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Two-Geometry Roundabouts: Design Principles

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Abstract

Although multi-lane concentric roundabouts have a greater capacity than single-lane roundabouts, they may encourage increased driving speeds and decrease in safety. Furthermore, lane changing is possible in multi-lane roundabouts, thus increasing the risk of crashes. To address these drawbacks, the authors present the "Two-Geometry" Roundabout. This type of roundabout discourages lane changing within the roundabout, lowers driving speed through the roundabout, and facilitates the manoeuvres of larger and longer vehicles. The paper discusses the concept of the Two-Geometry Roundabout and outlines its principal advantages. We first delineate characteristics of single-roundabouts and multi-lane roundabouts, focusing on the problems of the latter. Next, the development, main characteristics and typologies of Two-Geometry Roundabouts are illustrated (with some examples attached); therefore, we focus on the positive effects of the Two-Geometry Roundabout with particular attention on heavy vehicles. Finally, we present methods for calculating the capacity of the Two-Geometry Roundabout and conclude the paper.

Keywords: Traffic Engineering; Roundabouts Safety; Unconventional Roundabouts; Two-Geometry Roundabouts; Design Principles.

1. Introduction of single-lane and multi-lane roundabouts

First of all, it is appropriate to state a premise: this paper is inspired by L.G.H. Fortuijn's pioneering works on turbo roundabouts. Therefore, it should be noted that the first part of the article will be a continuation and an implementation of the studies already conducted by Fortuijn on classic single-lane and multi-lane roundabouts.

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Firstly, a brief introduction to the classic roundabout has been made. In particular, the differences between single-lane and multi-lane roundabouts, often seen as natural solutions to the problem of high traffic, are discussed. The advantages of single-lane roundabouts are summarized in the following list:

- Low speeds which contribute to the safety of the intersection, unlike the pre-modern roundabouts;
- Increased capacity due to lower speeds and improved geometry;
- Easier and safer accommodation of bicycles and pedestrians.

Therefore, the combination of all these and other factors has contributed to the success of the modern single-lane roundabout in many countries (including countries with a high number of vulnerable road users). However, too much traffic volume requires modification of the single-lane roundabout. Two interventions may be considered:

- Adding a bypass lane for right turns to one or more entries, and/or
- Conversion of the single-lane roundabout to a multi-lane roundabout.

The first solution is often used in three-leg roundabouts. In some cases, bypass lanes fail to resolve all capacity problems and it is natural to consider the second solution. However, multi-lane roundabouts introduce safety concerns as well as limited use of the innermost lane of the roundabout. So this paper discusses both how a Two-Geometry Roundabout addresses these problems, through its distinctive peculiarity that is the variability/flexibility of the width of the designed circulating carriageway, as well as the novelties concerning it with particular attention to new study approaches regarding classic intersections and their possible transformation into unconventional rather than Traditional Roundabouts.

2. The problem of concentric multi-lane roundabout

Related to the major safety issues of multi-lane roundabouts, both *Roundabouts: An Informational Guide* and a Queensland Department of Highways report: “International studies have shown that increasing the vehicle path curvature decreases the relative speed between entering and circulating vehicles and thus usually results in decreases in the entering-circulating and exiting-circulating vehicle crash rates. However, at multi-lane roundabouts, increasing vehicle path curvature creates greater side friction between adjacent traffic streams and can result in more vehicles cutting across lanes and higher potential for sideswipe collisions.”

At this point, therefore, it is possible to state that one of the most important dilemmas of multi-lane roundabouts is due to the curvature of the trajectories of the vehicles crossing the intersection. In the guidelines of the AASHTO (American Association of State Highway and Transportation Officials) standards for geometric design of roads and highways, it has been suggested that: "Adequate vehicle speeds through the roundabout are the most critical design goal." Therefore, when designing multi-lane roundabouts, tangential alignment flares are often provided for the entrances and exits. This design principle was presented in *Roundabouts: An Information Guide*. In the *Guide*, however, there are no recommendations regarding horizontal markings for the internal carriageways of roundabouts. Brilon and Bäumer suggest that road markings on the roundabout should be completely eliminated. In any case, different directives are adopted in each country both as regards to the resolution of the dilemma and for road markings. Following are examples of guidelines and regulations from various countries. In the Netherlands, in publication no. 126 Eenheid in Rotondes (A Unified Approach to Roundabouts) of the Dutch Information and Technology Platform (CROW), it is recommended to maintain slower speeds inside roundabouts by using specific road markings in order to solve the aforementioned dilemma.

In the Italian Ministerial Decree n.1699/2006 (“Functional and geometric rules for the construction of intersections”) standards for the widths of the carriageway, circulation ring and entrance and exit lanes as a function of the diameter outside of the roundabout are provided (Fig. 1). In particular, the Italian Decree classifies three basic types of roundabouts defined by the diameter of the external circumference:

- Conventional roundabouts (Diameter D = 40 to 50 m)

- Compact roundabouts (Diameter D = 25 to 40 m)
- Mini roundabouts (D = 14 to 25 m)

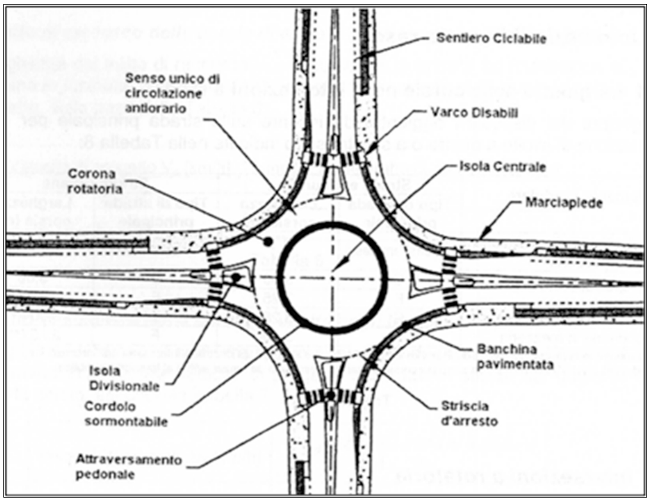

Fig. 1 Basic scheme of a Classic Roundabout (*source*: Italian Ministry of Infrastructures & Transport, DM n.1699/2006).

The curvature of vehicle trajectories crossing the intersection is not the only dilemma associated with multi-lane roundabouts. Another problem arises when the driver of a vehicle that is in the inside lane of the roundabout has to make a lane change manoeuvre in a noticeably short space, in order to be able to exit the intersection (even worse if there are two exiting courses). In these cases, accidents may occur due to conflicts between the aforementioned vehicles and those who are in the outer lane of the roundabout and want to continue along their route. All of this is further compounded by the fact that the concentric roundabout geometry requires that the following drivers have no way of knowing what the drivers ahead will be manoeuvring. In some American roundabouts, to remedy this problem, it is not allowed to change lanes once you have entered the roundabout. Driver discipline is governed by road markings as can be seen in the example shown in Fig. 2 of a roundabout in Lexington (Kentucky, USA). But in any case, the bottom line is that multi-lane roundabouts reintroduce one of the main drawbacks of the old intersections, which is the need to change lanes when cornering.

Fig. 2. Roundabout in Lexington, Kentucky, USA (*source*: Google Earth Pro™).

Despite these problems and dilemmas, it is possible to affirm that the multi-lane roundabout is, therefore, better than pre-modern roundabouts. However, the problems exposed as mentioned lead to a decrease in the safety of multi-lane roundabouts compared to single-lane roundabouts. This and other drawbacks, therefore, led the authors to seek a solution (other than multi-lane roundabouts) to the capacity deficit of single-lane roundabouts.

3. Development and Principal Characteristics of the Two-Geometry Roundabout

The goal of this research was to determine if an alternative to the standard multi-lane roundabout could be identified. The objective is to provide equivalent capacity with the safety of a single-lane roundabout. In summary, the main characteristics of such an alternative are:

- Higher capacity than single-lane roundabout;
- Safer travel speeds than multi-lane roundabouts;
- Fewer lane changing manoeuvres;
- Be suitable for the manoeuvres of heavy vehicles.

The considered approach is the Two-Geometry Roundabout. A Two-Geometry Roundabout is an unconventional roundabout with the shape of the outer edge different from that of the central island (usually the outer edge is elliptical and the central island remains circular). This entails a peculiarity of the Two-Geometry Roundabout, namely the fact of having the variable ring width (in classic roundabout it is constant). The main advantages of the Two-Geometry Roundabout include:

1. Thanks to their particular geometry, the deviation of the trajectories is well marked and consequently the travel speeds are low;
2. In the design phase they are less bulky than classic roundabouts and therefore more easily inserted in contexts with important restrictive constraints;
3. Thanks to their peculiarity, namely the variable-width ring lane, they are more easily passable even by large OSOW (OverSized/OverWeight vehicles).

The first point listed above is particularly important, both as it responds to one of the problems of the multi-lane roundabout, and from a more geometric point of view. In fact, the Two-Geometry Roundabout also solves the problem linked to situations in which one of the branches of the intersection would be displaced to the right with respect to the centre of the roundabout (if in this situation a conventional roundabout were used the vehicles would have too high speeds and therefore potentially dangerous accidents). Related to this topic, an image from *Roundabouts: An Informational Guide* is shown in Fig. 3.

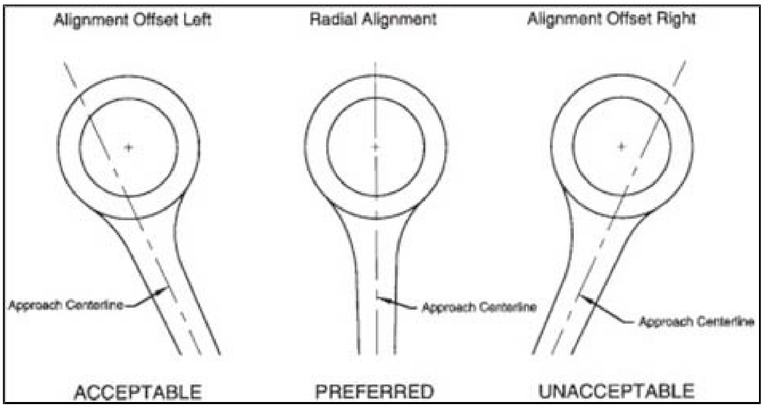

Fig. 3. Recommended radial alignment of entries for conventional roundabout (*source*: NCHRP - Roundabouts: An Informational Guide, 2010).

To date, some of Two-Geometry Roundabouts have been built in Italy. As an example, in the following Fig. 4, it is depicted the layout of a Two-Geometry Roundabout, located in Tuscany, on the SS n.1 - Via Aurelia, at a crossroads near Pisa. The main geometric characteristics of the aforementioned roundabout are: Major axis a = 42 m; Minor axis b = 34 m; b/a ratio = 0,8; R central island = 8 m; Overlapping band = 1,25 m; Max ring width = 11,25 m; Min ring width = 7,25 m.

Fig. 4. Instance of a Two-Geometry Roundabout project on SS n.1 – Via Aurelia, Pisa, It (*source*: courtesy by the Authors).

In detail, the alignment problem is faced as follows: the minor axis of the outer edge of the roundabout with two geometries is aligned to limit the offset of the approach centre line, in order to ensure sufficient reduction curvature of the speed at the entrance. Fig. 5 shows roundabout schemes that indicate the difference between the Classic Roundabout and the Two-Geometry Roundabout in two different cases: the central approach line is completely offset from the centre of the roundabout (top) and the central line of approach is aligned with the centre of the roundabout (below).

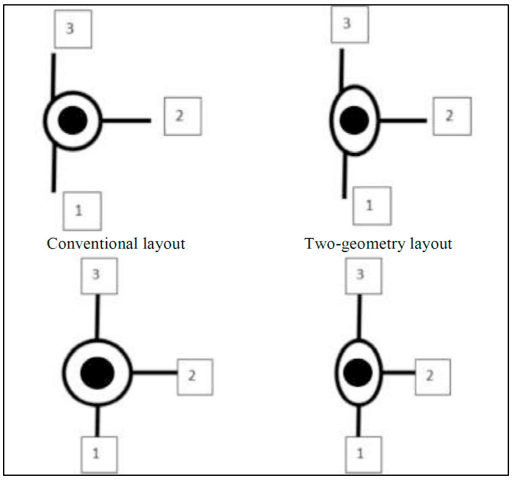

Fig. 5. Different roundabout schemes: Conventional layout vs. Two-Geometry layout (*source*: Gazzarri et al., 2014).

There are significant differences between layouts with a tangent approach centre line and centred ones. In a previous study, "Unconventional roundabout geometries for large vehicles or space constraints" (2014) Classic Roundabouts and Two-Geometry Roundabouts were compared using Aimsun simulation software. To test the sensitivity of performance to design parameters, simulations were conducted on each of the two layouts considering different combinations of traffic and geometry. A summary of the results obtained and the conclusions derived are reported below. The simulation results showed that there can be a significant difference between centre tangent-centred designs. Traffic queues are similar for Two-Geometry Roundabouts and Classic (pre-modern) Roundabouts for centred layouts. However, in the case of designs with a tangent approach line, a large disparity was found between the two types of roundabouts. Two-Geometry Roundabouts have shorter delays and consequently fewer traffic jams and shorter queue lengths, compared to Classic Roundabouts. The simulations indicated that the Two-Geometry Roundabout leads to major advantages in terms of capacity and safety, thanks mostly to the variable width of the ring road (there are wider lanes where the radius of the curve is lower and lanes narrower where the trajectories must be effectively diverted).

4. Different Variants of the Two-Geometry Roundabout

Rules of thumb for the most important geometric characteristics of Two-Geometry Roundabout are illustrated as follows (referring to Fig. 6): $0{,}75 < b/a < 0{,}90$; $b = R + x$; $a = R + y$; $4{,}00\text{ m} < x < 6{,}00\text{ m}$.

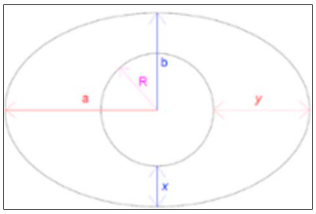

Fig. 6. Geometry of a Two-Geometry Roundabout. (*source*: courtesy by the Authors)

As one can see, there are practical rules to be respected that derive from experimental evidence. However, while remaining within these simple rules, the design possibilities of the Two-Geometry Roundabout are manifold. In fact, depending on the context and design needs, it is possible to vary the parameters a (major axis) and b (minor axis) at will, obtaining different operational results. Also, as regards the trajectory deflections, there are also here practical rules to be observed:

1. The curvature must be created by the central island (and this is one of the most important reasons because the central island is circular and not ellipsoidal);
2. The radius of the deflected trajectory should not exceed 80m - 100m (according to the type of roundabout).

Finally, as regards the fundamental geometric characteristics, two tables which indicate practical rules for sizing Two-Geometry Roundabouts in comparison with classic single-lane and multi-lane roundabouts are provided.

Table 1 shows the practical values to be used for sizing along the major axis "a" as a function of the diameter D of the Traditional Roundabout.

Table 1. Practical Value for Two-Geometry Roundabout (major axis "a")

	Traditional Roundabout	Two-Geometry Roundabout
Compact Roundabouts	D < 35 m	a < 42 m
Large Roundabouts	D > 35 m	a > 42 m

Table 2 specifies widths for the Two-Geometry Roundabout ring road as compared to those for Traditional Roundabouts. A distinction is made between minimum and maximum widths, due to the elliptical shape of the Two-Geometry Roundabout.

Table 2. Practical Value for Two-Geometry Roundabout (width of the ring "L")

	Traditional Roundabout	Two-Geometry Roundabout
Compact Roundabouts	Single-lane 7,5 m	Lmin 4,5÷5 m Lmax 7,5÷8 m
Large Roundabouts	Multi-lane 8,5 m	Lmin 5÷6 m Lmax 8÷9 m

As already mentioned, the ratio between the "b/a" axes must certainly be greater than 0,75. A final consideration regards horizontal road markings. In the Two-Geometry Roundabout, road markings are particularly important because they serve to guide vehicles well within the intersection. Hence, sometimes it may be useful to use a zebra pattern that traces the elliptical shape of the roundabout starting from the central circular island. Fig. 7 shows an example of lane markings for a Two-Geometry Roundabout project located in the province of Lucca.

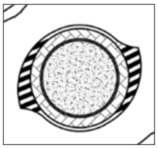

Fig. 7. Sample lane markings of a Two-Geometry Roundabout. (*Source*: courtesy by the Authors).

5. Positive Effects for oversize vehicles

The last advantage that was listed in reference to the Two-Geometry Roundabouts was that they are more easily passable even by large OSOW (OverSized/OverWeight vehicles). In general, roundabouts are designed to slow traffic at the points of conflict, in order to improve safety and lessen crash severity. For example, in the United States, roundabouts are often specially designed with narrow lane widths. Therefore, a problem that arises is how to facilitate OSOW travel safely through the narrow lanes and curve rays in roundabouts. While there are several international studies on this topic (the presence of OSOW on roundabout intersections) the topic is still being investigated. To this point, the Two-Geometry Roundabouts have several advantages over the classic roundabouts. The peculiar geometry and in particular the width of the variable lane of the Two-Geometry Roundabouts actually assists the movements of longer vehicles. In support of this, Fig. 8 shows how oversize vehicles may manoeuvre through the Two-Geometry Roundabout. These trajectories were developed through CadTools, a freeware software designed for civil engineers who use AutoCAD. CadTools allows you to easily draw roads, cycle paths, pavement drainage, road signs, etc. as well as having a catalogue of vehicles that can be selected to check the turning manoeuvres. In the case shown in Fig. 8, 2 manoeuvres were verified: the manoeuvre of crossing the roundabout for a vehicle of 24 meters and the manoeuvre of turning left for a vehicle of 16 meters.

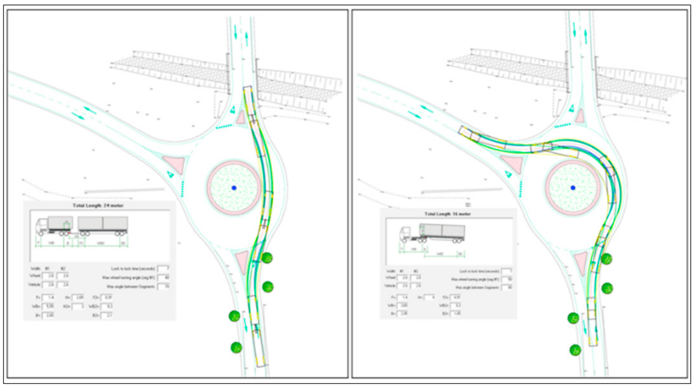

Fig. 8. Examples of turning manoeuvres in a Two-Geometry Roundabout on SS n.1 – Via Aurelia, Pisa, It (*Source*: courtesy by the Authors).

Fig. 8 shows that the Two-Geometry Roundabout was necessary in this case, as a Traditional Roundabout (single-lane or multi-lane) would have surely required more space to allow the manoeuvring of oversized vehicles. On the other hand, especially as regards the manoeuvre of crossing the roundabout by a 24-meter vehicle (Fig. 8, left side), the elliptical geometry of the Two-Geometry Roundabout allowed a good result. In fact, if a designer verified the same manoeuvre of the 24-meter vehicle on a Traditional Roundabout, he/she would get disappointing results and to reach the same level of efficiency it would take not only more construction space but also a greater economic burden.

6. Introduction to Estimation of Capacity of Two-Geometry Roundabout

It is also important to introduce one of the fundamental topics in the field of roundabout design, namely capacity estimation. This topic will be dealt with in detail in another report, however, it would be wrong not to submit anything in this regard.

The capacity of an entry into a roundabout can be determined through two different approaches: theoretical models, based on the "Gap-acceptance" theory and empirical models, obtained by regression on experimental data. In particular, the "Gap-acceptance" theory is of fundamental importance for the Two-Geometry Roundabout as there are different studies that estimate their parameters at the regional/national level. Therefore, according to the geography area, the corresponding parameters (if available) must also be used for the Two-Geometry Roundabouts. Regardless of this, the question is: "*Which capacity model should be used to calculate a Two-Geometry Roundabout?*" It is not easy to answer this question, however, is possible to affirm that the two most currently used methods for estimating the capacity of Two-Geometry Roundabout are: the German theoretical method of Brilon-Wu and the French empirical method of SETRA (Service d'Ètudes Techniques des Routes et Autoroutes).

7. Conclusion

The drawbacks of two-lane roundabouts presented an opportunity to develop a new type of design: the Two-Geometry Roundabout. The authors presented an innovative design, which has the following characteristics: no lane change (or at least as little as possible) inside the roundabout, slower driving speed through the roundabout, and advantages in the manoeuvres of oversized vehicles. Moreover, a Two-Geometry Roundabout requires less space than a Traditional Roundabout. Therefore, this paper concludes that they are highly promising for locations where space constraints are very restrictive and/or there are manoeuvring of heavy and long-size vehicles. These types of constraints often cannot allow the implementation of classic geometries. One of the few limitations of this research is the fact that there is not yet enough experimental data collected on Two-Geometry roundabouts to make a statistically robust comparison to Traditional Roundabouts. Nevertheless, during the last decade in Italy, a representative number of Two-Geometry Roundabouts were designed and built, achieving in each of these cases significant improvement goals, both in terms of road safety and traffic performance. Further and expected developments of this research topic could concern the collection and analysis of data on the real sample of Two-Geometry Roundabouts quoted above, in order to highlight road safety characteristics and investigate experimental aspects related to capacity.

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