Improving Roundabout Design Quality in the US

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Abstract

Well-designed, modern roundabouts can offer numerous benefits over signalized intersections. Drivers, cyclists, pedestrians and other users can benefit from a safer and potentially prettier intersection, increased mobility with fewer delays, lower speeds, less pollution, less noise, and a change in priority where pedestrians have the right-of-way over vehicles.

For users to obtain the aforementioned benefits, roundabouts must be well designed with special emphasis on speed control and accommodation of design vehicles. Ensuring proper design of roundabouts is essential to their expansion and attainment of their benefits.

Yet recent press reports have highlighted significant increases in crashes when roundabouts replaced signalized intersections. This paper seeks to highlight the most common design issues that are degrading the potential benefits of roundabouts in the U.S. and what could be done to reduce the number of poorly designed roundabouts. Material for this paper is drawn from the Author's experiences designing roundabouts, undertaking formal and informal peer reviews, design reviews that predicted specific problems that unfortunately came true and 55 post-construction reviews of poorly designed and built roundabouts over a 37 years in four countries. This paper will briefly discuss basic design philosophy, identify the most common design issues and provide some ideas as to improve roundabout design quality.

INTRODUCTION

Following the construction of the first modern roundabouts in the U.S. (Florida and Nevada) in 1992, there has been an explosion in the number of engineers designing roundabouts. Unfortunately, many of them are designing roundabouts without training or the necessary understanding of roundabout design principles and guidance provided in the national roundabout guidelines[1, 2]. For instance, many engineers do not seem to know how to use truck templates or, in some cases, do not know of their existence or the many other components that go into a successful roundabout design. These problems are compounded by the trend by a growing number of local agencies to only hire local consultants. In addition, many permitting agencies lack the expertise and knowledge of basic roundabout design. Another concern is the trend of some consultants who used roundabout experts as sub consultants to prepare roundabout designs from, which they prepare the construction plans, then claim ownership of the roundabout design.

Poorly designed roundabouts often increase property damage and injury crashes and/or problems such as trucks running over curbs, vehicles running into curbs, reduced capacities because of higher than desirable vehicle speeds and damage to the landscaping, etc. For example, several roundabouts that replaced signalized intersections had crash increases of several hundred percent[3], another had 84[4] crashes in the first year, most of which are attributable to drivers speeding through the roundabouts and failing to yield.

It is important to note that roundabouts are a traffic control system and are successful because they restrict the free movement of vehicles, hence lowering their speeds. Good design that forces drivers to slow down is paramount otherwise public resistance to roundabouts increases.

Design quality needs to be emphasized and engineers must gain a better understanding of roundabout users, their behavior, competing design philosophies, various design elements and most important the roundabout design guidelines.

MOST COMMON DESIGN PROBLEMS

Based on 57 post construction reviews the most common problems are as follows:

- Increase in crashes.
- High vehicle speeds with radar shots recording school buses going through a small one-lane roundabout at 32 mph and other vehicles clocked at 38 mph.
- Trucks running over curb lines on the inside and outside of the roundabout, which in one case lead a company to threaten to leave the city because its products are being damaged when their trucks drove over multiple curbs to pass through two roundabouts.
- Certain vehicles unable to make certain movements.
- Many vehicles, mainly passenger cars, hitting a particular area of curb and gutter.
- Vehicles running over the central island at high speeds.

When the reviews were undertaken, problems other than those that imitated the review were found. These additional problems were:

- Center islands offset from the center causing a see-through effect.
- Poor lighting.
- Lack of crosswalks or crosswalks in the wrong locations.
- Splitter islands too narrow to store pedestrians safely.

- Curbs too high.
- Poor or wrong markings.
- Poor sign placement, incorrect or excessive number of signs.
- Lack of landscaping, which limits conspicuity of the roundabout.
- Poor construction.
- Truck aprons flush with the pavement or with minimal tapered curb that were an ineffective vehicle barrier.

Separate to the above review projects there are a number of roundabouts built with the inner lane painted out for future removal. In every observed case, numerous drivers simply drove over the paint and continued through the roundabout faster.

Many of the roundabout reviews undertaken by the author, resulted in complete redesign and reconstruction of the roundabouts. Unfortunately, in many cases nothing was done and the problems were simply allowed to continue with the hope that they will fade away.

Post Construction Problems

Evidence of problems at roundabouts is usually very obvious, vehicle debris, tires marks across landscaping, curbs or sidewalks, missing or damaged signs, damaged landscape plants and materials, damaged poles, and curbs continually being hit. All too often, no action is taken to determine if it is a recurring problem that needs attention. In one case, a relatively low volume, one lane roundabout, had 11 significant crashes, five of them involved vehicles hitting the exit curb and chipping it away. The author notified the developer and County, neither of whom were aware of a problem but did implement suggested changes.

How many people would take notice of multiple tire marks left by trucks running over a curb or a sidewalk? Who takes notice of a continual strip of rubber left on curbs or chips out of curbs where multiple vehicles have scrapped along, run over, or hit the curb? How many people complain when few drivers yield to them when crossing at a roundabout, especially the departure lane? What reference do people have that would enable them to understand that the reason drivers are not yielding to them is due to a lack of speed control in the basic roundabout design?

These are simple factors to observe. Yet most people just go on their way, some complain to their friends or family, or develop a dislike of roundabouts and become future opponents. Ideally, the responsible road authority should undertake an annual review, at least for the first couple of years to look for problems that could be corrected.

Post Construction Reviews

An important and simple method of improving design quality is undertake post construction reviews and include them as an integral part of a design process to check that the design is meeting expectations or to seek enhancements for future designs or construction. Yet, how many designers conduct post construction reviews or talk to users about their roundabout experiences?

Another important reason for post construction evaluation is to look for changes in traffic distribution and volume, especially when replacing a signalized intersection. For example, the roundabout in Clearwater Beach, Florida that replaced three signalized intersections enabled a massive increase in traffic onto Clearwater Beach Island that made it necessary to include metering signals to manage very high peak traffic volumes. Over the years the author has undertaken hundreds of field reviews that have helped develop incremental design refinements mostly to improve construction quality.

Post construction reviews should be augmented with post construction crash and volume data if possible, although it is usually hard to persuade clients to collect this after data when a roundabout is “working.” However, for some roundabouts it can be critical to highlight crash problems so they can be fixed.

Just because no one is complaining about our designs does not mean that they are functioning as the public and we expect.

Speed Control

The single most important design element and the least understood or complied with element of roundabout design is speed control, not just for the through movements, but all movements and for all users. The fastest path method[1,2] shows one method to measure the likely vehicle speeds. Unfortunately, too many designers do not use this or any method to check design speeds and as a result roundabouts with fastest paths of 30 to 60 mph are common, even for turn movements.

Fastest paths are one measure of measuring design speed. However, it is easy roundabout design tool to manipulate. Simply moving the inflection point between R1 and R2 or R2 and R3 up/down or sideways changes both radii and hence design speeds. An alternate method that cannot be manipulated and has proven effective in the field by the author for more than 30 years, is to use a fixed radius for R2 based on the AASHTO[7] recommendation for radius, velocity, co-efficient of friction and super-elevation with a 6-foot offset to show the actual vehicle path. These two circles are placed to touch inside and outside curbs, but it is only effective with the on-center roundabout designs. Field tests have shown this method is very accurate in controlling entry and exit speeds within a few miles per hour of the desirable limit.

The importance of speed control for pedestrians can be summarized as, “Where pedestrians are present, tighter exit curvature may be necessary to ensure sufficiently low speeds at the downstream pedestrian crossing[1].” The same statement is in the Kansas and Washington State Roundabout Design Manuals’ yet the Offset Left Alignment has almost a straight exit. When coupled with an 85th percentile acceleration rate of 6.9 ft/sec^2 measured exiting speeds[3] can be significantly higher than entry speeds providing more complex crossings for pedestrians who face low approach speeds and higher exit speeds.

A good example of the speed issue is shown in Tables 50 to 59[5]. These tables show that for the roundabouts in the study through-exit speeds was 18 to 37 MPH, with left turn exit speeds of 8 to 31 mph (Table 54). Second, Table 57 shows entry speeds varying from 18 to 35 mph. Tables 56 and 59 show that where vehicle speeds are controlled by the exit path radius, RA roundabouts, had a maximum exit speed of only 22 mph whereas OLA roundabouts had higher exit speeds.

However, when working on traffic calming projects it is usually the small number of 15 percentile drivers who travel the fastest that create the greatest concern, same at roundabouts. Although the likelihood of a crash is low, higher vehicle speeds, especially at the exit crosswalks are unsettling for pedestrians, especially visually impaired pedestrians as detailed in a study by Minnesota Department of Transportation[4].

Limiting vehicle speeds decreases the effort by drivers to brake, stop, wait and then accelerate back to the preceding speed and therefore increases a driver’s willingness to obey the law and yield to pedestrians[10].

Pedestrian studies[6] at several roundabout people with vision disabilities and found that; “The rate of utilization of yields was very high at this site, at 85.4%. This may be explained by slower speeds that result in an overall reduced level of ambient noise.” The radial alignment at this roundabout not only provides low speeds on the entry and exit, the slower speeds lower noise levels making it easier for a people with vision disabilities to select and use available gaps. This is an important concept that needs further consideration, as slower entry and exit speed seem to make roundabouts more accessible.

In its summary, Page 5[6] noted, “There remains concern over the accessibility of single-lane roundabouts with vehicle speeds higher than those observed at the data collection sites, with higher traffic volumes, and with a lower likelihood of drivers yielding to pedestrians.” The author designed the one-lane roundabouts included in this study based on the radial alignment method, which limited entry and exit speeds. Yet concern was expressed in the report about higher exit speeds. This should make roundabout designers and road authorities more careful about ensuring low entry and exit speeds in the initial design or it may be found that speed tables or other devices may have to be added to one lane roundabout that have “high” exit speeds at a future date.

Another study also found driver yield rates at roundabouts decreased as vehicle speeds increased[9].

Design speed also has a large impact on crashes because as speeds increase the time to take evasive action decreases therefore compliance with the NCHRP 672 Guidelines for speed control is essential with the fixed radius method of measuring R2 is recommended as it cannot be manipulated.

Figure 1 is a sample of fastest paths where the even many of the measured vehicle movements exceed NCHRP 672 recommendations with mostly almost straight movements. A separate check found that the radii where even higher than shown. Figure 2 shows a roundabout where curb extensions were added to all three approaches post construction to slow vehicles.

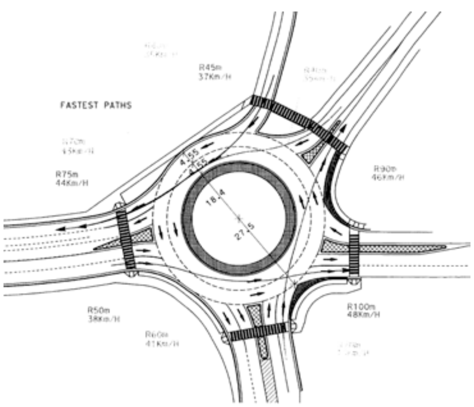

Figure 2 - Sample of fastest paths

Figure 1 - Not white curb extension added post construction to slow vehicles

Design Vehicle Templates

A basic element of roundabout design is the choice of the design vehicle. Therefore, before starting any roundabout design, it is necessary to determine the design vehicle for each movement as they can vary. Unfortunately, selection of a design vehicle is often overlooked or an inappropriate choice is made. Roundabouts designed without the use of design vehicle templates have resulted in unnecessary damage. Figure 3 shows large trucks turning right at a one-lane roundabout ran over the curb and sidewalk by more than eight feet in an area used by senior citizens for exercise.

In many cases, proposed roundabouts were submitted to the author for review with truck templates showing design vehicles running over curbs by varying amounts for different movements, sometimes up to eight feet. Figure 4 shows just one of many examples where truck templates submitted for review had trucks clearly running over the curb lines. Unfortunately it was built as shown despite review comments and trucks do in fact turn over the curb lines.

Figure 4 - Trucks running over sidewalks

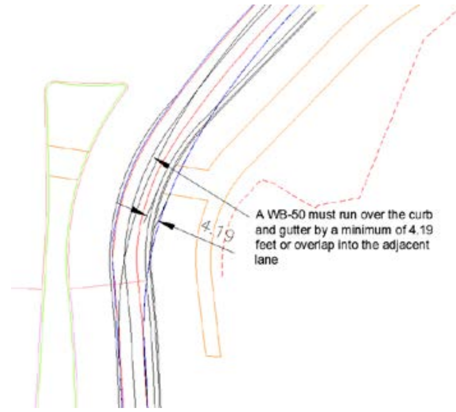

Figure 3 - Truck templates as submitted for review and constructed as shown

All roundabouts reviewed by the author based on the Offset Left Alignment had trucks running over the small, right side radius on the approaches, as shown in Figure 4 or the trucks were shown intruding into and taking most of the adjacent lane during their approach.

An important issue for designers is not to assume that drivers of large articulated vehicles can drive the exact path created by a Pline used to run truck templates. This is an impossible task and therefore roundabouts must be designed with clearance to both sides of the truck tire paths.

The use of AutoTURN, or other templates, is an essential element in roundabout design but they must be used by knowledgeable designers using smooth Plines with clearance from the tires to lane lines, the edge of gutter and curbs faces. Initial AutoTURN runs should concentrate on tires only with the design vehicle body added later to check sign placements, etc.

There is an interesting statement on Page 66[5]; “Review of the speed predictions for individual sites suggests that the current method for drawing through-movement paths is somewhat conservative, with drivers not cutting as straight a path as the method suggests.” If, as stated, drivers are not taking as straight a course as predicted then path overlap is less likely and may have been over emphasized.

“Y” Type Intersections

Most roundabouts at “Y” type intersections typically have very high through speeds as vehicles travel from the stem of the “Y’ to the right or from the top left of the “Y” to the bottom. These intersections are one of the hardest intersection types to design. Unfortunately, most designers of these roundabouts overlook the 25 mph speed limitation[1,2]. A round roundabout at these intersections is usually a poor choice unless extensive right-of-way is available; even then it must be larger than normal to ensure adequate deflection. An elliptical roundabout is the simplest to achieve the necessary speed control while minimizing right-of-way impact. Unfortunately NCHRP 672 does not mention this option.

Skewed Intersections

Again the mentality that roundabouts must be round again intrudes on good design at these intersections. The typical result of using a round roundabout is several right turn movements with fastest paths of 60 mph or more. Again shapes other than round can achieve the necessary speed recommendations. As for Y intersections above, NCHRP 672 does not mention the use of roundabout shapes other than round ones in this situation.

The author has used elliptical roundabouts for both Y and skewed intersections.

Right Turn Lanes

Some roundabouts require the use of right turn lanes. Standard right turn lanes can be well designed. However, often a short island is provided which pushes the yield/merge point just before the pedestrian crossing. These types of designs require the driver to look over his shoulder to see and select a gap in vehicles exiting from the roundabout that are almost behind them. Then as they move into a gap they can be confronted by a pedestrian immediately in front of them with almost no time to look for a pedestrian, let alone see, recognize, decide what to do and execute a maneuver to avoid a pedestrian in just a few feet, a difficult and risky task. Extending the right turn island to include the crosswalk is recommended to provide pedestrians with a safer crossing.

Other designs of a right turn slip lane include several types of bypass lanes, which can include a design that uses simple radii that directs the driver into an acceleration lane or a continuous lane. These designs encourage high-speed right turns, which is advantageous for the drivers but not pedestrians. The departure pedestrian crossings tend to be located well around the corner where a crossing pedestrian is hard for drivers to see, especially since drivers are looking over their shoulders to merge into the through lane, accelerating along an acceleration lane or turning onto a continuous lane. A compound curve can assist by minimizing vehicle speeds and a splitter island wider enough to accommodate a pedestrian refuge is highly desirable.

Often the splitter islands that create right turn slip lanes are smaller in size than recommended[1,2] for pedestrian refuges. Six feet is the recommended minimum from face of curb to face of curb, not six feet from lip of gutter to lip of gutter. Providing minimal space for pedestrians is difficult, but using a standard offset right turn lane exit past the pedestrian crossing close to 60 degrees can limit vehicle speeds and provide drivers with a reasonable chance of seeing approaching vehicles without turning their heads to the extreme where their vision can become blurred.

Off-center Placement of Roundabouts

Placement of a roundabout on center to the approach roads is the ideal location. Moving a roundabout off-center several issues:

- Extensive deflection in one direction and insufficient deflection in the other.
- See-through affects where drivers see across the truck apron and see the illusion of a continuation of the roadway. This condition is exacerbated at night because of highlight glare from opposing vehicles. An investigation of one roundabout found the central island was located to the left of the center line, with all central landscaping left of the center line, the overhead lighting was lower than normal because of night light restrictions. The result was a number of vehicles that drove over the central island, at significant speed as shown by the damage caused by the wheel marks, chips in the curb etc.

Off center design issue is a significant problem at Tee intersections where to save costs roundabouts are located off center such that the through leg of the Tee has an almost straight line through the roundabout while the other leg includes significant deflection. Whenever, roundabouts are moved off-center the approaches and departure lanes must be curved towards the center of the roundabout with bulb outs to forcibly move vehicles towards the central island.

Similar issues occur at elliptical roundabouts where approach and departure legs are not at 90 degrees to the central island. With all elliptical roundabouts the approach and departure legs should be at, or as close as possible to, 90 degrees to the central island.

Unfortunately, elliptical roundabouts often have one or several approaches at less than 90 degrees, which can lead to high entry and exit speeds on those legs. Elliptical roundabouts are harder to design due to different angles of approaches. Bending approach lanes so they intersect with the central island close to 90 degrees is often the best and simplest technique.

Other Design Elements

Sidewalks

All too often sidewalks are not added around roundabouts because they do not exist on the approach roads, and in many cases, even where considerable right-of-way is available, the sidewalks are placed at the back of curb; sometimes only five feet wide and instead of the recommended six feet. Section R305.6.1, Revised Draft Guidelines for Accessible Public Rights-of-Way says, “If walkways are curb-attached, there shall be a continuous and detectable edge treatment along the street side of the walkway wherever pedestrian crossing is not intended. Where chains, fencing, or railings are used, they shall have a bottom element 38 cm (15 in) maximum above the pedestrian access route.”

Pedestrian Crossings

There are two basic design principles related pedestrian crossings. One is to locate the crossing so that when one or multiple vehicles stop to yield at the roundabout the crosswalk is open for use by pedestrians. Second, locate the crossing approximately 20 feet from the normal position of a vehicle from the yield line for one lane and 38 feet two lane roundabouts, a slight difference from NCHRP 672.

Landscaping

It seems that there is a lack of understanding or appreciation of the essential role that central island landscaping can have on the conspicuity of a roundabout to reduce speeds and reduce or eliminate headlight glare from oncoming vehicles. The FHWA Roundabout Guidelines makes a number of references to the importance and benefits of landscaping.

Yet, in some cases, the central island is left as a flat expanse of grass that can be hard to see because of a lack of funds to maintain it. At the other extreme, some central islands are made into mountains that severely restrict sight lines and cause driver complaints. If there is a lack of maintenance funds then mounding the central island and covering it with rocks or adding a low height wall beyond the 15-foot clear zone would improve its conspicuity. Landscaping and mounding central islands at 1 in 5[1,2] can help reduce vehicle speeds and enhance the appearance of the roundabout. Landscaping of the splitter islands should also be considered. However, locating trees within a splitter island or median between the pedestrian crosswalk and the circulating roadway is not typically recommended, and should be thoughtfully analyzed, because only trees very close to a driver will create a shadow that will limit a driver’s vision of conflict vehicles or pedestrians.

Recommended planter width around roundabouts between sidewalk and curbing is 6 feet. If not possible, a minimum 2 feet wide planter strip, or a detectable edge treatment is essential.

Lighting

Lighting a roundabout is very important and several methods exist. The most attractive, and possibly the most effective, method is to highlight the landscape material with up lighting. Up lighting shines the light up and towards the vertical elements with the light reflected back to drivers providing better definition of the object ahead and from a greater distance. Also, colors are clearer and more definitive in aiding driver recognition of the roundabout.

Markings

Roundabout markings are another area of concern. Throughout the world only one line is used at the entry to a roundabout. However, in the U.S. many designers and local approving agencies often insist on two lines although the MUTCD[8] shows two lines with one being optional. There seems that there is a feeling among many designers that two is better than one, which raises the question, “Why is it that American drivers need two lines at a roundabout entry when the rest of the world only uses one?”

Another issue that can intrude into the decision-making process regarding roundabouts is what some reviewers call their “gut feelings”. These people who usually have had little to no roundabout experience want everything included in the standards even the optional items because that is their “gut” feeling and if they are not provided then a permit will not be issued. This attitude wastes money and can also affect geometric design and requires the engineer of record to sign and seal plans that contain items that they deems unnecessary or install a less safe treatment. This is an issue that the profession needs to address.

CAPACITY

Vehicle speeds affect gap selection and hence roundabout capacities. Gap selection, the method drivers use to enter a roundabout, is affected by their attitude, aggressiveness, and speed of the conflicting vehicles. As conflicting vehicle speed increases, entering drivers must wait for larger gaps reducing a roundabout’s capacity. A good illustration of this concept is the Clearwater Beach roundabout. The peak period circulating speed was measured at 9 to 16 mph, which enabled an hourly entry volume of 4,400 vehicles, a much higher than normal volume for a two-lane, six-leg roundabout.

A capacity study[5] of early roundabouts in the U.S., found a considerable variation between entry capacities of the study roundabouts. An average line was then drawn through the many actual entry capacities and that average line was then adopted as the maximum capacity of roundabouts in the US ignoring the actual capacities of many roundabouts that exceeded the “average”. One premise advanced for using these “lower” capacities is that drivers are just learning how to drive them. This premise is deficient in two areas:

Most roundabouts are designed for predicted traffic volumes expected 20 years in the future. But in 20 years time when the roundabouts reach their design capacity most drivers using those roundabouts would have had up to 20 years experience driving those roundabouts. Therefore, their gap selection will be more aggressive and the roundabout will operate at higher capacities.

Also, no distinction made between the capacities of roundabouts using the RA with lower speeds versus OLA designs that have higher exit speeds that can affect the adjacent entry rate. At the 2014 roundabout conference a presentation was made that highlighted the fact that the HCM 2010 saturation values are low and will be increased next year.

SUMMARY

Roundabouts are traffic control systems. They restrict free movement of vehicles and enable freer movement by bicyclists, and pedestrians. Therefore, good design is paramount because the consequences can include unnecessary damage or injuries. In addition, they can inconvenience trucks and buses that must run over curbs, pedestrians crossing higher than desirable vehicle paths where yield rates decrease, and the development of public resistance to roundabouts.

Design quality needs to be emphasized and engineers must gain a better understanding of roundabout users and their behavior as well as design philosophies, design elements and the principles laid out in roundabout guidelines. This paper was written to highlight many of the areas of concern that need more attention and in depth consideration coupled with some suggestions to help improve roundabout designs. Once a design is constructed designers should undertake post construction inspections to check the operation and to look at ways to improve their designs.

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Figures

Figure 1

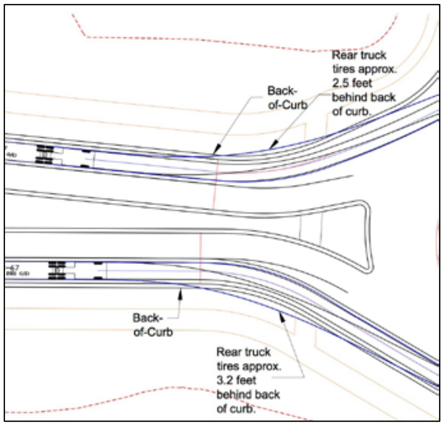

Figure 1 Roundabout submitted for review with truck template

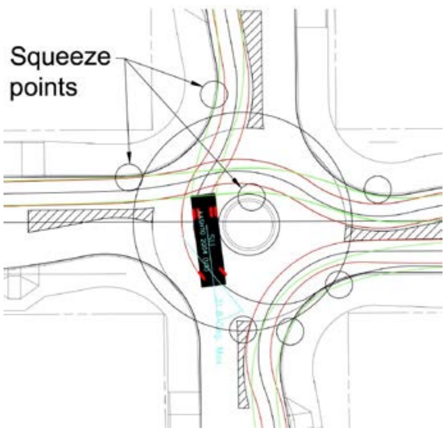

Figure 2 A second sample of a roundabout submitted for review with single unit truck templates. Note the squeeze points on both sides. It also runs over several curbs.