts - defined as an observable situation in which two or more road users approach each other in time and space to such an extent that there is risk of collision if their movements remain unchanged (Amundsen and Hyden, 1977). Conflicts are far more frequent than accidents and they are observable in real time on the site, allowing safety assessments without the occurrence of accidents. While the interest for the conflict technique has been considerable, its practical use has been limited due to questions concerning subjectivity in the
registration process and the costs involved with data collection. Automatic tracing of trajectories from video recordings is a recent and promising technology that addresses these questions (Ardö et al., 2012; Gettman et al., 2008) but the problem of predicting the safety benefit of a new geometry or circulation scheme remains. There is also still some debate regarding the connection between conflict measures and crash predictions (Tarko, 2012).

Microscopic simulation models are practical analysis tools that, over the past 30 years, have been used to evaluate traffic operation and management strategies. At present, they are looked as promising tools to evaluate road safety levels of existing and new infrastructures. The core of this new approach is a software developed by the FHWA (Surrogate Safety Assessment Model - SSAM) that automates conflict analysis by directly processing vehicle trajectories produced during the simulation (vehicle's position, speed and acceleration profiles). This approach has all the generic advantages of simulation (possibility of accessing the safety of new facilities before the occurrence of accidents, controlled environment, etc.) but has also some limitations: common microscopic simulation models are developed for traffic-flow analyses and lack some operational sub-models that are essential for safety analyses (e.g. overtaking with opposing flow, lateral movement, U-turns at intersections); actually, in microscopic traffic simulation incidents cannot occur as the basic modeling hypothesis in the underlying car-following models are designed to maintain a "safety to stop distance". Some authors proposed specific procedures to calibrate simulation models for safety assessment (Cunto and Saccomanno, 2008; Duong et al., 2010) but this is still an ongoing research field.

The practical experience with SSAM is limited and the results are not consensual. Gettman et al. (2008) found a significant correlation between simulated conflicts and crashes reported at 83 four-leg signalized intersections. Kim and Sul (2009) tested the effect of a change in the speed limit of an arterial road in Sungnam, Korea and concluded that VISSIM microsimulation represents well speeds and flows but is not sufficient in the field of safety analysis. Dijkstra et al. (2010) modelled 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. (2013) compared observed and simulated conflicts on 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 research described in this paper is part of the R&D Project AROUND - Improving Capacity and Emission Models of Roundabouts, supported by FCT (Portugal). Its specific objectives are to evaluate the safety of turbo-roundabouts using the SSAM technique (Gettman et al., 2008) coupled with the AIMSUN microscopic simulation model. It comprises two main parts: the first addresses the conceptual validation of SSAM by comparing its outputs against well-established accident prediction models; in the second part SSAM is used to evaluate the safety benefits of three roundabout layouts – single-lane, two-lane and turbo-roundabout.
2 Accident prediction models for roundabouts

The validation of the SSAM would be done ideally against accident records. However, as accidents (particularly in roundabouts) 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. In alternative, conventional accident prediction models (APM) 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. Three roundabout models are presented here: United Kingdom (Maycock and Hall, 1984), Australia (Arndt, 2004) and Portugal (Vieira Gomes, 2013).

2.1 United Kingdom

Maycock and Hall (1984) used accident records from 84 four-arm roundabouts to develop accident prediction models for roundabouts in the UK. At each site, traffic and pedestrian flow counts were obtained and detailed geometric measurements were made. Personal-injury accidents occurring over a six-year period (1974–1979) were also obtained. The resulting accident type groups are: 1) entering-circulating accidents (between an entering vehicle and a circulating vehicle), 2) approaching accidents (mostly rear-ends, but also changing lane accidents), 3) single-vehicle accidents (a single vehicle colliding with some part of the intersection layout or furniture), 4) other accidents (variety of non-pedestrian accidents) and, 5) pedestrian accidents (any accident involving a pedestrian casualty).

Since the SSAM method only defines conflict events for pairs of vehicles, crash types 3 and 5 (single and pedestrian, respectively) have been excluded from the current comparative analysis. The vehicle-vehicle models are:

\[
A_i = 0.052Q_e^{0.7}Q_c^{-0.4} \exp \left[ -40C_e + 0.14e - 0.007e\nu - 1/\left[ 1 + \exp(4R_e - 7) \right] + 0.2P_m - 0.01\theta \right]
\]

(1)

\[
A_i = 0.0057Q_e^{0.6} \exp (20C_e - 0.1e)
\]

(2)

\[
A_i = 0.0026Q_e^{0.7}Q_c^{0.8} \exp (0.2P_m)
\]

(3)

where \(A_i\) are personal injury accidents (including fatalities) per year per roundabout approach, \(Q_e\) and \(Q_c\) is the entering and circulating flow, respectively (1000s of veh/day), \(C_e\) is the is entry curvature (\(C_e = 1/R_e\) and \(R_e\) is the entry path radius for the shortest vehicle path (m)), \(e\) is the entry width (m), \(\nu\) 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, °).

2.2 Australia

Arndt (2004) 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 on the previous point, the first type was excluded from the current analysis.

The developed accident models require driver speeds on each geometric element to be estimated. Figure 1 indicates the 85th percentile speed on a horizontal curve, given the radius and the driver's desired speed. For this study we will assume that the desired speeds correspond to the 85th percentile speeds of unconstrained vehicles, which for urban and sub-urban conditions is approximately 20 km/h higher than the posted speed limit.

Approaching rear-end accidents occur on the approach legs and are given by the following equation:

\[
A_i = 9.62 \times 10^{-11} Q_a Q_c^{0.5} S_i
\]

where \(A_i\) are rear-end accidents per year (over $1000 property damage and/or personal injury), \(Q_a\) is the average annual daily traffic on the approach, i.e., one-way traffic only (veh/d), \(Q_c\) is the average annual daily traffic on the circulating carriageway adjacent to the approach, i.e., one-way traffic only (veh/d) and \(S_i\) is the 85th percentile speed on the approach curve (km/h).

The entering/circulating vehicle accidents are predicted by:

\[
A_c = 3.45 \times 10^{-12} Q_i \sum (Q_c^{0.5} S_i)
\]

where \(A_c\) is the entering/circulating accidents per year (over $1000 property damage and/or personal injury), \(Q_i\) is the average annual daily traffic on the approach, i.e., one-way traffic only (veh/d), \(Q_c\) are the various average annual daily traffic flows on the circulating carriageway adjacent to the approach, i.e., one-way traffic only (veh/d) and \(S_i\) are the various relative 85th percentile speed between vehicles on the approach curve and vehicles on the circulating carriageway from each direction (km/h).
The relative speed of an entry/circulating pair depends on the approach \( (S_a) \) and circulating \( (S_c) \) speeds and on the angle between trajectories \( (\alpha) \). It can be calculated using the law of cosines:

\[
S = \sqrt{S_a^2 + S_c^2 - 2S_a S_c \cos \alpha}
\]  

(6)

2.3 Portugal

Vieira Gomes (2013) using data from 94 intersections and 15 roundabouts in Lisbon, Portugal, developed models to estimate the frequency of accidents with injuries on urban road networks. These models describe the expected number of accidents as a function of a range of explanatory variables, namely vehicles and pedestrian traffic flow counts and highway geometric design characteristics. Two models were obtained for roundabouts: one that only depends on the traffic flow \( (7) \), and other that also depends on the number of entry legs \( (8) \). The global models for roundabouts, excluding accidents with pedestrians, are:

\[
Y_n = 1.9488 \times 10^{-7} FT^{1.0985}
\]  

(7)

\[
Y_n = 2.3845 \times 10^{-8} FT^{0.986} e^{4\Delta S \text{ LEG}}
\]  

(8)

where \( Y_n \) is the estimated number of accidents with injuries per year in the roundabout, when \( FT \) is total entering traffic flow in vehicles per day (AADT) and \( \text{LEG} \) is the number of legs of the roundabout.

3 SSAM technique

SSAM operates by processing data describing the trajectories of vehicles driving through a traffic facility and identifying conflicts. The vehicle trajectory input data for SSAM are generated by traffic simulation software (e.g. Aimsun, VISSIM or PARAMICS). SSAM calculates surrogate measures of safety corresponding to each vehicle-to-vehicle interaction and determines whether or not each interaction satisfies the criteria to be deemed a conflict. A table of all identified conflicts and their corresponding surrogate safety measures is then presented to the user and include the following: Minimum time-to-collision (TTC), Minimum post-encroachment (PET), Initial deceleration rate (DR), Maximum deceleration rate (MaxD), Maximum speed (MaxS), Maximum speed differential (DeltaS), Classification as lane-change, rear-end, or path-crossing event type, Vehicle velocity change had the event proceeded to a crash (DeltaV). Further details about surrogate measures can be found elsewhere (Gettman and Head, 2003; Laureshyn et al., 2010). In the present analysis we use Time-to-collision (TTC) as a threshold to define if a given vehicle interaction is a conflict and the Relative Speed (DeltaS) as a proxy for the accident severity. Their definition is:

- TTC is the minimum time-to-collision value observed during the interaction of two vehicles on collision route. This estimate is based on the current location, speed, and future trajectory of two vehicles at a given instant. If at any time step the TTC drops below a given threshold (usually 1.5 s), the interaction is tagged as a conflict;
- DeltaS is the difference in vehicle speeds as observed at the instant of the minimum TTC. More precisely, this value is mathematically defined as the magnitude of the difference in vehicle velocities (or trajectories), such that if \( v_1 \) and \( v_2 \) are the velocity vectors of the first and second vehicles respectively, then \( \text{DeltaS} = || v_1 - v_2 || \). This norm can be calculated by the law of cosines – Eq. (6).

Aimsun was the simulator used in this work. With the exception of the parameters that control the vehicles desired speed on links, most parameters kept their default values and a single vehicle type (cars) was considered. The time step was changed from the default value of 0.75 s to 0.20 s to increase the accuracy of the surrogate measures.

4 SSAM - Evaluation framework

4.1 Scenario definition

A conventional single-lane roundabout with four legs was considered for the reference scenario (Figure 2, left panel). It was designed according to the Portuguese Roundabout Design Guidelines (Bastos Silva and Seco, 2012) and 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 S-N and W-E directions.

The traffic demand was also considered equal for all entries, with 30% of the drivers turning right, 50% going through and 20% turning left. U-turns were disregarded. With this distribution the circulating traffic adjacent to each entry corresponds to 90% of the entry flow. These proportions were assumed constant during the day, while the entry flow was split according to a typical 24-h profile. It was further assumed that the roundabout integrates an urban road network with a 50 km/h posted speed limit and that 5% of all vehicles are motorcycles.

![Figure 2 – Roundabout layouts: A (left) - uniform leg distribution, B (right) – non-uniform leg distribution](image-url)
Taking the South entry as reference, the UK model depends on both the approach and circulatory trajectories (N-E, W-E and W-N). The approach has a 70 km/h P85 desired speed (20 km/h above the posted speed limit) and a 35 m minimum entry path radius. From Figure 1 the entry speed (47.6 km/h) is obtained. The relative speeds $S_i$ are obtained by combining the approach speed with the different circulatory speeds and the corresponding theoretical impact angle (Table 1).

<table>
<thead>
<tr>
<th>Direction</th>
<th>Layout A All approaches</th>
<th>Layout B South approach</th>
<th>Layout B East approach</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Radius (m)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N-E</td>
<td>18</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>W-E</td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>W-N</td>
<td>18</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>App.</td>
<td>35</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>Circ./Entry Speed $S$ (km/h)</td>
<td>33</td>
<td>40</td>
<td>33</td>
</tr>
<tr>
<td>W-E</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>W-N</td>
<td>33</td>
<td>33</td>
<td>33</td>
</tr>
<tr>
<td>App.</td>
<td>47.6</td>
<td>47.6</td>
<td>47.6</td>
</tr>
<tr>
<td>Conflict angle $\alpha$ (º)</td>
<td>53</td>
<td>53</td>
<td>53</td>
</tr>
<tr>
<td>W-E</td>
<td>53</td>
<td>53</td>
<td>53</td>
</tr>
<tr>
<td>W-N</td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>App.</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Rel. speed $S_i$ (km/h)</td>
<td>38.3</td>
<td>39.7</td>
<td>39.7</td>
</tr>
<tr>
<td>W-N</td>
<td>22.5</td>
<td>22.5</td>
<td>22.5</td>
</tr>
<tr>
<td>App.</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Angle (º)</td>
<td>90º</td>
<td>66º</td>
<td>114º</td>
</tr>
</tbody>
</table>

In the Aimsun model the drivers’ desired speeds are assumed to follow a normal distribution and were defined differently for the approach and circulatory sections. In the approaches the mean desired speed was set to 55 km/h (10% above the posted limit) and the standard deviation equal to 14.5 km/h, which results in a P85 desired speed of approximately 70 km/h. In each of the circulatory sections the speed was calculated by the program as the maximum speed a vehicle can take without sliding out of the road. The formula used ($V$ in m/s) is $V = \sqrt{g \cdot r \cdot \mu}$ where $g$ is the gravitational acceleration, $r$ is the average radius found in the turning and $\mu$ is the lateral friction coefficient (taken as 0.9). The formula tends to overestimate the circulating speeds but it was decided to keep the default calculation method to facilitate future comparisons.

4.2 Results

- Sensitivity to uniform traffic demand growth

The objective of this first test was to compare the models concerning a uniform traffic growth, when the total AADT varies from 0 to 40000 veh/d (per entry: $AADT_e = 10000$ veh/h). Figure 3 shows that although the regression models relate to specific scopes and are based on different assumptions, they still provide remarkably consistent estimates. The SSAM conflict-flow points are almost perfectly fitted by a convex curve (Figure 4), similarly 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. No significant trend was found regarding the AADT and the severity level but this is an aspect that requires further research.
Sensitivity to the circulating traffic

This second analysis had as objective to understand how models respond to changes in the circulating traffic, which common sense indicates as one of the most relevant accident/conflicts explanatory factors. The Portuguese model was not included here as it does not explicitly account for the circulating traffic (only implicitly, as circulating traffic is a function of the upstream entry traffic). Traffic flow at the South entry was assumed constant (5000 veh/d) and, to simplify the SSAM analysis, uniformly distributed during the day. We were also interested in understanding how models responded to changes in the origin/destination of the circulating traffic, as it is well known that some trajectory paths are much safer than others (e.g., in some roundabouts U-turns and right-turns do not actually conflict). This way, single origin/destination circulating traffic was simulated both in the Australian model and in Aimsun (the UK model is insensitive to the destination of the circulating traffic). The main results were: a) as expected, the accidents/conflicts increase with the circulating traffic; b) the regression models yield a concave curve (convex upwards) contrasting to a convex shape from the SSAM method; c) the Australian model predicts the maximum number of accidents (in the South entry) when all circulating vehicles are following the N-E trajectory, as is leads to a slightly higher relative speed (see Table 1 – layout A). In the simulation all entry-circulating paths have the same conflict angle and the maximum number of conflicts is obtained for the W-E path, probably due to a slightly higher average speed of the circulating traffic. Anyway, in both cases the differences are almost insignificant.
• Sensitivity to geometric changes

The objective of this last analysis was to understand how the safety models respond to relatively subtle geometric differences. Specifically, the East leg was rotated clockwise defining 66° with the South leg and 114° with the North leg (see Figure 2, right panel and Table 1 – layout B). According to most design manuals, this layout should be avoided as it increases the number and severity of accidents due to the higher impact angle at the South entry and to the increased approach speeds at the East entry. For the base 24h profile and directional split and an 8000 veh/day entry demand, the models predict the accidents / conflicts indicated on Table 2. Both regression models yield estimates consistent with the expectations – an increased number of accidents both at the South and East entries. SSAM also predicts an increased number of conflicts in the South entry but, surprisingly, a reduction in the East entry. This effect is most probably related with the reduction of the congestion levels in the approach: the increased approach radius allows higher entry speeds which results in less wasted entering opportunities, less waiting time on the yield line and, consequently, less risky maneuvers (triggered in Aimsun when the waiting time exceeds a given threshold). The breakdown of the accidents by relative speed, taken as surrogate for the crash severity, predicts a higher occurrence of the most severe accidents at the East approach, which is consistent with the previous explication and agrees with the expectations.

Table 2 – Effect of the roundabout layout on the safety indicators and breakdown of accidents by relative speed (DeltaS) at instant of minimum TTC (SSAM analysis)

<table>
<thead>
<tr>
<th>Approach</th>
<th>Regression</th>
<th>SSAM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>UK (acc./year)</td>
<td>Australia (acc./year)</td>
</tr>
<tr>
<td>All (90°)</td>
<td>0.688</td>
<td>0.261</td>
</tr>
<tr>
<td>South (66°)</td>
<td>0.762</td>
<td>0.280</td>
</tr>
<tr>
<td>East (114°)</td>
<td>0.697</td>
<td>0.566</td>
</tr>
</tbody>
</table>

Figure 5 – Accidents vs circulating traffic (total – UK model, disaggregated by OD - Australian model)

Figure 6 – Conflicts vs circulating traffic (disaggregated by OD - SSAM technique)
Conclusion

Although these tests do not form a definitive validation framework, they suggest a good qualitative agreement with the conventional accident prediction models. It is particularly remarkable the resemblance between the Australian model and SSAM, as both models account for the approaching and circulating vehicle trajectories to estimate the relative speeds at the point of impact. Naturally, APM are restricted to their calibration domain and are unable to evaluate innovative layouts or demand scenarios. This way, on the following section SSAM will be used to evaluate the relative safety of the recent turbo-roundabout concept, against the conventional single-lane and two-lane layouts.

5 Application

A turbo-roundabout is a variation of the conventional multi-lane roundabout, where drivers are forced to follow a specific path according to their intended destination. The carriageway consists of continuous spiral paths, using curbs to separate lanes in the entry, circulatory and exit zones. The installation of curb dividers has two major implications: the elimination of conflict points caused by weaving manoeuvres, and speed reduction due to increased deflection (Fortuijn, 2009). Several studies suggest a 70% lower crash risk when a double-lane roundabout is converted into a turbo-roundabout (Fortuijn, 2009). Other studies, based on conflict analysis techniques applied to 9 layouts with different demand scenarios, show a 40-50% reduction in the accident rate (Mauro and Cattani, 2010). The comparison of the number of conflict points – 8 in a single lane roundabout, 24 in a two-lane roundabout and 14 in a turbo-roundabout also suggests improved safety when compared with the two-lane layout.

The first turbo-roundabouts were installed in 2000, in the Netherlands. This was followed by their adoption in Poland and most recently in Germany (Brilon, 2005), Finland, Norway and Slovenia. Since then, more than 190 turbo-roundabouts have been implemented in the Netherlands and some design guidelines have been published (CROW, 2008). The Dutch government no longer constructs multi-lane conventional roundabouts, having adopted turbo-roundabouts as current practice (Fortuijn, 2009).

In Portugal, the first turbo-roundabout is expected to be constructed in Coimbra, to replace an existing single-lane roundabout (Choupal Rbt, Figure 7). In a previous work (Vasconcelos et al., 2013) it was demonstrated that a turbo-roundabout offers capacity levels between the single-lane and two-lane layouts and so it will undoubtedly contribute to cut delays, particularly in the North approach during the morning peak hour.
Figure 7 – Choupal Rbt (Coimbra). Left: aerial view (source: Google Maps), Right Top: installation of pneumatic detectors to obtain 24h flow and speed data, Right Bottom: video recordings to obtain directional splits.

This section addresses the safety issues. Three layouts, of similar implantation area, were modelled in Aimsun – the existing single-lane solution, a two-lane alternative and a turbo-roundabout. Traffic flows and speeds at the North and South legs (separately for each direction, Figure 8) were recorded continuously during a 24h period and associated with directional splits observed from video recordings to produce 1-hour OD matrixes for the whole 24 h period.

![Figure 8 - 24h entry flows](image)

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. No changes were made to the remaining parameters that control the car-following...
and gap-acceptance behaviour. A comprehensive calibration was not deemed necessary as the 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.

The three models were simulated with the current traffic demand (23816 veh/d). The SSAM analysis produced the results indicated on Table 3 and Figure 9. It indicates, as expected, the two-lane roundabout as the worse solution both in the number and severity of conflicts, mostly due to the weaving manoeuvres. The turbo-roundabout, compared with the single-lane solution, has fewer conflicts, but these are more severe, due to the increased angle between entry and circulating trajectories.

It should also be noted that the lane drops in the new solutions are responsible for a considerable number of conflicts (114 in the two-lane roundabout, 145 in the turbo one) that can be almost eliminated by extending the additional exit lanes. In that case the difference between the number of conflicts on the single-lane and two-lane layouts would be minimal. This indicates that the safety improvements are the result of a trade-off between the intersection geometry (better in the single-lane roundabout) and the intersection capacity, as it reduces congestion and risky maneuvers induced by it (better in the two-lane and turbo roundabouts). This is an aspect that is often disregarded by conventional safety analysis methods.

### Table 3 – SSAM results for the Choupal Rbt

<table>
<thead>
<tr>
<th>Layout</th>
<th>Relative speed (m/s)</th>
<th>(conflicts/day)</th>
<th>&lt; 5</th>
<th>5 - 10</th>
<th>&gt; 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-lane roundabout</td>
<td>420</td>
<td>46%</td>
<td>44%</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>Two-lane roundabout</td>
<td>539</td>
<td>49%</td>
<td>37%</td>
<td>14%</td>
<td></td>
</tr>
<tr>
<td>Turbo roundabout</td>
<td>301</td>
<td>51%</td>
<td>36%</td>
<td>13%</td>
<td></td>
</tr>
</tbody>
</table>
6 Conclusions

Safety assessment based on conventional accident prediction models raises questions related to the availability and quality of crash data and is not viable to study new layouts or facilities operating outside the models’ calibration domain. Recently, there has been interest to expand the use of microscopic simulation models to safety assessment. This study evaluated the potential of the SSAM approach to access the safety of roundabouts in general and of turbo-roundabouts in particular. A conceptual validation, based on conventional accident prediction models, allowed drawing the following conclusions:

- The testing of the sensitivity of the models against variable demand flows showed a strong relation between accidents predicted by the regression models and conflicts predicted by simulation models;
- The testing of the models regarding their capacity of predicting changes in the roundabout geometry showed that SSAM outputs are comparable to the Australian model, the one with the stronger consideration for geometric factors.

After this limited validation, SSAM was used to access the relative performance of three roundabout layouts – single-lane, two-lane and turbo-roundabout. The turbo-roundabout is the solution with fewer conflicts, but these are more severe than those of the single-lane type. It was also found that, if one disregards the conflicts at the lane drops, the standard single-lane and two-lane have a similar number of conflicts. This happens due to two opposing effects: by one hand, the two-lane
layout creates weaving conflicts; on the other hand it increases capacity, thus reducing congestion and the number of related risky maneuvers.

This work allows two main conclusions: despite some limitation related to the nature of current traffic microsimulation models, SSAM analysis is a very promising approach to access the safety of new facilities or innovative layouts; based on a limited conceptual validation, it was found that the safety performance of a turbo-roundabout is similar to a single-lane, but with the advantage of offering much higher capacity levels.

References


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