# TRAFFIC ENGINEERING SOLUTIONS FOR MINIMIZING DELAYS AND RISKS AT ROUNDABOUTS

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**Abstract:** Introduction of a roundabout is a proven method of minimizing delays and risks at an intersection simply due to the reduction in number of conflict points, implementation of give way rule, single directional circulation and reduced speed due to the lateral displacement. However, there arestill opportunities and desires for improvements in reducing the delay and increasing the safety at roundabouts. The safety risk and delay is significant when vehicular volume is high. Roundabout performance can degrade if precautions are not taken eitherduring the design or the operation phases. Therefore this study is focused on seeking traffic engineering solutions to minimize the delay and risk of accidents at roundabouts to be implemented at design and construction stages.

During the study, it was realized that a solution should be obtained through both literature reviews and data analysis. Therefore a comprehensive literature review was carried out on related sub topics. Crash and geometric data were collected for two normal roundabouts and analysed.

Increasing the diameter of the central island up to the required level specified by the guidelines, decreasing the approach curve radius, elevating the circulating carriageway with respect to the approach carriage by introducing a ramp for the entering vehicles are proposed for the roundabouts as traffic engineering solutions.

**Keywords:**Roundabouts, delays, road safety

## 1. Introduction

A roundabout is an intersection where a traffic control measure has been implemented to eliminate the congestion and improve the safety through space sharing while consuming a little more time than ata normal intersection. This includes not only the pavement area, but typically the adjacent sidewalks and pedestrian curb cut ramps, adjacent cycle lanes or cycle paths.

Normally, the practice would be to install a roundabout at an intersection where there is a higher delay to the minor road traffic and the safety risk is significant due to the increased traffic volume. However, it is a costly solution, reduces the efficiency of road users as it increases the waiting time and takes some time to implement. If the safety risk and the delay can be reduced in roundabouts by some other means, the life expectancy of road users can be extended which in turn saves a significant amount of money to the country. Thus the objective of this study is to find effective and efficient traffic engineering solutions to improve safety and reduce delays at roundabouts.

## 2. Methodology

This study is about finding general solutions or improvements that will help to improve the safety or reduce the delay at roundabouts.In order to achieve this objectivethe following path was identified. That is reviewing the related literature and conducting a case study and find out the general design and construction deficiencies and opportunities for further development. Therefore an extensive

literature survey was done to find out the existing problems, crash contributory factors and thereby possible improvements of roundabouts in general. In addition, two case studies were done for selected roundabouts. As the intention was to find out general improvements not the unique ones, only two roundabouts were analyzed because only one or two examples are normally enough to identify general design and construction weaknesses as they are similar in all. Then the crash data obtained from the Sri Lankan Police Accident Database for these two roundabouts were analyzed. Depending on the data analysis and literature survey, general improvements and recommendations are discussed and suggested.

## 3. Literature Review

Despite the good safety record, roundabout performance can be degraded if precautions are not taken either during the design or operation phase (Montella, 2007). Especially in countries where roundabout design is a relatively new concept, issues frequently arise that negatively influence the roundabout safety record. Therefore, additional information on the safety of roundabouts is extremely helpful for planners and designers in identifying existing deficiencies and in refining the design criteria currently being used. Information on crash contributory factors is an essential means of understanding why crashes occurred and how the occurrence of similar events may be prevented in the future(Montella, 2011).

### 3.1. Geometric Design

Overall, numerous contributory factors related to the road and environment deficiencies but not related to the road user or to the vehicle have been identified. The most important factors related to geometric design were the radius of deflection and the deviation angle. In existing roundabouts, the improvement of these factors might be quite expensive, but the crucial role of a moderate radius of deflection and a large deviation angle in the design of new roundabouts is stressed(Montella, 2011). When it comes to the geometric properties of a roundabout, the deviation angle at the entry affects the safety of the roundabout significantly. Low values of the deflection angle contribute to failures to give way, increased pass-through speeds, and underestimations of these speeds by conflicting parties in the subsequent approach on the right(Montella, 2011). A crash data analysis done by Montella in 2011 shows that, in single-lane roundabouts, there was a greater proportion of crashes at the entry (68% vs. 49%)(Montella, 2011). These figures bear witness how crucial this entry of a roundabout is to its safety. The most frequent crash types were the following: (1) angle at the entry (entering-circulating), (2) rear end at the entry, (3) rear-end at the exit, (4) hitting an obstacle in the carriageway at the exit, and (5) rear-end in the circulating roadway(Montella, 2011). The lateral displacement at the roundabout forces the driver to have a great importance for the speed of approaching cars to a roundabout. The speed reducing effect is large already at a 2 m deflection. At larger deflection the mean speed is on the same level, i.e. about 30–35 km/h(Christer Hyden, 2000)

The most common geometric design factors are (1) an excessive radius of deflection of the entering approach, (2) an excessively low angle of deviation of the entering approach, and (3) an excessive radius of deflection of the left approach. The radius of deflection of the entering approach was associated with angle and rear-ends crashes at entry. Too low angle of deviation of the entering approach and an excessive radius of deflection of the left approach were associated with angle crashes at entry. Furthermore, the combination of the radius of deflection and the angle of deflection of the entering approach was associated with angle crashes at entry(Montella, 2011). An excessively low angle of deviation of the entering approach is greatly associated with low inner circle diameter of a roundabout.

### 3.2. Markings and Signs

Many of the contributory factors are related to markings and signs, and these factors could be easily removed with low-cost safety measures. Furthermore, because of the association between the markings, signs, and geometric design contributory factors,Montella suggest that the improvement in markings and signs might also have a significant effect in the sites where geometric design deficiencies were identified as contributory factors(Montella, 2011). Montella in one of his research studies done in Italy from 2004 to 2009 including 15 urban roundabouts, shows that markings were a contributory factor in 142 crashes (51.8%), a major factor in 128 crashes (46.7%), and a minor factor in 63 crashes (23.0%). However, given the general rule of priority in the Highway Code,

drivers not seeing the yield sign, the yield line, and/or the yield symbol that are approaching the roundabout believe that they have priority over the drivers circulating in the roundabout. At the same time, drivers in the circulating roadway believe that they have priority over the drivers approaching from the right because they are running through a roundabout (Montella, 2011).

Parking allowed by road markings in the roundabout area, which is a design and traffic control mistake, was a contributory factor in 9 crashes. As in the case of the yield lines and symbols, if the yield signs in the approach is missing or is poorly visible, both the drivers approaching the roundabout and the drivers in the circulating roadway believe that they have priority. This stresses the continuous maintenance of the signs and markings are a significant factor in increasing the safety of the roundabouts (Montella, 2011).

### 3.3. Give Way Rule

In all roundabouts included in Mette Moller's studydone in 2008, car drivers entering or exiting the roundabout must yield to road users circulating in the roundabout. The large majority of the cyclists (88%, $n$ = 904) were aware of these traffic rules. However, 11% ($n$ = 114) were not. Of these 114 cyclists, 86 did not know the yield rule for drivers entering the roundabout. Nineteen did not know the rule regulating road users exiting the roundabout whereas nine cyclists did not know any of the relevant traffic rules. Sixty percent ($n$ = 68) of the cyclists who did not know the traffic rules were 45 years old or older. No association between gender and knowledge about traffic rules was found. Forty-seven percentage ($n$ = 54) of the cyclists who did not know the relevant traffic rules had a drivers license and drove a car on a regular basis (Mette Moller, 2008). This information stresses the idea of reinforcing the awareness of the road users about the roundabout rules by any mean. Observations of interactions between road-users showed that over 40% of the bicyclists entering the roundabout did not yield to circulating cars, while a great majority of entering drivers yielded to circulating bicyclists.

### 3.4. Cyclists

Andras Varhelyi(2000) in one of his studies reveals that a particular roundabout had a relatively large diameter (18 m) already from the beginning as a provisional roundabout. When it was rebuilt into a permanent roundabout the inner-diameter was increased to 24 m. After the permanent roundabout replaced the provisional one the risk for car drivers decreased while the risk for vulnerable road-users increased. This change can be a result of the increased inner-diameter which makes it more difficult for bicyclists to pass the roundabout. Behavior observations revealed that almost every third bicyclist had an-from a safety point of view-incorrect and inappropriate route choice through the roundabout (Christer Hyden, 2000).

Stijn Daniels in one of his studies revealed that the results of a crash data analysis showed that vulnerable road users (moped riders, motorcyclists, bicyclists and pedestrians) are more frequently than expected involved in crashes at roundabouts. Roundabouts with cycle lanes close to the roadway were clearly performing worse than roundabouts with off-road cycle paths. The crash severity is strongly dependent of the types of road users involved. Pedestrians, bicyclists, moped riders and motorcyclists have a higher probability of getting seriously injured in a crash. Bicyclists represent almost the half of all the killed or seriously injured in multiple-vehicle collisions at the investigated roundabouts (Stijn Daniels, 2010)

## 4. Data Collection

### 4.1. Boralesgamuwa Roundabout

- **Crash Data**

Crash data for Boralesgamuwa roundabout for the year 2012 were collected from accident database of Sri Lankan Police Department. It is a detailed set of data describing all the aspects of an accident taking into account all the necessary details. Among the many variables, crash data related to node number 662904, which is the Boralesgamuwa roundabout, was filtered for analysis. As this is a general study of all the roundabouts which is not specifically looking at this particular roundabout, only the set of data belonging to the most recent one year was considered. A comparison done with the accident data of other years showed that the basic set of information derived is similar.

Therefore accident data related to the most recent year were analyzed to achieve the purpose.

- **Geometric Data**

The site was inspected by a set of traffic and safety engineering professionals and some of the crash contributory factors were identified based on site inspection and rigorous analyses. Relevant geometric data were measured.
Inner circle diameter = 2.44m
Outer circle diameter = 17.68m
Average entry width = 9.75m

- Field Data by Inspection
  - ✓ An approach curve radius could be rarely seen in some lanes
  - ✓ As the inner circle diameter is very small, the deflection angle for the entering vehicles is negligible which in turn encouraged them to go through the roundabout without reducing their speed when it is not congested
  - ✓ There was no guard rail provided to separate the pedestrian walkway and the circulatingcarriage way of the roundabout at the corners
  - ✓ There were multi axle heavy vehicles using the roundabout frequently in the mornings

## 4.2. Pepiliyana Roundabout

- **Crash Data**
  Similar to the previous roundabout

- **Geometric Data**
  The site was inspected by a set of traffic and safety engineering professionals and some of the crash contributory factors were identified based on site inspection and rigorous analyses. Relevant geometric data were measured. Inner circle diameter = 3.6m Outer circle diameter = 26.92m Average entry width = 8m

- **Field Data by Inspection**
  - ✓ As the circulating carriage width is high, multiple vehicles try to travel within it at the same time
  - ✓ The others are similar to the previous roundabout

# 5. Analysis

## 5.1. BoralesgamuwaRoundabout

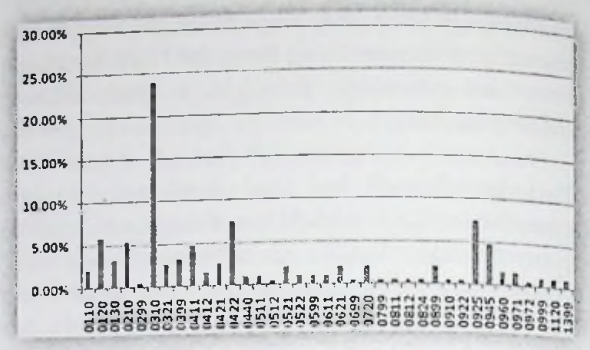


**Figure 1:**Accident percentage Vs Collision type in 2012

Majority of the accidents are of type 0310 which is 'Rear-end crash hitting a vehicle in position for going straight ahead' of which the percentage is about 24% and the other two significant types of accidents are 0422 which is 'Shifting lane or merging to the left' and 0925 which is 'With pedestrian entering the road section from the left sidewalk, shoulder etc.' and both with a percentage of 7%.

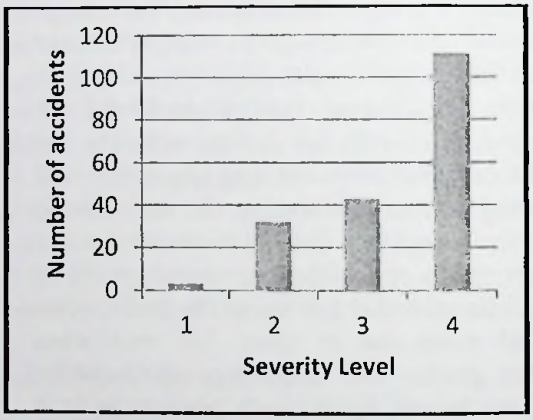


**Figure 2:** Number of Accidents Vs Highest Severity
1 - Fatal
2 - Grievous
3 - Non grievous
4 - Damage only

According to the Police crash data majority of the crashes (59%) are 'damage only' type, and only a few numbers of fatal or other severe types of accidents can be seen. It consists of several sub contributing factors. They will be described later in detail.

### 5.2. Pepiliyana Roundabout

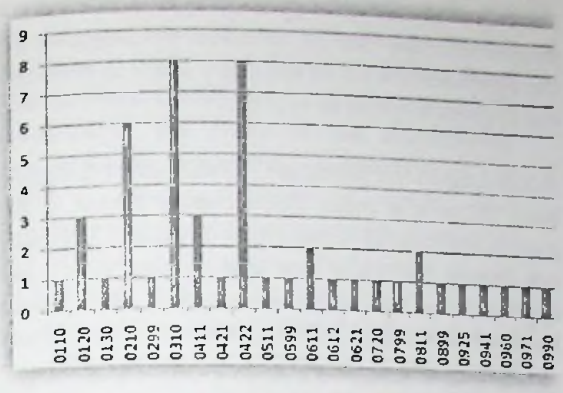


Figure 3:Accidents Vs Collision Type in year 2012

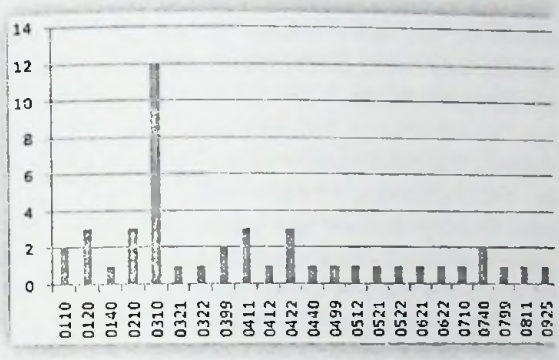


Figure 3:Accidents Vs Collision Type 2011

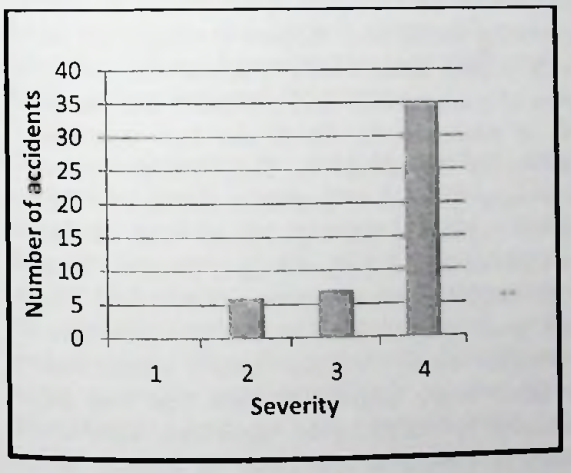


Figure 4:Accidents Vs Severity

## 6. Discussion

The new concept of roundaboutsis much more complex than the previously used version of its which was known as the traffic circles. This complexity occurs due to the advanced geometric features considered during the design stage. As far as geometric features of roundabouts are concerned, according to the literature, the most important factors related to geometric design were the radius of deflection and the deviation angle. Low values of the deflection angle contribute to failures to give way, increased pass-through speeds, and underestimations of these speeds by conflicting parties in the subsequent approach on the right. Modern roundabout design places a high priority on speed control through geometric features such as deflection at the entry, limited curve radius to naturally slow down all movements and reduce gap length required for entering vehicles.

Literature reviews and crash data analysis bear witness on how important the entry point of the roundabout is with respect to its safety. When referring to literature and the crash data analysis, we can realize a certain association in between design deficiencies at the entry of the roundabout and the collision type which is 0310 according to the Sri Lankan police accident data base (Rear-end crash type). Through literature, it can be observed that the radius of deflection at the entering approach was associated with angle and rear-end crashes at entry. A too low angle of deviation of the entering approach and an excessive radius of deflection of the left approach were associated with angle crashes at entry and an excessively low angle of deviation of the entering approach is greatly associated with low inner circle diameter of a roundabout. When the deflection of the approaching vehicles insisted by the central island is inadequate, the through moving vehicles and the right turning vehicles are encouraged not to reduce their speeds and hence they try to move through at the same speed or at a slightly less speed which is not enough from a safety point of view. Although there is a circulating vehicle in the circulating path, the approaching vehicles are reluctant to reduce their speeds and try to intervene the circulating carriage way where they wait for the last few seconds to decide whether to stop for the circulating vehicle or interfere. At this point, it can develop many conflicting movements which at times could result in an entry-angle type crash. On the contrary when the approaching vehicles decide during the last few seconds, to avoid the conflict, at most times there is a big probability to take a harsh action which will cause trouble to the vehicle following in the approach lane. In the case that the particular following vehicle is unable to avoid conflict, this would result with an entry-rear end type crash. The other reason that can increase the number of this type of

crashes is the unexpected interference of the pedestrians in the approach lanes. It could be observed during the site inspection that pedestrians are trying to cross the road near the entry point of the roundabout which is the shortest path to move to the other side without using the pedestrian crossing which is a bit away from the entry point and thus at the beginning of the approach lane. This is because there is no physical separation between entry of the approach lane and circulating carriageway with the pedestrian walk way. If it is possible to have a guard rail which acts as the separation mentioned above, which runs up to the pedestrian crossing to avoid pedestrian interference, the number of entry-rear end type crashes can be reduced.

When the circulating speed is less, the entering vehicles need only a small gap to enter which they can find at most times and hence the efficiency goes up and vice versa. When the inner circle diameter is high, vehicles tend to travel at higher speeds as the required centripetal force is low and vice versa. Therefore the circulating speed can be lowered by lowering the inner circle diameter. However, it on the other hand reduces the deflection at the entry which would again result in increased safety risk as entering vehicles tend to merge at the same approaching speed (which is a higher speed) and do not give way or yield as they are reluctant to reduce their speed without any definite reason. For example, in the two roundabouts that were studied to collect data, it could be observed that the vehicles trying to travel in the same speed as they approach, leads to conflicts. Therefore, the best solution is to maintain the inner circle diameter at an acceptable range. 'Suggesting an acceptable range of centre island diameter for roundabouts in urban areas in Sri Lanka' can be identified as a research gap where several researches can come up with a solution for this. Until then, it can be recommended to stick to the center island diameters specified by the 'Austroads: Part 6: Guide to Traffic Engineering Practice' which is used by the Road Development Authority of Sri Lanka as the design standards. More over it is essential to comply with the design standards used by the Sri Lankan government. The specified centre island diameter range is 5 to 8 meters for the local street roundabouts.

When referring to the field data acquired from roundabouts, it could be clearly seen that the approach curve is not at all enough to encourage drivers to slow down their speeds to the required safe level (not enough radius been provided). This can be avoided by improving the approach radius of the entry lanes to reduce the approach speed of vehicles.

According to the literature, markings and signs have become a major contributory factor in a significantly large amount of crashes. Drivers not seeing the yield line and symbol that are approaching the roundabout think that they have priority over the circulating drivers and circulating drivers think they have the priority as usual and hence this leads to a conflict. These contributory factors can easily be removed by low cost safety measures and continuous improvement and maintenance of markings and signs which might also have a significant effect at the sites where geometric design deficiencies were contributory factors because of their association.

Among the contributory factors for the crashes at roundabouts, the most significant contributory factors are associated with the 'give way rule'. After a continuous observation of the roundabouts for a few minutes while doing the field data collection, it was noted that majority of the vehicles do not follow the 'right hand rule' of the roundabout which is to give priority for the circulating vehicles. Because of this reason, it reduces the speed of the circulating traffic and induces a congestion of traffic in peak times which in turn increases the delay at roundabouts and increases the safety risk at roundabouts. There are two possible reasons for this problem. They are the poor awareness (proved in literature survey) of the drivers regarding the 'right hand rule' of the roundabout and not practising it properly due to the negative encouragement induced by the poor geometric design features like excessive approach curve radius and insufficient deviation entry angle. The first one can be overcome by enforcing the 'right hand rule' on minds of people at the stage of issuing the license through proper practice and study (written test – Although now it is included in the written test, more emphasis should be given to this rule. The literature shows to what extent drivers lacked the awareness about this rule in countries where written tests are conducted when issuing licence). The general awareness about this rule can be increased in the public through advertisements on mass media. The drivers can be compelled to comply with the rule by the law enforcement through the Police Department.

The other reason has a connection with the entry of the roundabout. All the geometric properties and markings and signs collaboratively contribute to an increased rate of crashes at the entry of the roundabout. Improving the geometric properties is an expensive solution where it needs land acquisition and some legal measures associated with it. So it is more likely not to be implemented soon. Therefore it is recommended to stress the improvement of geometric design features in the design standards. On the other hand we can suggest a solution for this problem which will not incur a lot of money and would not take much time while providing a solution which roundabouts have at the entry. The suggestion is to elevate the level of the circulating carriageway with respect to the level of the entry and exit lanes and introducing a sharp slope at the entry to the circulating carriageway and a smooth slope at the exit of the carriage way. The ramp at the entry of the roundabout will make every entering vehicle reduce its speed to a minimum and together with the give way rule; the vehicles will stop at the entry before entering to the circulating lane. This will compel all the road users to practice the 'give way rule' and hence will reduce the safety risk by eliminating one of the main contributory factors for the conflicts at roundabouts. As the vehicles exiting the roundabout, the smooth slope will make sure they will not be undergoing any additional delays due to the level difference.

The crash severity is very high when the vulnerable road users are involved. The literature depicts the increased inner circle diameter as one of the major contributory factors that affects vulnerable road users who are cyclists, pedestrians, motorcyclists and moped riders. When the inner circle diameter is large, it makes cyclists difficult to pass the roundabout which in turn compels them to make incorrect and inappropriate route choice through the roundabout. This becomes a reason for the conflicts with vulnerable road users. This can be avoided by maintaining the inner circle diameter within an acceptable range which is not too large and not too small. This range can be different in urban environment and rural environment. Safety performance of roundabouts with cycle lanes near the roadway was worse than the roundabouts with off road cycle paths.

## 7. Recommendations

- Comply with the design standards to establish the center island diameter. In Sri Lankan context, the specified centre island diameter range is 5 to 8 meters for the local street roundabouts as per the 'Austroads: Part 6: Guide to Traffic Engineering Practice' which is used by the Road Development Authority of Sri Lanka as the design standards. 'Suggesting an acceptable range of centre island diameter for roundabouts in urban areas in Sri Lanka' is identified as a potential research study
- Improve the approach radius of entry lanes to reduce approach speeds of vehicles
- Establish a guard rail starting from the point at which there is a pedestrian crossing in the approach lane and which runs to the point at which there is a pedestrian crossing of the consecutive exit lane which covers the circulating carriageway as well preventing pedestrians entering the road
- Continuously improve and maintain markings and signs
- Improve the awareness of the 'right hand rule of roundabouts' in drivers at stage of issuing license and in general public through mass media
- Have an off road cycle path near the roundabouts where possible in order to reduce the safety risk
- Elevate the level of the circulating carriageway with respect to the level of the entry and exit lanes and introducing a sharp slope at the entry to the circulating carriageway and a smooth slope at the exit of the carriage way. This can be identified as a potential research study as well to find out whether this actually reduces the accidents or not by constructing one and observing it for a certain period of time

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