Safety diagnostic method in urban circular intersections

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Abstract

The available knowledge of traffic safety at roundabouts is not a complete reference for geometric design; where there are organizational schemes for junctions characterized by a geometric design, quite different driving behaviours are required from those that are observable at roundabouts.

This is very frequent in urban areas, where the existing constraints, particularly physical ones, often render it necessary to make “compromise choices” relating to one or more geometric features of the roundabout (central island shape, circulatory roadway width, symmetry and number of the arms, entry width, etc). The objective of this study is to explain the accident phenomenology of this kind of road scheme, with reference to the most frequent accidents for the junctions examined in different traffic and risk exposure conditions. The study also intends to verify the effectiveness of risk analysis by means of an infrastructural scenarios method, devised in previous research by the author.

In this paper, in order to deduce the contribution of the accident-causing factors to each type of accident and to evaluate the relative contribution in determining the level of risk for the different scenarios, the risk model has been checked considering specific accident classes. The results confirm the applicability of the risk evaluation method to urban road schemes, characterized by peculiar geometric features such as the impossibility of applying the safety methods proposed in the literature regarding traditional roundabouts; moreover, in the terms of greatest interest to road designers, they provide useful elements for evaluating the effects of deviations from design rules on urban road safety. Keywords: road safety, circular intersection, roundabout, risk analysis, infrastructural scenario.
1 Introduction

The sustainable road transport facilities are a priority objective of the road infrastructure engineering, since directly correlated to reduce road crashes. This is true particularly for road intersections, that are the elements of the road network characterized by a considerable reduction in crashes after the installation of geometric schemes in order to produce the improvement in safety performance.

The geometric design of a roundabout and, especially, the transformation of existing urban circular intersections (characterized by traffic conditions influenced by local city planning constraints) in roundabouts, can produce a significant reduction in both injury and property-damage crashes, as long as the administrator is able to assess preventively the traffic insecurity conditions joined to new traffic conditions.

Table 1: The injury crash reduction at 11 American intersections converted to roundabouts.

<table>
<thead>
<tr>
<th>Type of Roundabout</th>
<th>Sites</th>
<th>Before Roundabout</th>
<th>Roundabout</th>
<th>Percent Change 5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Total  Inj. 3 PDO 4</td>
<td>Total Inj. PDO</td>
<td>Total Inj. PDO</td>
</tr>
<tr>
<td>Small/Moderate¹</td>
<td>8</td>
<td>4.8 2.0 2.4</td>
<td>2.4 0.5 1.6</td>
<td>-51% 73% -32%</td>
</tr>
<tr>
<td>Large²</td>
<td>3</td>
<td>21.5 5.8 15.7</td>
<td>15.3 4.0 11.3</td>
<td>-29% -31% -10%</td>
</tr>
<tr>
<td>Total</td>
<td>11</td>
<td>9.3 3.0 6.0</td>
<td>5.9 1.5 4.2</td>
<td>-37% -51% -29%</td>
</tr>
</tbody>
</table>

Notes
1. Mostly single-lane roundabouts with an inscribed circle diameter of 30 to 35 m (100 to 115 ft).
2. Multilane roundabouts with an inscribed circle diameter greater than 50 m (165 ft).
3. Inj. = Injury crashes
4. PDO = Property Damage Only crashes
5. Only injury crash reductions for small/moderate roundabouts were statistically significant.

Source [5]

Roundabout crash records are limited in Italy, because of the quite recent installation of roundabouts; so the crash experiences of other countries can be used to help design roundabouts in our country. The overall examination of crash statistics experienced in various European Countries [1][2], in the U.S.A. [3] and in Australia [4], allows to assert that roundabouts perform better in terms of safety than other intersection forms. In particular, a crash study of eleven intersections converted to roundabouts in the United States showed a reduction in both injury and property-damage crashes after installation of a roundabout [5]. As shown in table 1, the statistically significant result is the injury crash reduction for small and medium roundabouts, that perform better in terms of safety than conventional intersections and than roundabouts with a great inscribed circle diameter or multilane roundabouts.

The safety benefits after building a roundabout are referable to the reduced speeds, especially for entering and crossing manoeuvres [6]. The mean crash reductions in various countries are shown in table 2; the results of these studies
show that injury crashes are reduced more considerably than crashes involving property damage [5].

Table 2: Mean crash reductions in various countries.

<table>
<thead>
<tr>
<th>Country</th>
<th>Mean reduction (%)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All crashes</td>
<td>Injury crashes</td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td>41 -61%</td>
<td>45 -87%</td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>- 57 - 78%</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td>36%</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Netherlands</td>
<td>47%</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>U.K.</td>
<td>- 25 - 39%</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>U.S.A.</td>
<td>37%</td>
<td>51%</td>
<td></td>
</tr>
</tbody>
</table>

Source [5]

Most of these studies also show that the percentage reduction of crashes by user type is higher for motor-cars than pedestrians (for bicycles, this reduction is much shorter). Table 3 shows the crash percentage per type of crash and per type of roundabout in several countries.

Table 3: The percentage of the three main crash types reported in different countries.

<table>
<thead>
<tr>
<th>Country</th>
<th>Crash description</th>
<th>Type of Roundabout</th>
<th>Type of Crash</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Entering-circulating</td>
<td>Rear-end</td>
</tr>
<tr>
<td>Australia</td>
<td>All crashes</td>
<td>Single and multilane</td>
<td>51%</td>
</tr>
<tr>
<td>France</td>
<td>Injury crashes</td>
<td>Single and multilane</td>
<td>37%</td>
</tr>
<tr>
<td>Germany</td>
<td>All crashes</td>
<td>Single lane</td>
<td>30%</td>
</tr>
<tr>
<td>Switzerland</td>
<td>All crashes</td>
<td>Single and multilane</td>
<td>46%</td>
</tr>
<tr>
<td>U.K.</td>
<td>Injury crashes</td>
<td>Single and multilane</td>
<td>20-71%</td>
</tr>
</tbody>
</table>

Percentages do not necessarily sum to 100% because only three major crash categories are shown. Source: [5]

Table 4 presents a summary of the percentage of crashes by collision type for roundabouts designed according to local practices in France, Australia, and the United Kingdom; as shown, the data illustrate that unlike percentages are referable to different geometric features of roundabouts and to driving behaviour. It should also be noted that these crash reductions are generally for sites where roundabouts were installed to replace complex intersections and, therefore, they do not necessarily are an absolute safety comparison with all other intersections types [5].

In spite of this, to reduce crash rate and severity, attention should be turned to:
- minimize potential conflicts in relation to the peculiar geometric configuration of roundabouts;
- minimize the potential relative speed between two vehicles at the point of conflict, reducing the absolute speeds of both vehicles or the angle between the vehicle paths;
- limit the variation in speed between consecutive horizontal geometric elements.

Table 4: Collision types at roundabouts in different countries.

<table>
<thead>
<tr>
<th>Collision Type</th>
<th>France</th>
<th>Queensland (Australia)</th>
<th>United Kingdom¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Failure to yield at entry (entering-circulating)</td>
<td>36.6%</td>
<td>50.8%</td>
<td>71.1%</td>
</tr>
<tr>
<td>2. Single-vehicle run off the circulatory roadway</td>
<td>16.3%</td>
<td>10.4%</td>
<td>8.2%⁴</td>
</tr>
<tr>
<td>3. Single vehicle loss of control at entry</td>
<td>11.4%</td>
<td>5.2%</td>
<td></td>
</tr>
<tr>
<td>4. Rear-end at entry¹</td>
<td>7.4%</td>
<td>16.9%</td>
<td>7.0%</td>
</tr>
<tr>
<td>5. Circulating-exiting</td>
<td>5.9%</td>
<td>6.5%</td>
<td></td>
</tr>
<tr>
<td>6. Pedestrian on crosswalk</td>
<td>5.9%</td>
<td>3.5%⁴</td>
<td></td>
</tr>
<tr>
<td>7. Single vehicle loss of control at exit</td>
<td>2.5%</td>
<td>2.6%⁴</td>
<td></td>
</tr>
<tr>
<td>8. Exiting-entering</td>
<td>2.5%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Rear-end in circulatory roadway</td>
<td>0.5%</td>
<td>1.2%</td>
<td></td>
</tr>
<tr>
<td>10. Rear-end at exit</td>
<td>1.0%</td>
<td>0.2%</td>
<td></td>
</tr>
<tr>
<td>11. Passing a bicycle at entry</td>
<td>1.0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. Passing a bicycle at exit</td>
<td>1.0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13. Weaving in circulatory roadway</td>
<td>2.5%</td>
<td>2.0%</td>
<td></td>
</tr>
<tr>
<td>14. Wrong direction in circulatory roadway</td>
<td>1.0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15. Pedestrian on circulatory roadway</td>
<td>3.5%⁴</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16. Pedestrian at approach outside crosswalk</td>
<td>1.0%⁴</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other collision types</td>
<td>2.4%</td>
<td></td>
<td>10.2%</td>
</tr>
<tr>
<td>Other sideswipe crashes</td>
<td>1.6%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes:
1. Data are for “small” roundabouts (curbed central islands > 4 m [13 ft] diameter, relatively large ratio of inscribed circle diameter to central island size).
2. Reported findings do not distinguish among single-vehicle crashes.
3. Reported findings do not distinguish among approaching crashes.
4. Reported findings do not distinguish among pedestrian crashes.

Source: [5]

In urban area, the geometric design is often conditioned by different and local constraints that render necessary to make “compromise choices” relating to one or more geometric features of the roundabout (central island shape, circulatory roadway width, symmetry and number of the arms, entry width, etc). This often causes the acceptance of road circular schemes characterized by traffic conditions very different from roundabouts.

Moreover, the results of diagnostic studies obtained for road schemes (roundabouts) only partially comparable to the circular intersections examined in this research, of which the corresponding level of risk is known (or predictable), cannot be used to value the safety conditions of above-mentioned circular intersections.

In these cases, the specific features of atypical roundabouts (as the circular intersections examined in this study), especially diffused in urban area, allow to reproduce only partially the hierarchy of the risk factors characterizing roundabouts. This is a problem to apply the road safety audit procedure, as those existing for a long time in various countries and only recently introduced into...
Italy [7], particularly where intersections are characterized by a high concentration of accidents (about 67% of overall road crashes, in according to Italian crash statistics [8]).

2 The risk analysis method

In a previous research [9], the effectiveness of risk analysis by means of an infrastructural scenarios method was verified with reference to urban circular intersections (not necessarily conform to good roundabout design), characterized by geometric features such as the impossibility of applying the safety methods proposed in the literature regarding traditional roundabouts.

This method was devised considering a sample of 655 crashes from ten urban circular intersections in Palermo City for the period 1996-2000; about these intersections, the aggregate analysis [10] highlighted the crash frequencies of peculiar collision types and further specific aspects as the crash location, types of accident-causing factors, crash percentage per type of user, etc. The accidents were subsequently put down to each infrastructural scenario (similar and recurrent road situation), as shown in figure 1, by a “delocalization procedure”.

![Figure 1: Graphical depiction of infrastructural scenarios.](image)

So six main scenarios were identified at the examined intersections and marked as follows:
1. arms tangent to the circular intersection;
2. arms tangent to the circular intersection with interferences at the sides;
3. circulatory roadway elements between two consecutive arms characterized by short length;
4. circulatory roadway elements between two consecutive arms characterized by short length with interferences at the sides;
5. entries with local restricted visibility conditions;
6. entries with local restricted visibility conditions with interferences at the sides.

The basic idea is that the accident phenomenology, concerning similar road situations (infrastructural scenarios), recurs when the same infrastructural
scenario occurs. So the risk model was devised in order to value the riskiness of different circular intersections, even if quite unlike from traditional roundabouts.

In this paper, in order to deduce the contribution of the accident-causing factors to each type of accident and to evaluate the relative contribution in determining the level of risk for the different scenarios, the risk model, previously proposed [9], has been checked considering specific accident classes. Then, the examined circular intersections were took to an equivalent traffic condition, in order to establish homogeneous terms of comparison to value the risk levels observable in different traffic and risk exposure conditions.

So crash prediction equations, proposed in the literature [1] between the three major identified accident classes (k) and traffic (Q), were used:

\[ A = b \cdot (Q)^\beta \]  \hspace{1cm} (1)

The coefficients of the above-mentioned equations were checked in relation to the circular intersections of the sample. Particularly, as shown in the next paragraph, the traffic flow was characterized, according to the UK crash models [1], in different way in relation to the accident classes identified in this research. For the intersection characterized by the highest traffic flow (Q_{\text{max}}), the number of expected accidents, for each k accident class, can be computed as follows:

\[ A_{jk} = b_k (Q_{\text{max}})^{\beta_k} \]  \hspace{1cm} (2)

The homogenization coefficients of the other intersections of the sample - if \(1/\alpha_{jk}= 1\) for the intersection characterized by the highest traffic flow (Q_{\text{max}}) - can be computed considering crash prediction equations, shown in eqn (1), obtained for each k accident class examined, as follows:

\[ \frac{1}{\alpha_{jk}} = \frac{A^*_{jk}}{A_{jk}} = \left( \frac{Q_{\text{max}}}{Q_j} \right)^{\beta_k} \frac{A^*_{ijk}}{A_{ijk}} \]  \hspace{1cm} (3)

The homogenization coefficients, shown in eqn (3), valid for the accidents of the same i infrastructural scenario, can be computed as follows:

\[ A^*_{ijk} = \frac{A_{ijk}}{\alpha_{jk}} \]  \hspace{1cm} (4)

Therefore, disaggregated the accidents of the different classes by a delocalization procedure and grouped to the infrastructural scenarios, the elements of the vector \([R]\), for each k accident class, can now be computed as follows:

\[ [R_{ki}]_{i=1,\ldots,n} = \left[ \sum_{j=1}^{m} \frac{A_{ijk}}{\alpha_{jk}} \right] \]  \hspace{1cm} (5)

where:
\( A_{ijk} = \) accidents of \( k \) class related to \( i (i = 1, 2, \ldots, n) \) infrastructural scenario at the \( j (j = 1, 2, \ldots, m) \) circular intersection;
\( A_{ijk}/\alpha_j = \) homogenized accidents with reference to the greatest traffic flow \( (Q_{\text{max}}) \);
\( 1/\alpha_j = \) homogenization coefficients for the crash level \( A_{ijk} \).

The elements of the vector, shown in eqn (5), are, in homogeneous terms (because took back to an equivalent traffic condition), the relative hierarchy of risk levels characterizing the infrastructural scenarios at the different circular intersections of the sample. Figure 2 shows the steps of the safety diagnostic method applied on the circular intersections examined.

\[\text{Figure 2: The flowchart of the safety diagnostic method.}\]

### 3 Results of the risk analysis method

In relation to the atypical geometric and functional features of the circular intersections examined, the \( b \) and \( \beta \) coefficients (see above paragraph 2) were computed in relation to the type and the features of the data sample; a good data fitting was obtained both with reference to all crashes happened during the five years selected for the study [9] and with reference to the three major accident classes identified at the junctions examined.

The statistical correlations between the number of accidents (both with reference to all crashes and to injury crashes) and traffic flow, regarded particularly significant for the aims of this research, are pertinent to the class 1: “single vehicle” (16%), to the class 2: “accidents between vehicles on the same road element” (35%) and to the class 3: “entering- circulating accidents” (21%), as shown in figures 3, 4 and 5.

In accordance with all that is proposed in the literature regarding the above-mentioned correlations [1], the \( Q \) variable is:
- the entering flow (1,000s of entering vehicles), for the accident class 1 and 2;
- the product between the entering flow (1,000s of entering vehicles) and the circulating flow (1,000s of circulating vehicles), for the accident class 3.

The risk level of every infrastructural scenario, computed with reference to \( k \) accident classes \( (k = 1, 2, 3) \), is shown by the vectors \( [R_{ki}]^T_{i=1,2,\ldots,n} \), as follows:
- \( R_T^1 = [0.053; 0.404; 0.031; 0.126; 0.03; 0.356]^T \), for the class 1 “single vehicle” (\( \beta = 0.9411 \));
- \( R_T^2 = [0.03; 0.39; 0.04; 0.22; 0.02; 0.30]^T \), for the class 2 “accidents between vehicles on the same road element” (\( \beta = 0.8851 \));
- \( R_T^3 = [0.027; 0.391; 0.03; 0.145; 0.035; 0.372]^T \), for the class 3 “entering-circulating accidents” (\( \beta = 0.7394 \)).

\[
y = 0.2485x^{0.9411} \\
R^2 = 0.6428
\]

\[
y = 0.2919x^{0.8293} \\
R^2 = 0.6498
\]

Figure 3: The correlation between the class 1 “single vehicle” and traffic flow.

\[
y = 0.639x^{0.8851} \\
R^2 = 0.6567
\]

\[
y = 0.2901x^{1.0296} \\
R^2 = 0.7129
\]

Figure 4: The correlation between the class 2 “accidents between vehicles on the same road element” and traffic flow.

The results, as depicted in Figure 6, allow us to highlight:
- for the “single vehicle” class, the scenarios 2 (40.4%) and 6 (35.6%), both with interferences at the sides, are the more dangerous road situations, followed by the scenario 4 (12.6%). The correlated potential accident-causing factors are: the inadequate geometry at the approaches (entry curvature, longitudinal slope of arms and visibility conditions) and the unsuitable uses at the sides (especially the regulation of parking);
- for the “accidents between vehicles on the same road element” and “entering-circulating accidents”, classes, the same considerations about the “single vehicle” class are valid. Moreover, the scenario 4 is more relevant in relation
to the peculiar geometric and functional features of examined circular intersections. The correlated potential accident-causing factors are: the local geometric anomalies, depending on traffic and design characteristics (circulatory roadway width, entry width) of sites.

Figure 5: The correlation between the class 3 “entering-circulating accidents” and traffic flow.

Figure 6: The risk level analysis. The exam for every accident class $k$.

The results also suggest the risk directly derives from geometric features of examined road schemes, that may cause improper driving behaviours. Especially, the inadequate geometry at the approaches can cause “single vehicle
loss of control at entry”, because of high speed (or because of the speed inconsistent with geometric features); the short length of the circulatory roadway elements between two consecutive arms can constrict road users to slacken roughly during changing lanes manoeuvres in the circulatory roadway; the reduced circulatory roadway width (or the relative variability of the width and the length between two consecutive arms) can hamper the changing lanes manoeuvres in the circulatory roadway and can increase the likelihood of vehicular conflicts. The local restricted visibility because of obstacles at the sides of the road can determine a more carefully driving, but the greater care of the driver isn’t adequate to avoid the effects of unexpected events that may increase the risk of the different scenarios (especially for the scenario 1, 3 and 5).

4 Conclusions

The research explained in the previous paragraphs concerns the accident phenomenology of circular intersections examined, with reference to the most frequent accidents really happened in different traffic and risk exposure conditions. The above also allows to confirm the effectiveness of risk analysis by means of an infrastructural scenarios method, applied to junctions (not necessarily conform to good roundabout design) characterized by geometric features that render difficult to apply the safety methods proposed in the literature concerning traditional roundabouts.

With regard to the applications, especially in urban area where road schemes are characterized by lots of existing physical constraints, the proposed risk model highlights the possibility to improve considerably the road safety performances, getting better the visibility conditions at the junction and, in general, reducing (or eliminating) the interferences at the sides through the suitable regulation of parking and private accesses.

Acknowledgement

I’d like to express my own thanks to Professor O. Giuffrè for the indications offered during the progress of this research.

References


[7] Circ. Min. LL.PP. n°3699 del 08/06/01 – “Linee guida per le analisi di sicurezza delle strade”.

