Visibility, perception and roundabout safety

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Abstract

In Italy, over the past fifteen years, modern, or second generation roundabouts have become very popular. On these roundabouts, entering vehicles must yield to vehicles already within the circle. This modern design provides for much higher capacity of operation. Although first implemented in the UK in the 1960s, it took twenty years for the second generation to begin to spread to other European countries. Between 1987 and 2002, in particular, Germany, France and Switzerland conducted research that led to standards techniques that, along with English ones, now comprise the major technical references. The causes of the delay in implementation are uncertain and the subject of much speculation. The United States has only recently begun implementation, as it was not until the 1998 version did a chapter on roundabouts appear in the Highway Capacity Manual (developed further in the 2000 edition). In Italy, the first standards were proposed for the 1993 New Road Code, but it was not until 2004 that the standards were passed through national legislation. However, these codes are approximate and inadequate, and lack elementary technical foundations (see for instance Art. 4.5 of D.M. 19/04/2006, no.1699). A quick calculation for 4 legs and 60 meters diameter is sufficient to demonstrate its failure and infeasibility. The design of a roundabout, like that of any other road element, should be based on principles of safety, and should be deployed in a systemic context that combines geometric characteristics to meet capacity requirements – the perception of road space is also important. When designing a roundabout, the engineer should consider simultaneously both safety factors and capacity. But in addition to using geometric standards, formulas and models, aspects of perception and visual appeal should be considered.

Keywords: roundabout design and safety, roundabout visual perception, inner island visual appeal and appraisal, solid angle.

WIT Transactions on The Built Environment, Vol 107, © 2009 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/UT090511

1 Introduction

Modern roundabouts are divided into three types based on the size, D of the diameter of the circle inscribed: mini roundabouts, with D less than 22 m; compact roundabouts, with D between 22 and 40 m; and major roundabouts, where D is greater than 40 meters. Mini roundabouts are typically found in residential areas or city centres. Compact roundabouts are suitable for peripheral areas. Large roundabouts are designed for higher speed roads, particularly for bypass or ring roads in suburban areas [1].

This paper deals with only compact and large roundabouts, whereas mini-roundabouts are typically designed primarily in order to improve road space and perception. When designing a roundabout, it is important to consider human factors. Rather than simply relying on mathematical formulas or codes, the designer should consider driving behaviour. Research should consider statistical correlations experimentally observed operational factors. As with all types of intersections, including roundabouts, practical experience indicates four basic safety and operational considerations, namely: clarity, visibility, comprehensibility and space for design vehicles [2]. These four basic requirements are listed in the first column of Table 1, with corresponding design elements listed in column two.

Table 1: Basic requirements of a safe intersection design [2].

Requirements of Safe Intersection Design	*Range of Design Elements*
1) Clarity of the situation for approaching drivers	Geometric layout; lateral and forward visibility
2) Visibility between road users	Lateral and forward visibility
3) Comprehensibility of traffic operations	Geometric layout; pedestrians; cyclists; signs and lighting
4) Space for the largest permitted vehicles	Geometric layout

The degree of traffic safety for new construction or reconstruction is dependent on a design approach which is, in turn based on fundamental knowledge of relations between different geometries, ancillary components and aspects of environment, scale, and the behaviour of drivers. A well-designed roundabout offers the real possibility of reducing the rate of crashes at an intersection as long as the designer considers the rules and interactions among the main elements of geometry that most affect safety. By contrast, a roundabout that does not meet standards and conformity among geometric elements can likely increase the probability of crashes and their severity. The designer must, at the same time, be aware of the objective of improving safety even in the preliminary design phase. Designs which are gradually refined and detailed in subsequent phases remain generally influenced by the original concept. When preparing the design, it is well advised to consider changes that may be

introduced to improve aesthetics which may adversely affect safety. Good roundabout design also considers traffic scenarios for the present condition and future planning horizon. Further, as the roundabout is in place 24 hours a day, the designer should consider safe performance for a variety of traffic flows and speeds. Ultimately, the design of a roundabout should be considered as a holistic activity, as its performance as a system is not necessarily the same as what may be predicted as the sum of the performance of its parts.

2 Elements of greater safety of roundabouts

Today, we can benefit from the experience of several European countries, including the results of research conducted on driver behaviour, various geometries and different traffic conditions at roundabouts. The greater degree of safety generally attributed to roundabouts is supported by numerous studies where statistics are related to a number of design factors, operational aspects and driver behaviour, or human factors, often in mutual interaction.

2.1 Design factors

At a modern roundabout, deflection trajectories force drivers to reduce their speed, leading to both lower probability of severity of crashes. The actual deflection trajectories of vehicles are thus the main factors of the geometry of a roundabout which directly affect the safety of movement of the roundabout. As a result of deflection on a trajectory curve the vehicle is subject to heel because of centrifugal force and the driver is consequently led to combat it by reducing the speed at the same time you have a greater attention to driving. Decreases so the probability of a crash because the seriousness of a possible collision.

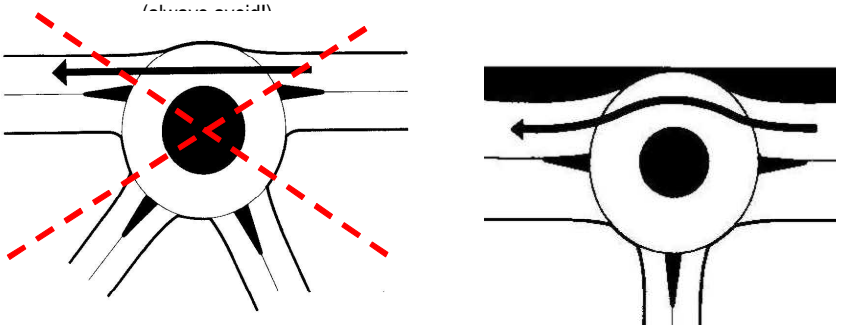

Figure 1: (a): Wrong, the failure deflection trajectory is always to be discarded for the high probability of a crash-induced. (b): Appropriate, provided that the correction of the geometry of the branches is able to induce an effective deflection on faster trajectories.

Geometry should be provided to reduce the likelihood of vehicles passing straight through the roundabout. Inadequate deflection trajectory angle between the legs of contiguous approaches is particularly problematic for three-leg intersections where an existing T intersection has been converted to roundabout (Figure 1a). It is sometimes difficult, if not impossible due to the presence of local space constraints, to center the central island on the intersection of the three approach axes. In such cases we must intervene if possible so as to affect the trajectories of the vehicles in their approach by imposing deflection (Figure 1b). It is in fact the geometry that determines the maximum speed of a vehicle along the roundabout. That is, in the absence of traffic and without stopping to enter, the individual vehicle may tend to cross the roundabout following the path of least resistance (straight through, if possible).

Verification of deflection trajectory for each approach is mandatory for large roundabouts and should be performed for compact roundabouts as well, according to various technical literature. Figure 2 shows the pattern of verification suggested by Italian CNR in its guidelines report [3]. This figure also shows recommended maximum radii of curvature for deflection trajectories, to reduce speeds and assist in enforcing yield on entry to vehicles already within the roundabout.

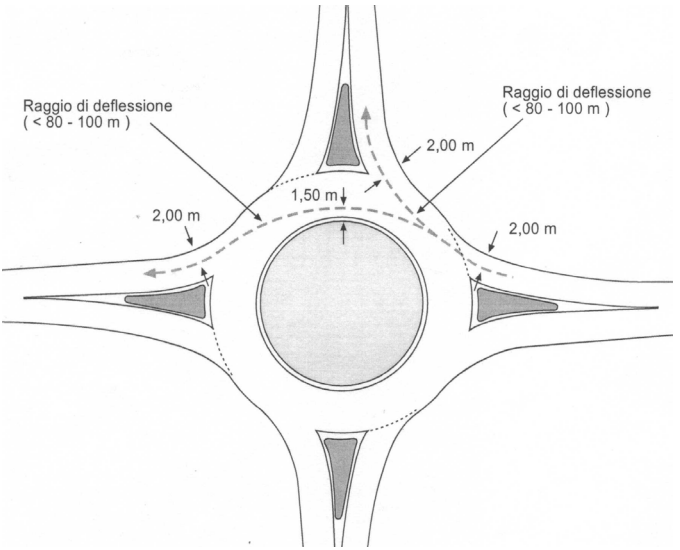

Figure 2: Verification of deflection for construction of paths faster vehicles in roundabout [3].

The relatively low speeds of the roundabout help make driving easier and less risky. The crash rates found in Table 2 attest to this effect. Traffic splitter islands and barriers reduce the number of conflict points in the modern roundabout. For example, while conventional T intersections have 9 conflict points, four-leg roundabouts have only 8, and while 3 approach roundabouts have only 6.

2.2 Operational factors

The one-way movement inside the ring, the obligation to yield for entering vehicles, and the small number of conflict points provides ease of operation and control for all drivers.

A driver entering the roundabout must look only to the left for an acceptable gap inside the circle. Weaving manoeuvres occur only if there is a very large roundabouts, over 100 m in diameter with multiple lanes (2 or 3), and this is simplified by the relatively lower speeds. However, even with two lanes, diameters of 50 to 70 meters have distances between successive approaches which are not suited for proper weaving manoeuvres.

2.3 Behavioural factors

All drivers entering a roundabout must yield and change trajectories. Therefore, they are more likely to reduce speed and pay more attention to their surroundings (e.g., pedestrians) that at conventional intersections. When empowered by the green light at a conventional intersection, or when trying to beat the yellow, a driver is much more likely to push his or her limits of attention and ability to avoid pedestrians, bicyclists or other vehicles.

Table 2: Annual crash rates, i.e. crashes per million entering vehicles, recorded at Norwegian intersections [4].

Intersection Type	*Crash rate per year*
Ordinary four-way intersections	0.24
Signalized intersections	0.16
Roundabouts	0.04

2.4 Before and after studies

Many before and after studies have been conducted for locations where conventional intersections were converted to modern roundabouts. Here we refer only to some of the results for Europe and the United States [5].

- Denmark: a study for both urban and suburban locations noted: a reduction of 85% of crashes with injuries; the average number of injuries per crash decreased from 2.1 to 1.25; the average percentage of serious and fatal crashes decreased from 9.2% (7.8%) for 2 (and 3) phase signals to 4.2% for two-lane roundabouts.
- France: statistical data collected at 83 sites indicated: a 78% reduction of crashes with injuries; an 82% reduction of crashes with fatalities.
- Germany: research conducted by the University of Bochum [6] on 32 cases of conversion of stop controlled intersection to roundabout indicated: 40% lower frequency of crashes; 90% fewer serious injury crashes; 88% fewer minor injury crashes; 87% fewer property damage only crashes.

- Netherlands: a 1990 study conducted by SWOV, a Dutch public research institute reported the results of a survey of 201 roundabouts replacing intersections as follows: 47% fewer crashes in general; 71% fewer fatal crashes.
- United States: Table 3 shows some results from the United States where a before-and-after study of roundabout conversions has been developed using the empirical Bayes method to control for regression-to the-mean and other trends in crash occurrence [7].

Table 3: Changes in crash rates for U.S. at-grade intersections in urban, suburban and suburban locations after their transformation to roundabout [5].

Intersection Type	*Change in Total Crashes*	*Change in Severe Injury Crashes*
All four-way intersections	- 35%	- 76%
Two-Way Stop Controlled Urban	- 72%	- 87%
Two-Way Stop Controlled Suburban	- 32%	- 71%
Two-Way Stop Controlled Rural	- 29%	- 81%

2.5 Cross sectional studies

Many cross sectional studies have been conducted to analyze the probability of crashes and crash rates at uncontrolled or signalized intersections and roundabouts. Most reach the conclusion that roundabouts are by far the safest. The following summarizes some of the experimental evidence.

- Norway: a 1987 study found that the crash rate at roundabouts was 0.04 as compared to 0.16 - four times as much - at intersections controlled by traffic signals [4].
- Australia: a search conducted in the State of Victoria in the 1980s found a rate of 0.57 serious crashes per year for the roundabout, as compared to a value of 0.90 per year for signalized intersections.

3 Aspects of vision and recognition

An important aspect of roundabout design is the provision of adequate sight distance for all approaches. Another important aspect of visibility is the ability of drivers to perceive or recognize the main canalization features of the roundabout – the central island, which may contain aesthetic items such as a flower bed – and approach canalization due to the splitter and raised islands.

3.1 Visibility

Clear sight distance, as provided by obstacle free areas, is important to the safety of any roadway design element. Visibility for roundabouts require that entering (yielding) drivers be able to see vehicles with which may come into conflict, both on the right (vehicles that may have slowed or vehicles that may enter next) and left (to which the entering vehicle must yield). The U.K. Standards [8] define an area to be free from obstructions as seen in Figure 3 (figure is for left side drive). This definition refers to a point located in the middle of the entrance lane at a distance 15 meters before the yield line from which clear sight distance should be provided:

a) backwards to the previous entrance (along a tangent to the outside of the circulation road), or, for large roundabouts, 50 meters along the centreline circumference of the circulation road, whichever is less;
b) forward to the next exit (along a tangent to the outside of the circulation road), or, for large roundabouts, 50 meters along the circumference of the circulation road, whichever is less.

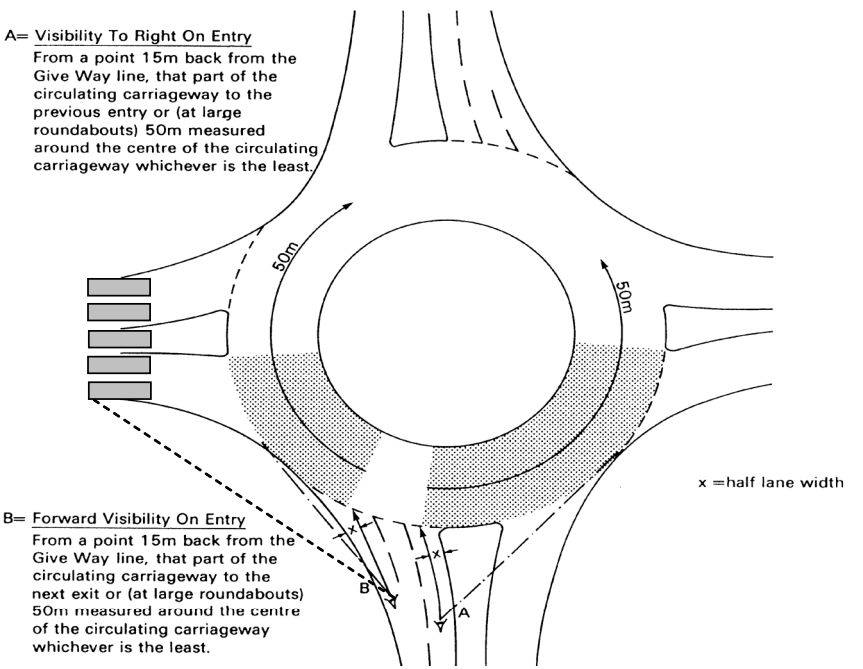

Figure 3: Construction of roundabout sight distance areas (left-lane drive) [8].

It should also be noted that in case of pedestrian crossings, the forward sight distance should be measured to the furthest point of the nearside pedestrian

crossing, rather than to the point of entrance tangency (see Figure 3). Moreover, it should be noted that sight distance is not required beyond of the central island, nor is it necessarily even preferred.

At roundabouts, as indeed for any other intersection at grade, grades should be limited to ± 2% and in exceptional cases up to ± 4%, but never beyond. At these low values, it is generally unnecessary to audit longitudinal sight distance. However, rules for audit have been codified worldwide in standard guidelines for the construction of roads and intersections.

3.2 Recognition and perception

The "legibility" of a roundabout can be defined by a set of unmistakable and peculiar factors that are visible and contribute to the driver's recognition of the intersection. Pertinent and specific regulations on legibility and recognition can be found in recent standard provisions such as:

- paragraph B, point 9 "Visibility Distance" and point 10 "Perceptions of the Central Island" of the Technical Standards of Switzerland SN640263, "Roundabouts" [9];
- paragraph 9.1.1 "Perception" and paragraph 9.1.3 "Visibility" of French Standards CERTU, "Guide to Urban Roundabouts" [10].

In modern roundabouts, where traffic yields on entry, the central island may be furnished with elements of significant size such as trees, large bushes, or artistic features which are generally considered obstructions to sight distance for safe movement.

However, a driver entering the roundabout in fact should be concentrating his or her attention to the left – this is the direction that needs sight distance – not straight through the roundabout. In particular, the standard cited in Switzerland SN640263 recommends that the central island have trees or other objects that prevent the entering driver from seeing beyond it [9], thus distracting his or her attention from what is more important (vehicles to his left, in front, pedestrians, etc.). A driver within the roundabout should then turn his or her attention to what is the front and to the right.

In neither of these cases should the driver focus attention on the other side of the roundabout. The details of the roundabout and a distinctive central island are therefore very important for perception and recognition at a distance from the intersection. Therefore, the central island, if designed and lit in a particularly distinctive manner, may contribute, in combination with other geometric factors to the safe operation of the intersection and to the greater moderation of speed on approach.

In Europe, the central island has also found use as a place of honour for statues and other honoraria, in addition to attractive sculptures and works of art and gardening, taking advantage of otherwise wasted space.

4 Central islands

For the central island of a modern roundabout, implementation of technical standards such as those referenced above allow for many types of treatments. We propose to generalize these into the following three basic types of development:

a) reduced development
b) compressed development
c) streamlined or slender development

For each of these three types we list below the main dimensional characteristics and features and provide some particular suggestions for sizing and design.

4.1 Reduced development

"Reduced" means a development of contained height, *Hp*, and spread on the surface of the entire central island (Figure 4). Examples could include a hill with a simple lawn, or a lawn embellished with low shrubs (cotoneaster, myrtle, lavender, etc.) or seasonal flowers (tulips, pansies, etc.). The practical limit for *Hp* should be stated as follows:

$$Hp \leq 1.25 \text{ m} \tag{1}$$

Figure 4 shows an example of the transverse section of a central island built as reduced development type.

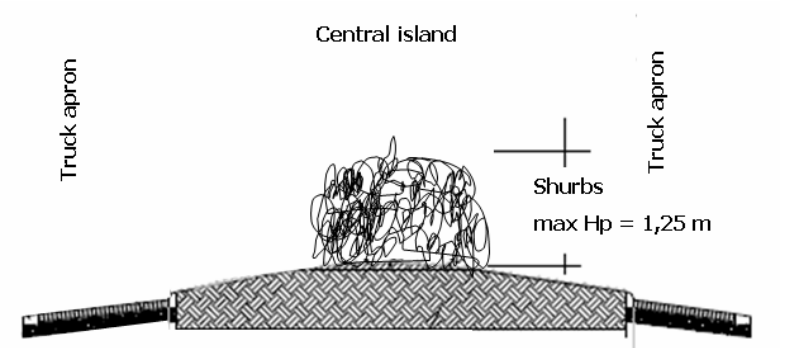

Figure 4: Section outline of a typical "reduced development" central island.

4.2 Compressed development

Figure 5 shows a sample section of compressed development – that is to say development of a certain height but stocky form, which can occupy in part or in full the space of the island. If bushes are used, they should exceed 1.25 m (4 feet) in height. If trees are used, they should have long hanging branches, such as Cycas or Phoenix Canariensis palms. It is defined "squat" any object that can be inscribed into a box with a ratio of major base *b* to height *h* less than 1.5 (e.g., a

sculpture having its major horizontal dimension not too different from its vertical one). Therefore, a compressed development requires:

$$\frac{Bm}{Hp} \geq 1.5 \tag{2}$$

$$Hp > 1.25 \text{ m} \tag{3}$$

where both condition (2) and condition (3) should be equally satisfied. A decorative concrete curb with a height of up to 40-50 cm above the truck apron is often used to protect the central island furniture.

4.3 Slender development

Island treatments of the slender type are designed with a prevalent central element - for example, a tree canopy, a tall thin sculpture, an attractive pole lighting, or even a totem advertising - usually positioned at the centre of the central island.

In order to define a standard, we may suggest a circumscribed box to the inner apparels, trees and/or statues, showing its major base *Bm* length 5 to 7 times less than the central island diameter *Dc* and with a height *Hs* great or equal to 3 to 4 times of the previous base *Bm*:

$$\lambda Bm \leq Dc \tag{4}$$

$$\alpha Bm \leq Hs \tag{5}$$

where $\lambda = 5 \div 7$ and $\alpha = 3 \div 4$. Again, we may use a protective curb around the island of 40 to 50 centimetres in height above the apron. As an example of a typical slender development, Figure 6 shows the obelisk sculptured by the famous Belgian artist Jean-Michel Folon, which is placed at the centre of a roundabout located in Pietrasanta, Lucca, Italy.

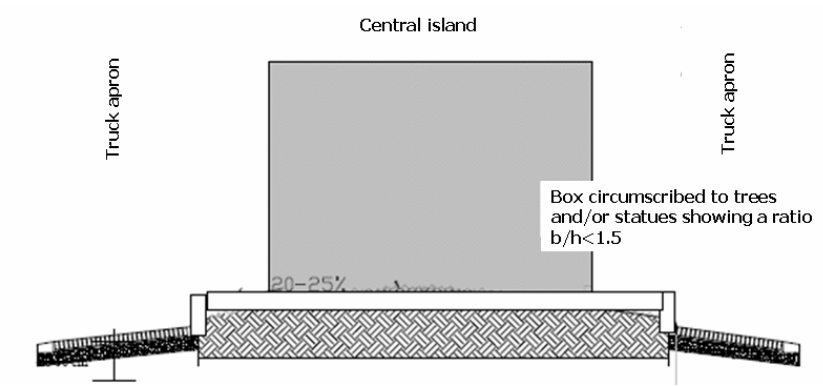

Figure 5: Section outline of a “compressed development" central island.

4.4 Toward a visual appraisal

The term of “visual intrusion” is usually referred to some extents at the whole effect that a facility brought about visual quality of its surrounding landscape. Nevertheless, such a definition not implies a negative way of judgement. There

are cases where the insertion of a new element has a visual decorative effect and therefore it is positive. The main problem to evaluate visual intrusion lies in the deeply individual judgement related to any consideration about the matter.

Any case, it is possible to derive a measure of the visual obstruction of a given object from a given viewpoint distance by the value of its related solid angle.

The solid angle is that fraction of the surface of a sphere that a particular object covers, as seen by an observer at the sphere's centre. To people acquainted with ordinary angles the concept of solid angle is a bit mysterious if not perplexing.

Figure 6: The Folon's obelisk in Pietrasanta (Lucca, Italy) is an example of the central island "slender" development.

This is due to the fact that an ordinary angle can be conceived of without reference to an arbitrary reference circle, but a solid angle cannot be properly understood without reference to an arbitrary sphere [11]. For a small region, or spherical surface, of area A the numerical value of the solid angle Ω is:

$$\Omega = A / r^2 \tag{6}$$

where r is the radius of the sphere. Although the solid angle has a dimensionless value, it is generally expressed in units of steradians (sr). The solid angle is function of direction. In order to evaluate the visual obstruction of a given central island development one may refers both to the minimum safe-stopping distance before the yield line [12] and the specific type of inner development outlined previously.

5 Conclusions

Reduction in the frequency and severity of crashes at roundabouts has been demonstrated by many studies, both for conversion of unsignalized and signalized intersections. But among the many factors involved in the design of a

modern roundabout, those relating to driver behavior have the greatest degree of impact on traffic safety. Proper geometric design is able to affect the deflection, hence the trajectories and speed of vehicles.

Factors related to visibility, perception and identification of road space also significantly affects road safety. While good visibility is required, it is most important for entering vehicles looking to the left and right, not through the central island. This allows beneficial use of the space in the central island whose features may assist drivers in recognizing the intersection type.

This last factor is important because to safely negotiate the roundabout the driver must clearly perceive in and understand the permitted maneuvers before reaching the intersection.

In order to quantify the visual percepyion degree of roundabouts, we have proposed a classification criteria based on the central island develompment and its related geometric references. Moreover, we have outlined the solid angle as a well-suited measure of how big or small such a development could be appraised for a driver looking from an approaching lane.

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