Comparative Analysis of Four New Alternative Types of Roundabouts: “Turbo”, “Flower”, “Target” and “Four-Flyover” Roundabout

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Abstract
Analysis of literature shows that “modern roundabouts” nowadays exist in all European countries, as well as in more than 60 countries elsewhere in the world. Nowadays, a growing number of studies, presented in scientific and professional literature, point out a poor traffic safety characteristics of “standard” two-lane roundabouts and lower capacity than was expected. These problems are resolved in more ways in different countries; however the solution, whereby the number of conflict spots is diminished has proven to be the most successful. Lower number of conflict spots is one of characteristics of the alternative types of roundabouts. The alternative types of roundabouts are usually more recent and implemented only in certain countries. It is typical for them that they differ from “standard” one- and two-lane roundabouts in one or more design elements, while the purpose of their implementation is also specific. This paper illustrate four relative new alternative types of roundabouts – “turbo”, “flower”, “target” and “four flyover” roundabouts and their comparison from designing, capacity and traffic – safety point of view.

Keywords
Turbo roundabout · flower roundabout · target roundabout · four flyover roundabout · comparative analysis

1 Introduction
Lately, a growing number of foreign studies, presented in scientific and professional literature, point out a poor traffic – safety characteristics of “standard” two-lane roundabouts and lower capacity than was expected [1]. These problems are resolved in more ways in different countries. Many countries are solving the problem by decreasing the number of conflict spots, which is one of the main characteristics of alternative (or unconventional) types of roundabouts.

Some of them are already in frequent use all over the world (hamburger, dumb-bell, etc.), other types and have only been implemented within certain countries (turbo, turbo-square, dog-bone, compact semi-two-lane roundabout, etc.) or are still at the development phase (e.g. “flower”, “target” and “four flyover” [2, 3]).

Alternative types of roundabouts typically differ from standard one- or two-lane roundabouts in one or more design elements, as their purposes for implementation are also specific.

In the paper, “turbo”, “flower”, “target” and “four flyover” roundabouts are presented and compared from designing, capacity and traffic – safety point of view.

2 Basic characteristics of turbo, flower, target and four flyover roundabout

2.1 Turbo roundabout
The turbo roundabout (Fig. [1]) is relatively innovative arrangement of the two-lane roundabout that has revolutionised roundabout design in the Netherlands and in several European countries [4].

The idea of the turbo roundabout was very rapidly (just over a few years) transposed into several countries such as Slovenia [5], Germany [6], Denmark, Lithuania [7] and Czech Republic [8], as also Hungary, the Former Yugoslavia Republic of Macedonia and several other countries.

In the turbo roundabout the traffic flows run separately even before the entry into the roundabout, they occupy separate lanes all the way throughout the roundabout, whereas traffic flows run separately also at the exit from the roundabout [4].

Physical separation of traffic lanes is interrupted only in
Fig. 1. Typical layout and geometric design of a basic - turbo roundabout places of entry into the inner circulatory carriageway. Physical separation is achieved by specially shaped elements – delineators, which hinder (but not prevent) the change of traffic lanes in the roundabout – weaving conflict.

The central island is designed by means arcs of circumferences with different centers and radius (cfr. Fig. 1b and Table 1). Also can be used the Archimedean spiral [9] with the aim to limiting the variation of the centrifugal acceleration around the central carriageway.

2.2 Flower roundabout

The roundabout with "depressed" lanes for right-hand turning, in short the "flower roundabout" (see Fig. 2), was invented as a solution for achieving a higher level of traffic safety on existing, less-safe standard two-lane roundabouts [2]. The flower roundabout is a roundabout with two lanes at entries, two lanes at exits and a ring lane which makes right-turning vehicles get onto a bypass lane, and not into the ring.

2.3 Target roundabout

The “target roundabout” [2][10] is presently at the development phase. A target roundabout is designed as a two one-lane roundabout with different outer diameters, located on dual levels (Fig. 3), and all right-hand turners on both roundabouts have their own, separate right-hand turn bypass lanes. The target roundabout “forgives errors”; if a driver mistakenly stays on the left-hand lane at the entrance it is still possible to turn right at the next exit (different to the turbo roundabout). Driving at a target roundabout is the same as on the turbo roundabout (the same philosophy of signposting and lane-marking).

2.4 Four flyover roundabout

The roundabout with segregated left-hand turning bypasses (slip-lanes) on major roads – in short the "four flyover round-
Tab. 1. Turbo roundabouts radii values

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>MINI</th>
<th>STANDARD</th>
<th>MEDIUM</th>
<th>LARGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_1$ [m]</td>
<td>10.50</td>
<td>12.00</td>
<td>15.00</td>
<td>20.00</td>
</tr>
<tr>
<td>$R_2$ [m]</td>
<td>14.70</td>
<td>16.20</td>
<td>19.20</td>
<td>24.20</td>
</tr>
<tr>
<td>$R_3$ [m]</td>
<td>18.90</td>
<td>20.40</td>
<td>23.40</td>
<td>28.40</td>
</tr>
<tr>
<td>$R_4$ [m]</td>
<td>10.50</td>
<td>12.00</td>
<td>15.00</td>
<td>20.00</td>
</tr>
<tr>
<td>$R_5$ [m]</td>
<td>14.70</td>
<td>16.20</td>
<td>19.20</td>
<td>24.20</td>
</tr>
<tr>
<td>$R_6$ [m]</td>
<td>18.90</td>
<td>20.40</td>
<td>23.40</td>
<td>28.40</td>
</tr>
</tbody>
</table>

$\Delta R = 4.20$ m (Lane width = 3.50 m)

$\Delta R = 4.45$ m (Lane width = 3.75 m)

$\Delta R = 4.70$ m (Lane width = 4.00 m)

3 Comparative analyses of turbo, flower, target and four flyover roundabout

3.1 Designing elements comparison

- **Turbo roundabout.** The best characteristic of turbo roundabout is that they exist different types of turbo roundabouts \([3][11]\). The selection of the type depends on the predominant direction of the main traffic flow. The geometrical form of the turbo roundabout is a little bit complicated, and is formed by the so-called turbo block. This is a formation of all the necessary radii, which must be rotated in a certain way, thereby obtaining traffic lanes or driving lines. The centre of a turbo block must be located in a way that a radial connection of all entries into the roundabout with a spiral course of a circulatory carriageway is possible.

- **Flower roundabout.** Probably the best characteristic of a flower roundabout is that it is implemented within an existing standard two-lane roundabout. When reconstructing a standard two lane roundabout into a flower roundabout, all the curbs of the circulatory carriageway, splitter islands, and access roads remain in the same positions. The planning stages required for its planimetric composition are given in \([2]\).

- **Target roundabout.** The geometrical form of the target roundabout is somewhat simpler. A target roundabout is designed as a two roundabout with different outer diameters ($D_{\text{outer}} = 41$ m and $d_{\text{outer}} = 29$ m), located on dual levels, and all right-hand turners on both roundabouts have their own, separate right-hand turning bypass lanes ($D_{\text{bypasses}} = 46$ m). A target roundabout is especially useful within suburban areas, with plenty of space, where two-level interchanges (standard diamond, diverging diamond, cloverleaf interchange...) are all possible solutions. However, this solution is acceptable also in urban areas due to small size.

- **Four flyover roundabout.** It is designed as a one large one-lane roundabout ($D_{\text{outer}} = 80$ m) at upper level, and both left-hand turners on the major roads have their own separate left-hand turn bypass lanes ($R = 35$ m), located at another, lower level. A four flyover roundabout is especially useful in ur-
ban areas, where we do not usually have plenty of space, and
can not be seen as a feasible solution.

3.2 Traffic safety comparison

A turbo roundabout has a higher level of traffic safety in com-
parison to a “standard” two-lane roundabout for several reasons.
The most important is a lower number of conflict spots. A turbo
roundabout reduces the number of conflict spots (by reducing
the number of crossing traffic flows), and eliminate weaving conflict spots (by the separate running of individual
direction flows). Conflict spots in the turbo roundabout with
two-lane entries and exits on major road and two-lane entries
and one-lane exits on minor road (4 crossing, 6 merging and 4
diverging) are presented on Fig. 5.

A recent research, in which a potential accident rate model
has been used [12], shows that turbo-roundabouts provide re-
ductions of the number of total potential accidents between 40%
and 50%, and reductions of the number of potential accidents
with injuries between 20% and 30%.

In the case of flower roundabouts (Fig. 6), there are no weaving in circulatory roadway but only eight conflict points (more
exactly, 4 diverging points and 4 merging points) which char-
acterize a standard one-lane roundabout. As to bypass lanes,
it is also required to calculate the numbers of diverging spots
concerning the right-turn routing manoeuvre and the merging
spots in the flow from the roundabout (4 diverging and 4 merging
points).

These conflict points are located at a certain distance from the
roundabout, where the effect on speed limitation is less notice-
able.

One of the basic characteristics of the target roundabout is the
same as at the turbo roundabout – physically separated traffic
lanes within a circulatory carriageway; bypasses and one-lane

<table>
<thead>
<tr>
<th>Roundabout Type</th>
<th>Circulating Flows</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard roundabout</td>
<td>$Q_{c,1} = Q_{1,2} + (Q_{1,2} + Q_{c,3})$</td>
</tr>
<tr>
<td></td>
<td>$Q_{c,2} = Q_{1,3} + (Q_{1,3} + Q_{c,4})$</td>
</tr>
<tr>
<td></td>
<td>$Q_{c,3} = Q_{1,4} + (Q_{1,4} + Q_{c,1})$</td>
</tr>
<tr>
<td></td>
<td>$Q_{c,4} = Q_{1,1} + (Q_{1,1} + Q_{c,2})$</td>
</tr>
<tr>
<td>Turbo roundabout (both</td>
<td>$Q_{c,1} = Q_{1,2} + (Q_{1,2} + Q_{c,3})$</td>
</tr>
<tr>
<td>the circulating flows $Q$</td>
<td>$Q_{c,2} = (Q_{1,3} + Q_{c,4})$</td>
</tr>
<tr>
<td>$Q_{c,3} = Q_{1,4} + (Q_{1,4} + Q_{c,1})$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$Q_{c,4} = (Q_{1,1} + Q_{c,2})$</td>
</tr>
<tr>
<td>Four flyover roundabout</td>
<td>$Q_{c,1} = Q_{1,2}$</td>
</tr>
<tr>
<td></td>
<td>$Q_{c,2} = Q_{1,3}$</td>
</tr>
<tr>
<td></td>
<td>$Q_{c,3} = Q_{1,4}$</td>
</tr>
<tr>
<td></td>
<td>$Q_{c,4} = Q_{1,1}$</td>
</tr>
<tr>
<td>Target roundabout</td>
<td>$Q_{c,1} = Q_{1,2}$</td>
</tr>
<tr>
<td></td>
<td>$Q_{c,2} = Q_{1,3}$</td>
</tr>
<tr>
<td></td>
<td>$Q_{c,3} = Q_{1,4}$</td>
</tr>
<tr>
<td></td>
<td>$Q_{c,4} = Q_{1,1}$</td>
</tr>
</tbody>
</table>

Fig. 5. Conflict spots in the “basic” turbo roundabout

Fig. 6. Conflict spots in the flower roundabout (for the circulatory roadway)
circulatory roadway sections; with no crossing conflict spots (unlike in the case of the “standard” two-lane or turbo roundabout), and also no weaving conflict spots (unlike in the case of the “standard” two-lane roundabout).

At the target roundabout there are just 8 merging and 8 diverging conflict spots (as at the two one-lane roundabouts) (see Fig. 7).

As pointed before, the four flyover roundabout is designed as a one large one-lane roundabout at upper, and both left-hand turners on the major roads have their own separate left-hand turn bypass lanes, located at another, lower level. By physically separating left-hand turning traffic flow on major roads, we obtain a one-lane roundabout, with no crossing and also no weaving conflict spots. At a four flyover roundabout there are just 6 merging and 6 diverging conflict spots (see Fig. 8).

3.3 Capacity comparison

**Turbo roundabout**

Practical evaluation data is presently not available for turbo roundabouts, because only in The Netherlands a large number of turbo roundabouts have been realised and very few of those are operating on or near capacity. Because of that, there are different ways to determine a capacity of a turbo roundabout.

The Dutch guidelines [13] do not contain equations for calculating the capacity of the turbo roundabout. But, they have so-called quick-scan model, developed by the Province of South Holland in The Netherlands, for comparison of the capacity of different kinds of roundabouts. The quick-scan model shows that the capacity of a turbo roundabout is about 25% to 35% higher than the capacity of a two-lane roundabout, depending on the balance of the traffic volumes on the approaches.

These results are also dependent on the design of the roundabouts and on the driver behaviour factors used in the quick-scan model.

For that reason, the results should mainly be interpreted as a comparison between the turbo and the two-lane roundabout and not as absolute conclusions about the capacity of the two roundabout options [14].

By means of the use of capacity equations show in Table 3 (15) founds that the capacities of turbo roundabout secondary entries are higher than roundabout capacities when the traffic flow in the inner lane of the circle is high and the traffic flow in the outer lane of the circle is in the low to lower-middle range.

On the contrary, the capacities of the main entries to roundabouts are always higher than the capacities of the main entries to turbo roundabouts.

A comparative analysis of capacities of the “standard” two-lane, turbo and flower roundabout, using a micro-simulation programme PTV Vissim was performed [5]. Results of the micro simulation show that there are no significant differences between the “standard” two-lane and turbo roundabout at low traffic loads - congestions and queue lengths are approximately the same. At higher traffic loads, the difference is in favour of the turbo roundabout.

**Flower roundabout**

The capacities of through and left-turn lanes ($C_1$) and right-turn bypass lane ($C_2$) can be estimated, under stationary conditions of vehicle flow [16][17], by means of different models. In the case of the slip lane may be adopted three different traffic regulations: Stop, Yield and Free Flow. Capacity relationships are given in Table 4, in which $Q_c$ is the circulating flow in front of the entry [veh/h] and $Q_u$ is conflicting flow, exiting from the next arm after the entry subject to capacity estimation [veh/h].

To estimate the capacity reduction factor for the entry lanes (respectively $M_1$ for lane 1 and $M_2$ for lane 2), due to the pedestrian flows (in urban context) the German method can be used [18][20] (cfr. Fig. 9).

The entry capacity can be evaluated by means of the same equation, presented in Table 3 (“Entry capacity” column) for the turbo roundabouts.

**Target roundabout and four flyover roundabout**

Practical evaluation data is presently not available for target roundabout and for four flyover roundabout, because these types of roundabouts are at the development phase.
Tab. 3. Formulas used for capacity evaluations of turbo-roundabout entries

<table>
<thead>
<tr>
<th>Arms (see Fig. 1k)</th>
<th>Lane or manoeuvre</th>
<th>Single-entry or single-manoeuvre capacity formula</th>
<th>Entry capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 and 3</td>
<td>Right</td>
<td>( C_{r,dh} = \frac{3600}{3.6} \left( 1 - 2.4 \left( \frac{Q_c}{300} \right) \right), ) ( \exp \left[ \frac{-Q_c}{300} (4.1 - \frac{2.9}{2} - 2.0) \right] ) ( C_{r,turbo} = \frac{\sum Q_{i}}{\sum I_{i}} )</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>( C_{l,dh} = \frac{3600}{3.6} \left( 1 - 1.6 \left( \frac{Q_c+Q_{i}}{300} \right) \right), ) ( \exp \left[ \frac{-Q_c-Q_{i}}{300} (4.5 - \frac{2.9}{2} - 2.0) \right] )</td>
<td>–</td>
</tr>
<tr>
<td>2 and 4</td>
<td>Right</td>
<td>( C_{r,dh} = \frac{3600}{3.6} \left( 1 - 2.0 \left( \frac{Q_c}{300} \right) \right), ) ( \exp \left[ \frac{-Q_c}{300} (4.1 - \frac{2.9}{2} - 2.0) \right] )</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>( C_{l,dh} = \frac{3600}{3.6} \left( 1 - 2.0 \left( \frac{Q_c}{300} \right) \right), ) ( \exp \left[ \frac{-Q_c}{300} (4.1 - \frac{2.9}{2} - 2.0) \right] )</td>
<td>–</td>
</tr>
</tbody>
</table>

Where \( Q_{i} = Q_{c,d} + Q_{c,i} \) is the sum of the traffic flow circulating in the outer lane \( (Q_{c,d}) \) and in the inner lane \( (Q_{c,i}) \) in front of the entry point; \( C_{r,dh} \) is capacity of the right-turning manoeuvre; \( C_{l,dh} \) is the capacity of the left-turning manoeuvre; \( Q_{c,i} \) is the flow rate of the lane "i" at entry "e" and \( C_{i} = \) capacity of the lane "i".

Tab. 4. Capacity laws

<table>
<thead>
<tr>
<th>Lane and traffic control type</th>
<th>Capacity Law</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left-hand turning</td>
<td>( C_1 = 1130 \cdot e^{-0.001 Q_{i}} ) ( (1) )</td>
</tr>
<tr>
<td>Right-turn bypass lane with Stop Sign</td>
<td>( C_2 = 1231, 4 \cdot e^{-0.0012 Q_{i}} ) ( (2) )</td>
</tr>
<tr>
<td>Right-turn bypass lane with Yield Sign</td>
<td>( C_2 = 1130 \cdot e^{-0.001 Q_{i}} ) ( (3) )</td>
</tr>
<tr>
<td>Right-turn bypass lane with Free–flow</td>
<td>( C_2 = 1250 \cdot e^{-0.0007 Q_{i}} ) ( (4) )</td>
</tr>
</tbody>
</table>

For Lane 1 of any arm "i" the antagonist flow is the circulating flow \( (C_{i,1} = f (Q_{c,i})) \). Instead, Lane 2 is a true right-turn bypass lane as its flow does not enter the ring carriageway. For entry "i" the contrasting flow is that coming out of the arm "i + 1" \( (C_{2,i} = f (Q_{c,di+1})) \).

Therefore, we have for \( C_1 \) (capacity of Lane 1) and \( C_2 \) (capacity of Lane 2) the following equations \( (4), (5) \):

\[
C_1 = 3600 \cdot \left( 1 - \frac{t_{min}}{t_f} \frac{Q_{c,i}}{3600} \right) \cdot \frac{1}{t_f} \cdot \exp \left[ -\frac{Q_{c,i}}{3600} \left( t_g - \frac{t_f}{3} - t_{min} \right) \right]
\]

\[
t_g = 3.86 + \frac{8.27}{d} \quad \quad t_f = 2.84 + \frac{2.07}{d} \quad \quad t_{min} = 1.57 + \frac{18.6}{d}
\]

(5)

The previous Eq. \( (4) \) highlights that capacity \( C_1 \) is a function of circulating vehicles \( Q_{c,di} \), drivers’ behaviors (through parameters \( t_g, t_f, t_{min} \)) and geometric layout of the intersection (i.e. inscribed circle diameter "d"). The expressions of \( C_2 \) are shown in Table \( (5) \) (\( Q_{di} \) stands for the contrasting flow).

In four flyover roundabout the arms Nos. 1 and 3 (cfr. Fig. 4), have an only entry lane, while the arms Nos. 2 and 4 have two entry lanes; also, the ring has only a single lane. The circulating flows in front of each entry are shown in Table \( \) 2.

As for arms Nos. 1 and 3, entry capacity \( C_1 \) can be estimated by applying the following relationship \( (4), (21) \):

\[
C_1 = 1130 \cdot e^{-0.001 Q_{i}}
\]

Arms Nos. 2 and 4 (cfr. Fig. 5) have two dedicated entry lanes, i.e., so it can be use the following value \( (4), (22), (23) \):

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### 3.4 Delays

Generally, target roundabout causes lower delays in all traffic conditions. In a past research Tollazzi et al. [4], have compared pollutant emissions at target, flyover and other types of roundabouts. In the present research the performance analysis (capacities and delays) of the following eight roundabouts types have been done:

- Basic Turbo roundabout;
- Target roundabout;
- Four flyover roundabout;
- Flower roundabout with right-turn bypass lane with yield sign (Flower-Yield);
- Flower roundabout with free-flow right-turn bypass lane (Flower-Free);
- Standard roundabout with an entry lane and a ring lane (1 + 1);
- Standard roundabout with an entry lane and two ring lanes (1 + 2);
- Standard roundabout with two entry lanes and two ring lanes (2 + 2).

The closed-form models presented in the previous sections were used for traffic simulations, instead for the cases of standard roundabouts were used the procedure described in the HCM 2010 manual [21].

Three different traffic distribution test matrices $\rho_1$, $\rho_2$ and $\rho_3$ have been examined, with a total entry arm flows ranging between 225 veh/h and 4,775 veh/h (equally distributed among the four arms of each intersection):

- OD Matrix $\rho_1$ = 72% of vehicles turn right, 13% cross and 15% turn left;
- OD Matrix $\rho_2$ = 13% of vehicles turn right, 72% cross, 15% turn left;
- OD Matrix $\rho_3$ = 15% of vehicles turn right, 13% cross, 72% turn left.

For those arms of the intersections in which there is only an exit lane ( turbo roundabouts, standard (1 + 1), standard (1 + 2)), if “the capacities of the entries are higher than the capacities of the exits, the former are limited by the latter” [24]. In this cases, the capacity of entry $i$, $C_{i,j}$, given the capacity of exit $j$, $C_j$ (1200 veh/h) can be evaluated as follows [24]:

$$C_{i,j} = C_j \frac{OD_{i,j}}{D_j}$$

### Tab. 5. Bypass lane capacity laws (Lane 2 capacity)

<table>
<thead>
<tr>
<th>Traffic control type</th>
<th>Capacity Law</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stop Sign</td>
<td>$C_2 = 1231.4 \cdot e^{-0.0124_1} Q_u$ (6)</td>
</tr>
<tr>
<td>Yield Sign</td>
<td>$C_2 = 1130 \cdot e^{-0.001} Q_u$ (7)</td>
</tr>
<tr>
<td>Free–flow</td>
<td>$C_2 = 1250 \cdot e^{-0.0007} Q_u$ (8)</td>
</tr>
</tbody>
</table>

### Fig. 10. Typical diagram of entry capacity for all the arms with two entry lanes
Where $OD_{i,j}$ is the flow rate from entry $i$ to exit $j$ [veh/h] and $D_j$ is the destination flow from all entries to exit $j$.

When $C_{i,j}$ is totally utilized, the maximal possible flow rate at the entry $i$ is:

$$C_{i,j}^* = C_i \frac{Q_i}{D_j}$$  \hspace{1cm} (14)

$C_{i,j}$ is the maximal flow rate at entry $i$ for the case that at exit $j$ the capacity $C_j$ is reached and $O_i$ is origin flow from entry $i$ to all exits [veh/h].

Finally, for each lane vehicle delays were estimated through the following formulations:

$$d_i = \frac{3600}{C_i} + 900T$$

$$+ \left[ \frac{Q_i}{C_i} - 1 + \sqrt{\left( \frac{Q_i}{C_i} - 1 \right)^2 + \left( \frac{3600}{C_i} \right) \left( \frac{Q_i}{C_i} \right)} \right] + 5 \min \left[ \frac{Q_i}{C_i} - 1 \right]$$  \hspace{1cm} (15)

Where $d_i$ is the average control delay for Lane $i$ [s/veh]; $T$ is reference time (h), ($T=1$ for a 1-h analysis, $T=0.25$ for a 15-min analysis. In the research we used $T=0.25$).

Total average delay at entry “$i$” is expressed by the following equation:

$$d_j = \frac{1}{\sum Q_i} \sum d_i \cdot Q_i$$  \hspace{1cm} (16)

The Fig. 11 shows the typical diagram of control delay (cfr. Eq. (14)), as function of the ratios $Q_i/C_i$ (degree of saturations $\rho_i = Q_i/C_i$), for all the arms with two entry lanes, namely:

- arms numbers 1 4 of turbo roundabouts (cfr. Fig. 1);
- arms numbers 1 4 of flower roundabouts (cfr. Fig. 2);
- arms numbers 1 4 of target roundabouts (cfr. Fig. 3);
- arms numbers 2 and 4 of four flyover roundabout (cfr. Fig. 4).

The average delay of each intersection has been calculated with the weighted average of delays at each entry “$i$” (by using entry flow as weight).

The results, presented in Figs. 12-14 show the relationship between average delays at roundabouts and the total entry flow.

As expected, respect to the other intersections, the target roundabout (two-level roundabout) produces lower delays in all traffic conditions examined.

As regards four flyover roundabouts, they result to be more suitable when left-turning manoeuvre prevails (as happens in Matrix $\rho_3$, see Fig. 13).

Concerning the at-grade intersections, standard roundabouts (2+2) provide lower delays than other standard roundabouts (1+1) and (1+2).

Instead, the best performance of turbo roundabouts occur when the most of the entry flow turn right (i.e. Matrix $\rho_1$, see Fig. 12).

4 Conclusions

This paper illustrate two relative new alternative types of at-grade roundabouts: turbo roundabout, flower roundabout and two alternative types of two-level roundabouts at development phase: target and four flyover roundabouts and their comparison from designing, capacity and traffic-safety point of view.

All of them have their advantages and deficiencies, which makes sense, since they are intended for solving particular problems.

As concerns the functional analysis, the comparison was made by means of the delays, evaluated under numerous traffic conditions, characterized by three traffic distribution test matrices: $\rho_1$ (70% of traffic coming from every arm turn right), $\rho_2$ (70% of entry traffic crossed the intersection), $\rho_3$ (70% of traffic turned left).

In all, eight roundabouts types have been analysed by means of closed form capacity and delay models.

Among the at-grade intersections, the standard roundabouts (2+2) show the lower delays. Flower roundabouts are always more convenient than roundabouts (1+1), also they lead to similar delays to those generated by roundabouts (2+2) with elevated right-hand turning flows. Instead, the best performance of turbo roundabouts occur when the most of the entry flow turn right.

Target roundabout is a two-level intersection and has higher construction cost (when compared with the at-grade roundabouts) but given lower delay, while the four flyover roundabouts are suitable only when left-turning manoeuvre prevails.

In the near future, we can expect further developments of alternative types of roundabouts, intended for solving specific problems, which will certainly represent a challenge for our branch of science.

![Fig. 11. Typical diagram of control delay for all the arms with two entry lanes](image-url)
Comparative Analysis of Four New Alternative Types of Roundabouts
References


13. CROW, Turbo roundabouts, Publicatie 257; The Netherlands, 2008.


