Two Roundabouts are Better than One
(Comparison of Roundabout Designs for a Complex Rural Interchange in Tuscany, Italy)

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Abstract
This paper summarizes the calculations and considerations for a comparative assessment between three alternative proposals for redesign of the interchange between the Pisa North toll plaza of Motorways A11 and A12 and the Via Aurelia (highway SS1) located in the Migliarino region of Tuscany, Italy. The complex interchange also includes access to a local minor road, (Via Traversagnola) and is topographically constrained by the proximity of an important drainage channel which runs alongside the Via Traversagnola. Three designs are evaluated: first, a large elliptical layout, second, a very large circular layout, and third, a layout with twin large roundabouts and slip bypass ramps. These three designs were actually proposed by two different Italian Highway Agencies. Comparisons are made through the respective proper analysis model (i.e., British model for the elliptical traffic circle and French SETRA model for the twin roundabout solution and the very large circular layout) evaluating capacity and performance requirements. Results are summarized and they highlighted that the twin roundabout design is assessed as the preferred solution for traffic operations, as well as safety, maintenance, visual intrusion, and lighting requirements. Finally, from a general point of view, the paper is an applied example that supports the basic idea of distributing maneuvers and conflicts on two facilities is often better than trying to cope with them in a single, even very large facility, mixing flows altogether at the same time and place.

1. Introduction
In this paper, we compare three alternative roundabout concepts for a major at-grade interchange redesign in the Migliarino region of Tuscany, Italy. The basic question is whether the interchange should be redesigned as a single large elliptic traffic circle, or a series of two smaller roundabouts, or a single very large roundabout. The complex interchange includes access to an important local road, (the Via Traversagnola), the Pisa North toll plaza of Motorways A11 and A12 and a regional highway (the Via Aurelia or Highway SS1). The Via Traversagnola provides the only local access to the Motorways for industry and housing for a several kilometer radius. The complexity of the interchange is further complicated by topography as it is constrained by the proximity of an important drainage canal which runs alongside the Via Traversagnola. The existing interchange is channelized with a median and provides storage lanes for left turning vehicles on the mainline (SS1), as well as slip ramps for free rights to and from A11/A12. See Figure 1 for an aerial view of existing conditions. The two existing intersections comprising the existing interchange have poor crash histories and do not operate efficiently due to their close proximity and the number of conflict points (see Figures 2 and 3 for driver’s views of vehicles entering at the northern intersection and view departing the Motorway).
Generally, the “T” intersection operates under capacity. However, there are frequent periods of peak tourist traffic, most concentrated in the summer and on weekends, when significant congestion and delay is experienced. In addition, the sudden convergence of long straight high speed roads, especially the SS1, creates a safety problem which has worsened over time. Moreover, the nearby City of Vecchiano envisions improvements to the intersection, emphasizing the fact that the Via Trasversagna is the only access point from SS1 to an expanding industrial area. For these and other reasons two roundabout intersection designs were proposed.

The first geometric design is large elliptical traffic circle, as proposed by the Italian Motorway Company, a private toll road authority. This first design is hereafter referred to as the “Motorways UNO” design. A second design includes twin smaller roundabouts, and was proposed by the National Highway Authority, or ANAS, a public authority, in their Tuscany Division. This second solution is referred to as the “ANAS” design. The third option is a single very large roundabout, also proposed by the Italian Motorway Company and it is referred as the “Motorways DUE” design.

We report on a technical comparison of the three geometric solutions in three stages: 1) traffic data collection, 2) capacity analysis, and 3) performance testing. In addition, we consider aspects of safety, maintenance and environmental issues, which further accentuate differences between the three designs.

Figure 1. Study Area (Source: Google Earth).
Figure 2. Vehicles entering SS1 Southbound from Via Traversagna (Source: Google Maps).

Figure 3. Vehicles exiting the Motorway SW-bound to SS1 (Source: Google Maps)

2 Traffic Patterns and Design Traffic Scenarios

2.1 Data

First, a traffic survey was conducted at the intersection of SS1 and A11/12 (Caserta, 2008). Counts were taken from 7:00 to 9:00 am and from 3:00 to 7:00 pm, in four days of one week (Tuesday, Wednesday, Saturday and Sunday) in order to identify peak traffic. The highest flows were found on Sunday (April 27, 2008), and the
peak hour factor was measured to be 0.90. Truck volume was light during the peak (less than 4 percent). Figure 4 illustrates peak hour turning movements.

![Diagram of traffic flows]

Figure 4. Turning movement volumes Sunday 27 April, 2008 5:00 – 6:00 PM (6:00 – 7:00 PM Standard Time)

Traffic data for the Via Traversagna was provided by the Public Works Department of the City of Vecchiano, although the most recent data were available only for October 1999. Peak traffic (total in both directions) was attained on Sunday evenings 6:00 – 7:00 PM, and reached 587 pce/h, and in the absence of specific data, a 50/50 directional split was assumed.

Traffic data for the SS Aurelia No.1, north and south of the interchange was provided by the Province of Pisa (Pisa, 2002) for Thursday, April 11, 2002, 6:00 – 7:00 PM. North of the interchange, traffic flow was 1049 pce/h northbound and 940 pce/h southbound. South of the interchange, traffic flow was 879 pce/h northbound and 720 pce/h southbound.

2009 Motorways for Italy data reveal inconsistency in the interchange traffic, as in summer, readings are well above average. On Sunday, June 14, the peak day for 2009, the peak hour was observed to be 4:00 – 5:00 PM. See Figure 5 for hourly traffic patterns for the A11 Motorway for this day.
Figure 5. Hourly traffic entering (blue) and exiting (red) the A11 Motorway (Pisa North Tollbooth) Sunday, June 14, 2009 (source: Motorways of Italy Company).

2.2 Design Scenario

For the purposes of subsequent calculations, the most complete data was provided by the University of Pisa study, which includes inbound, outbound and turning movement counts. These values are supplemented with those reported for the Via Traversagna (i.e. 587 pce/h, which for a PHF of 0.90 results in a flow of 652 pce/hr distributed as in 326 pce/h in each direction. Figure 6 presents the design volumes used for the redesign.

Figure 6. Design traffic movements (pce/h).
In order to determine turning movement volumes for both directions of Via Trasversagna traffic was allocated in proportion to that of the SS 1 Aurelia as follows:

Via Trasversagna to Pisa = \( \frac{390}{939 + 390} \times 326 = 96 \text{ pce/hr.} \)

Via Trasversagna to Viareggio = \( 326 - 96 = 230 \text{ PCE/hr.} \)

Pisa to Via Trasversagna = \( \frac{637}{1203 + 637} \times 326 = 113 \text{ pce/hr.} \)

Viareggio to Via Trasversagna = \( 326 - 113 = 213 \text{ pce/hr.} \)

which results in the following correction to the flow of SS 1 north of the interchange of:

- southbound = \( (390 + 813 + 213) - 96 = 1320 \text{ pce/hr.} \)
- northbound = \( (637 + 299 + 230) - 113 = 1053 \text{ pce/hr.} \)

As a check, inbound and outbound flows are summed for the interchange and verified to be equal:

\[ \Sigma in = 1160 + 648 + 326 + 1320 = 3454 \text{ pce/hr.} \]

\[ \Sigma out = 739 + 326 + 1336 + 1053 = 3454 \text{ pce/hr.} \]

3. "Motorways" designs

Two different layouts are proposed for the interchange by the Italian Motorways Company: one is a very large ellipse rotary, another is a very large circular roundabout.

3.1. Motorways UNO solution

The first, or "Motorways UNO" layout, constitutes a very large ellipse with major axis of 146 meters (479 feet) and minor axis of 80 m (262 feet) – see Figure 7. For instance, a football or soccer field could fit easily inside this space. Traffic operations within such a “rotary”, or “Ben-Hur race track” shape, are to be considered closer to weaving maneuvers instead of priority-to-the-circle operations. Therein, traffic flows are a function of geometry and dimensions of successive weaving sections. In particular, the size of the large oval and its related four approaches lead to four successive short weaving roadway segments, which is the computational approach required by Italian National Guidelines (Ministero LLPP, 2006).
This way, one is not able to evaluate the entry capacity through any of the models proposed for modern roundabouts. It is therefore necessary to use the British method (ITE, 1982), which is well-suited for short weaving sections and calculates the value of the maximum hourly flow rate \( Q_{\text{max}} \) for each individual segment. Where \( Q_{\text{max}} \) is a function of the average roadway width, length of weaving section, and the proportional flow of traffic movements.

\[
Q_{\text{max}} = \frac{A w(1 + m/w)(1 - P/3)}{(1 + w/L)}
\]

where:

- \( A = 302 \), or 354 if \( Q_{\text{max}} \) is greater than 4000 pce/h
- \( w \) = width of circulating roadway, downstream of entrance.
\[ L = \text{length of circulating roadway, downstream of entrance,} \]
\[ m = (m_1 + m_2)/2 = \text{average width of entrance lane and circulating roadway width at entrance} \]
\[ P = \text{proportion of flow which is weaving in the downstream section (with respect to the total flow } Q_t) \]

The following computation can then be used to estimate the Level of Service:

\[ \eta Q_{\text{max}} \geq (a + b + c + d) = Q_t \]

LOS "C" \( \eta = 0.70 \)

LOS "D" \( \eta = 0.80 \)

Table 1 presents the O/D flow between all entrance/exit pairs of the proposed large oval shaped rotary (see Figure 6 for turning movement counts and Figure 7 for notation used to develop the O/D table).

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>( Q_{\text{enter}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>294</td>
<td>813</td>
<td>213</td>
<td>1320</td>
</tr>
<tr>
<td>2</td>
<td>524</td>
<td>0</td>
<td>523</td>
<td>113</td>
<td>1160</td>
</tr>
<tr>
<td>3</td>
<td>299</td>
<td>349</td>
<td>0</td>
<td>0</td>
<td>648</td>
</tr>
<tr>
<td>4</td>
<td>230</td>
<td>96</td>
<td>0</td>
<td>0</td>
<td>326</td>
</tr>
<tr>
<td>( Q_{\text{exit}} )</td>
<td>1053</td>
<td>739</td>
<td>1336</td>
<td>326</td>
<td>3454</td>
</tr>
</tbody>
</table>

Table 2 presents geometric and flow data as well as flow checks (LOS C) for the weaving sections of the Motorways UNO designed rotary.

From Table 2, we can see that Section 2-3, between the toll road and SS1 in the direction of Pisa does not meet LOS C conditions. Further calculation shows that the section does not even meet LOS D criteria.

The elliptical geometry of the Motorways UNO proposed design shows a minor to major axis ratio of \( 80/143 = 0.55 \). The Swiss regulation "Guide Suisse des Giratoires" suggests a minimum ratio of 0.75 for speed reduction and increased safety (VSS, 1991).
Table 2. Input data and LOS C checks for the “Motorways UNO” design.

<table>
<thead>
<tr>
<th>Input:</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Section</td>
<td>m</td>
<td>w</td>
<td>L</td>
<td>A</td>
<td>Qt</td>
</tr>
<tr>
<td>meters</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-2</td>
<td>5.5</td>
<td>7</td>
<td>140</td>
<td>302</td>
<td>1471</td>
</tr>
<tr>
<td>2-3</td>
<td>5.5</td>
<td>7</td>
<td>54</td>
<td>302</td>
<td>1450</td>
</tr>
<tr>
<td>3-4</td>
<td>5.5</td>
<td>7</td>
<td>58</td>
<td>302</td>
<td>974</td>
</tr>
<tr>
<td>4-1</td>
<td>5.5</td>
<td>7</td>
<td>66</td>
<td>302</td>
<td>919</td>
</tr>
</tbody>
</table>

Results and checks:

<table>
<thead>
<tr>
<th>Section</th>
<th>P</th>
<th>Qmax</th>
<th>Qt</th>
<th>0.70 Qmax</th>
<th>Check.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>0.833</td>
<td>2596</td>
<td>1765</td>
<td>1818</td>
<td>YES</td>
</tr>
<tr>
<td>2-3</td>
<td>0.663</td>
<td>2603</td>
<td>2186</td>
<td>1822</td>
<td>NO!</td>
</tr>
<tr>
<td>3-4</td>
<td>0.650</td>
<td>2638</td>
<td>1498</td>
<td>1847</td>
<td>YES</td>
</tr>
<tr>
<td>4-1</td>
<td>0.613</td>
<td>2715</td>
<td>1498</td>
<td>1901</td>
<td>YES</td>
</tr>
</tbody>
</table>

3.2. Motorways DUE solution

The second design option is the so called “Motorways DUE” which consist in a singular, very large circular roundabout, with inscribed diameter D = 95 m (312 feet) and four approaches. One can say that this is a “naïve” solution: there is an intersection of four roads and a large roundabout design is required due to small angles between adjacent approaches. Table 1 shows again the O/D flow between all entrance/exit pairs of the proposed large single roundabout (see Figure 8 for notation used to develop the O/D matrix). Capacity computations are performed applying the French SETRA formula, applicable to suburban roundabouts with central island radius larger than 15 m (SETRA, 1998) which has the following general expression of entry capacity:

\[ C_e = f(\text{SEP}, \text{ENT}, \text{ANN}, Q_u, Q_c) \]

Where SEP, ENT and ANN, are the width of the splitter island, the entry width and the circulating roadway width, respectively. The term \( Q_u \) is the exiting flow, while \( Q_c \) is the circulating flow. The computations steps are:

a) computing of the equivalent exiting flow \( Q_u^* \) in function of exiting flow \( Q_u \) (pce/h) and of SEP (m):

\[ Q_u^* = \frac{Q_u (15 - \text{SEP})}{15} \]

with \( Q_u^* = 0 \) when \( \text{SEP} \geq 15 \text{ m} \)

9
b) computing of the global obstructing flow, $Q_g$, which is function of $Q_c$ and $Q_u$ and ANN:

$$Q_g = [Q_c + (2/3)Q_u^*][1 - 0.085(ANN - 8)]$$

c) finally, the entry capacity is obtained as:

$$C_e = (1330 - 0.7Q_g)[1 + 0.1(ENT - 3.5)]$$

Figure 8. Layout and leg notation for “Motorways DUE” design

Motorways DUE has $ANN = 9.0$ m (circulating roadway width) and its other geometric characteristics required by SETRA model are summarized in Table 3.

Table 3. Geometric characteristics for the “Motorways DUE” design.
Finally, capacity checks lead to the following results:

a) Entry capacity:

<table>
<thead>
<tr>
<th>Approach</th>
<th>Entry capacity (pce/h)</th>
<th>Flow rate (pce/h)</th>
<th>Check</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Aurelia dir. Viareggio</td>
<td>1211</td>
<td>1320</td>
<td>NO !</td>
</tr>
<tr>
<td>2) Aurelia dir. Pisa</td>
<td>942</td>
<td>1160</td>
<td>NO !</td>
</tr>
<tr>
<td>3) Casello A12-A11</td>
<td>1100</td>
<td>648</td>
<td>Yes</td>
</tr>
<tr>
<td>4) Via Traversagna</td>
<td>594</td>
<td>326</td>
<td>Yes</td>
</tr>
</tbody>
</table>

The entry capacity check is not satisfied for approaches 1) and 2). Therefore, computation of related indices, such as delay queue and level of service would be meaningless.

4. ANAS design

The ANAS solution calls for a double roundabout intersection (see Figure 9). The configuration of twin roundabouts separates traffic between the SS1 Aurelia exit A11 and the SS1 Via Aurelia and Via Traversagna. The ANAS solution also provides a two lane bypass of roundabout B, substantially reducing the traffic load on that roundabout.
Flows for Roundabout "A" are shown in Figure 10. Note that the flow of 390 pce/h to Pisa is comprised of 294 pce/h from Viareggio and 96 pce/h from the Via Traversagna, all of which may bypass Roundabout B via a slip road. Thus, of the 1203 pce/h departing Roundabout A, only 813 pce/h need enter Roundabout B in order to access the toll motorway.
Table 5 presents the O/D flow between all entrance/exit pairs of the proposed “A” roundabout. (See Figure 6 for turning movement counts and Figure 9 for notation used to develop the O/D matrix).

**Table 5. O/D rate of flows for the ANAS design “A” Roundabout**

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>$Q_{exit}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>1107</td>
<td>213</td>
<td>1320</td>
</tr>
<tr>
<td>2</td>
<td>823</td>
<td>0</td>
<td>113</td>
<td>936</td>
</tr>
<tr>
<td>3</td>
<td>230</td>
<td>96</td>
<td>0</td>
<td>326</td>
</tr>
<tr>
<td>$Q_{exit}$</td>
<td>1053</td>
<td>1203</td>
<td>326</td>
<td>2582</td>
</tr>
</tbody>
</table>
Flows for Roundabout "B" are shown in Figure 11. Note that the flow of 523 pce/hr. from the SS 1 to the A11/A12 may bypass Roundabout B via a slip road (free right).

![Figure 11. Entering and Exit Flows for Roundabout “B”.](image)

Table 6 presents the O/D flow between all entrance/exit pairs of the proposed “B” roundabout. (See figure 6 for turning movement counts and Figure 11 for notation used to develop the O/D table).

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>$Q_{exit}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>813</td>
<td>813</td>
</tr>
<tr>
<td>2</td>
<td>637</td>
<td>0</td>
<td>0</td>
<td>637</td>
</tr>
<tr>
<td>3</td>
<td>299</td>
<td>349</td>
<td>0</td>
<td>648</td>
</tr>
<tr>
<td>$Q_{exit}$</td>
<td>936</td>
<td>349</td>
<td>813</td>
<td>2098</td>
</tr>
</tbody>
</table>
The two twin roundabouts, A and B, of the ANAS solution, have an inscribed circle diameter $D = 55$ m, a ring width of 9 m and operate with a 2-lane width of 8 m (4 m when operating as one lane). The two roundabouts are joined by an 85 meter stretch of road. To calculate the capacity and the performance, we apply the French SETRA formula (SETRA, 1998) similar as above for the Motorways DUE.

4.1. Checks for Roundabout “A”

The geometric data for the entry lanes and the splitter islands to apply the SETRA method to Roundabout "A" are given in Table 7, while the width of the circulating roadway is $ANN = 9.0$ m.

**Table 7. Geometric data for Roundabout “A”**

<table>
<thead>
<tr>
<th>Leg</th>
<th>Splitter island width (m)</th>
<th>Entry lane width (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Highway SS1 direction: Viareggio</td>
<td>9.8</td>
<td>8.0</td>
</tr>
<tr>
<td>2) Highway SS1. Direction: Pisa and Motorway</td>
<td>7.4</td>
<td>8.0</td>
</tr>
<tr>
<td>3) Via Traversagna</td>
<td>12.5</td>
<td>4.0</td>
</tr>
</tbody>
</table>

Single entry capacity checks for Roundabout "A" are satisfied as indicated in Table 8:

**Table 8. Single entry capacity checks for Roundabout “A”**

<table>
<thead>
<tr>
<th>Leg</th>
<th>Incoming Flow (pce/h)</th>
<th>Flow Capacity (pce/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Highway SS1 to/from Viareggio</td>
<td>1320</td>
<td>&lt; 1613</td>
</tr>
<tr>
<td>2) From/to the A11/A12 Motorway (Pisa Nord interchange) and Highway SS1 to/from Pisa</td>
<td>936</td>
<td>&lt; 1353</td>
</tr>
<tr>
<td>3) From/to the Via Traversagna</td>
<td>326</td>
<td>&lt; 819</td>
</tr>
</tbody>
</table>

**Simplified Capacity Check:** Simple capacity is defined as the flow rate value reached in each entry when the first entry becomes congested (Mauro, 2010). This check is satisfied as follows:

minimum multiplier of the incoming flows : $\delta_{\min} = \delta_1 = 1.18 \geq 1$ (entry 1).

Therefore, a uniform growth of 18% of all the entry flows leads to congestion at entry 1 first.
Practical Total Capacity Check: Total capacity is reached when all the entries reach capacity, and this condition leads to solve for a system of as many equations as the number of entries (Mauro, 2010). The check consists of computing the summation of the total entry capacity values obtained in this way and testing that it must be less than the corresponding summation of the entry flow rates. This check is satisfied as follows:

$$C_{tot} = 3326 \geq 2582 \text{ pce/h} \quad \text{(sum of the entry rate of flows)}$$

The SETRA method produces performance measures based on the obstructing traffic $Q_d$, entry flows (adjusted to be equivalent to a flow with entry width of 3.5 m). Performance measures include the average waiting time $E[t]$ and the maximum queue length $L_{99}$ not exceeded 99% of the time. Average waiting time is determined by a level of service calculation analogous to unsignalized T intersections, such as documented in Exhibit 17.2 of the HCM 2000. See Table 9 for Roundabout “A” performance measures.

<table>
<thead>
<tr>
<th>Leg</th>
<th>$Q_d$, obstructing flow, (pce/hr)</th>
<th>$Q_e$, entry flow (pce/hr)</th>
<th>$L_{99}$ (vehicles)</th>
<th>$L_{99}$ (meters)</th>
<th>$E[t]$ (seconds per vehicle)</th>
<th>LOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Highway SS1 to/from Viareggio</td>
<td>311</td>
<td>910</td>
<td>13</td>
<td>7</td>
<td>9.5</td>
<td>A</td>
</tr>
<tr>
<td>2) From/to the A11/A12 Motorway (Pisa Nord interchange) and Highway SS1 to/from Pisa</td>
<td>567</td>
<td>646</td>
<td>8</td>
<td>48</td>
<td>7.0</td>
<td>A</td>
</tr>
<tr>
<td>3) From/to the Via Traversagna</td>
<td>786</td>
<td>310</td>
<td>3</td>
<td>18</td>
<td>4.5</td>
<td>A</td>
</tr>
</tbody>
</table>

4.2. Checks for Roundabout “B”

The geometric data to apply the SETRA method to Roundabout "B" are given in Table 8 (width of the circulating roadway $ANN = 9.0$ m).

<table>
<thead>
<tr>
<th>Approach</th>
<th>Splitter island width (m)</th>
<th>Entry lane width (m)</th>
</tr>
</thead>
</table>

Table 10. Geometric data for Roundabout “A”
Capacity tests for Roundabout "B" are satisfied as indicated in Table 11:

<table>
<thead>
<tr>
<th>Approach</th>
<th>Flow entering (pce/h)</th>
<th>Entry Capacity (pce h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) From/to Viareggio and Via Traversagna</td>
<td>813</td>
<td>&lt; 1338</td>
</tr>
<tr>
<td>2) From/to Highway SS1 in the direction of Pisa</td>
<td>637</td>
<td>&lt; 1083</td>
</tr>
<tr>
<td>3) From/to the A11/A12 Motorway (Pisa Nord interchange)</td>
<td>648</td>
<td>&lt; 1169</td>
</tr>
</tbody>
</table>

Simplified Capacity Check: minimum multiplier incoming flows $\delta_{\text{min}} = 1.30 \geq 1$ (entry 2)

Practical Total Capacity: $C_{\text{tot}} = 2695 \geq 2098 \text{ pce/hr. (sum of incoming flows)}$

See Table 12 for Roundabout “B” performance measures.

<table>
<thead>
<tr>
<th>Leg</th>
<th>$Q_{o}$, obstructing traffic, (pce/hr)</th>
<th>$Q_{e}$, entry flow (pce/hr.)</th>
<th>L 99 (vehicles)</th>
<th>L 99 (meters)</th>
<th>$E [t]$ (seconds per vehicle)</th>
<th>LOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) From/to Viareggio and Via Traversagna</td>
<td>582</td>
<td>561</td>
<td>7</td>
<td>42</td>
<td>8.3</td>
<td>A</td>
</tr>
<tr>
<td>2) From/to Highway SS1 in the direction of Pisa</td>
<td>833</td>
<td>439</td>
<td>7</td>
<td>42</td>
<td>8.0</td>
<td>A</td>
</tr>
<tr>
<td>3) From/to the A11/A12 Motorway (Pisa Nord interchange)</td>
<td>748</td>
<td>447</td>
<td>5</td>
<td>30</td>
<td>6.5</td>
<td>A</td>
</tr>
</tbody>
</table>

4.3. Checks for adequate queuing space
Measured from the outer circumference, the twin roundabouts are separated by 85 meters. The space between Roundabout “B” and the slip bypass road is also 85 meters. The following checks were performed:

a) for Roundabout "A", the 99% entry queue length for leg 2 (to/from the Motorways) is 48 m, which is much less that the available space of 85 meters.

b) for Roundabout "B", the 99% entry queue length for leg 1 (to/from Viareggio and the Via Traversagna) is 42 m, which is much less that the available space of 85 meters.

c) for Roundabout "B", the 99% entry queue length for leg 2 (From/to Highway SS1 in the direction of Pisa) is 42 m, which is much less that the available space of 85 meters

To improve the safety of the section of roadway connecting the twin roundabouts, it was designed to accommodate 2 lanes in each direction in order to further reduce the chance the queue may back up into the upstream roundabout or diverge areas.

5. Conclusions

This paper compared three circular traffic flow based options for a constrained area in Tuscany, Italy. Design traffic was computed for the peak conditions for the area, rush hour on a summer holiday and based on data from Motorways for Italy, the Province of Pisa, the City of Vecchiano, and the University of Pisa.

Under this scenario, traffic was assessed for three instances, “Motorways UNO” - a very large elliptical rotary, “Motorways DUE” – a very large circular roundabout, and “ANAS” - which includes two twin roundabouts and slip by-pass roads.

The British method was used to assess the “Motorways UNO” rotary solution, operating as a series of short weaving segments. All segments performed at LOS C or above with the exception of one which could not meet LOS D criteria. Further, the ratio of minor to major axis of the large elliptical design falls below the minimum recommended threshold of 0.75.

The French SETRA method was used in respect to the “Motorway DUE” 4-leg very large roundabout solution, leading to entry capacity values sometimes less than the corresponding entry traffic flows. Generally speaking, this design option is not capable of attaining capacity requirements, mainly due to the fact that all traffic demands are concentrated and mixed in few points related to the four approaches.

The third design (ANAS) was also assessed using the French SETRA method which concluded that LOS A could be provided for all legs of both roundabouts, with an average waiting time less than 10 seconds per vehicle. Expected 99% confidence queues would not come close to exceeding available separation spaces in the constrained area.

Both ANAS and Motorway DUE exhibit modern roundabouts operations, with the same total traffic conditions and same model approach. Nevertheless, the most distinctive factor between the ANAS solution and
the previous Motorways DUE is that in the former case different traffic flows are separated on two facilities and many conflict maneuvers are avoided by managing merging traffic at two different locations. In this way, capacity and performance are enhanced as well as safety.

One can consider the ANAS solution as an example supporting the basic idea of distributing maneuvers and conflicts on two facilities is often better than trying to cope with them in a single, even very large facility, mixing flows altogether at the same time and place.

For these reasons, the ANAS solution could be considered far superior to both the Motorways UNO and Motorways DUE solutions in terms of capacity and performance.

![Figure 12. Annual crash frequencies and size of the inscribed circle diameter observed in France (CETUR, 1986).](image)

Finally, the ANAS solution provides several other distinct advantages, including:

a) **road safety**: circular roundabouts with diameters between 50 and 70 m have the lowest annual crash frequency in respect to elliptical roundabouts, that have a value 3 to 4 times higher, or in respect to roundabouts with diameters over 90 m, showing over doubled crash frequency values (see Figure 12, drawn from the survey results observed on French roundabouts by CETUR, 1986);

b) **efficacy**: the traffic from Viareggio to Pisa is never mixed with turning flows. Similarly, traffic on SS1 from Pisa to the Motorway entrance (A11 or A12) does not interact with roundabout traffic;
c) *construction and operating costs*: given the smaller size and the reduced need for general work, it is easier, faster and less costly to build the ANAS solution;

d) *maintenance*: the maintenance of green areas in the ANAS solution is simplified, and the roundabouts consume far less space (1660 vs. 4301 vs. 9175 square meters). Further, the hydraulic maintenance of the Ditch of the Traversagnola becomes much easier.

e) *environment and landscape*. This is not a secondary concern given the context of the Migliarino and San Rossore area. The size and more reasonable dimensions of the ANAS solution create relatively minor impacts on the environment through the stages of construction as well as reduce the visual intrusion on the finished landscape. Additionally, the ANAS solution is superior for reducing light pollution as it requires less lighting to adequately serve drivers (see Figure 13).

![Figure 13. Simulation of lighting conditions for very large diameter roundabouts compared to smaller, twin roundabout](image)

In spite of the all above considerations, evidence and results, one should not forget that any experimental finding in the field of traffic engineering is strictly linked to the local driver habits, rules and environmental conditions. Only general guidelines can be transferred to other contexts and basic assumptions should be evaluated in respect of the designer specific knowledge. In this case, the lesson repeated is “less may be more.”

**References**

Caserta, P. "Design of road infrastructures and infrastructures of the new commercial area of Vecchiano", LD Thesis in Civil Engineering, Faculty of Engineering, University of Pisa. 2008.


Other relevant works


