# Conception to Construction: Safety Impacts of Roundabout Design Changes During Implementation

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Roundabouts can often be a safer alternative to traffic signals and offer improved traffic operations over four-way stop controlled intersections. However, not all roundabouts are created equal and the original details of the design versus the corresponding construction can have unintended impacts to both safety and traffic operations. This paper documents a case study completed for a newly constructed roundabout that was experiencing a surprising level of public complaints and collisions. A safety review was conducted of the site to evaluate the as-constructed roundabout geometry, traffic guidance elements, and to determine if adjustments may be necessary. Elements that were evaluated as part of the safety review included:

- Geometric elements (sight distances, vehicle speeds)
- Traffic guidance devices (permanent signing and pavement marking)
- Collision data, vehicular conflict data, and public complaints
- Human factors

Based on the observations made during this review, it was determined that the original design concept differed from the as-constructed condition. Review of the roundabout operation showed there was some driver confusion and vehicle trajectories often did not match those expected within a well-designed roundabout. This paper discusses each of the elements that could be revised, relates them directly to the observed poor driver behavior, and presents suggested modifications to the geometry that could improve behavior. Each of the recommendations is related to advice contained in the FHWA Guide and the new MUTCD. The paper also illustrates how adherence to those design principles results in good roundabout design.

## INTRODUCTION

The focus of this paper is to document a case study of a recently constructed roundabout that was experiencing a higher than expected number of public complaints and collisions. This paper discusses the existing site layout, the safety analysis that was conducted, differences from the design concept, and recommendations and next steps.

## EXISTING SITE LAYOUT

The subject roundabout has four legs and two circulating lanes. The north-south street (Street A) is classified as a minor arterial, and the east-west street (Street B) is classified as a minor arterial to the west and as a collector arterial to the east. Posted speeds vary by approach and are as follows:

- Southbound Approach 40 mph
- Northbound Approach 35 mph
- Eastbound Approach 35 mph
- Westbound Approach 25mph

Both Street A and Street B are two lane facilities with a single travel lane in each direction between intersections. On the northbound and southbound departures from the roundabout, there are two receiving lanes, of which the second lane drops within 150 feet of the roundabout. On the westbound and eastbound departures there is only one receiving lane. Figure 1 shows the existing lane configuration and a schematic layout of the roundabout.

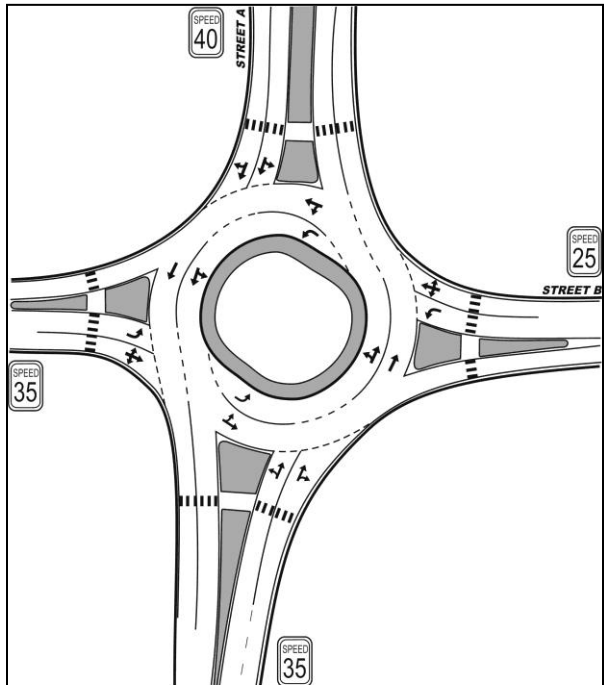

**Figure 1: Schematic Layout of Existing Roundabout**

The recently constructed roundabout appeared to be experiencing a surprising level of public complaints and collisions. As a result, a safety analysis was conducted to evaluate the site and determine if mitigations were needed. The following sections discuss the safety analysis and findings.

## SAFETY ANALYSIS

The purpose of the safety analysis was to evaluate the as-constructed roundabout geometry and traffic guidance elements, to determine if mitigations were needed. The evaluation of roundabout safety was performed based on historical collision data, traffic counts, and field observations. Elements that were evaluated as part of the safety review included:

- Roundabout geometry
- Collision and conflict analysis
- Human factors

The following sections summarize the key elements of the safety review.

**Roundabout Geometry**

Roadway geometry and traffic controls are primary factors in the safe and proper function of traffic flow at an intersection. The layout of the subject roundabout was analyzed to identify key geometric characteristics and possible existing deficiencies in deflection/path overlap, sight distance, and vehicle speeds.

*Deflection/Path Overlap*

According to FHWA guidelines[i] there are two key geometric factors in roundabout design:

- Appropriate deflection of entry paths to reduce speed differentials in the conflict zone and to insure entry speeds are not too high for vehicles to be able to negotiate the subsequent curves as they negotiate the roundabout
- Appropriate deflection in adjacent entry lanes so the natural paths of vehicles entering from adjacent lanes do not conflict

One main component in achieving safety is reducing speeds through the roundabout. Vehicles are required to negotiate a series of curves that reduces the relative speed of vehicles traveling in conflicting traffic streams. The proper amount of deflection (offset of the vehicle path from a straight line) reduces the speed of a vehicle before entering the roundabout. In the case of a multilane roundabout, large curvature in vehicle paths can increase path overlap between adjacent traffic flows, resulting in more vehicles cutting across lane lines. These are conflicting geometric design parameters that require a balance between providing enough path curvature to slow vehicles, but not too much that it results in drivers cutting across lanes.

FHWA guidelines identify optimal entering, circulating and exiting radii so that constant speed and appropriate deflection is achieved. Also by providing the appropriate design radii a simple constant curved path can be achieved for negotiating the roundabout. From visual inspection it appeared that the radii for the existing multilane roundabout varied to the point that they would produce non-uniform speeds through the roundabout and paths that involved compound curves. A compound curve occurs when the path of the driver transitions from one smooth curve of a specific radius to a second curve of a different radius, while still turning in the same direction. This requires the driver to perform additional steering adjustment.

The natural path is the path an approaching vehicle would naturally take through the roundabout when traffic is present in all approach lanes. The natural path of a vehicle maneuvering a roundabout is determined by the speed and orientation of the vehicle at the yield line. A sketch of natural vehicle paths through a typical multilane roundabout can be seen in Figure 2.

The natural paths through the study roundabout for both lanes are shown in Figure 3. There are path overlaps for all approaches except the eastbound approach. The entering angle for the outside lane directs vehicles toward the central island causing their natural path to cross over into the inside travel lane. The entering angle for the inside lane directs vehicles to the central island which causes the driver to correct and swing out into the natural path of the outside lane. The overlap of natural paths creates additional conflict points between adjacent traffic streams. FHWA guidelines[ii] suggests two methods for setting entry angles to provide appropriate natural paths, these are:

- Provide an inner entry curve that is curvilinear tangential to the central island
- Use a small radius curve approximately 50 feet upstream of the yield line and then provide a larger radius curve between the first curve and the circulatory roadway. This will slow approaching vehicles with the small radius curve and will align the vehicle's trajectory along a path that is tangential to the central island.

The existing multilane roundabout is not consistent with either of these methods. The trajectory of vehicles entering the roundabout from the inside lane is not tangential to the central island.

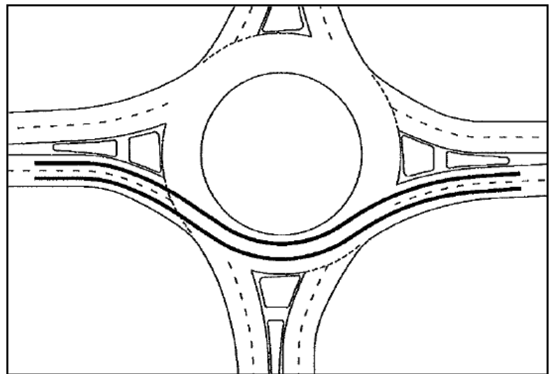

**Figure 2: Sketched Natural Paths Through a Double-Lane Roundabout** ***Source: FHWA, Roundabouts: An Informational Guide Exhibit 6-44***

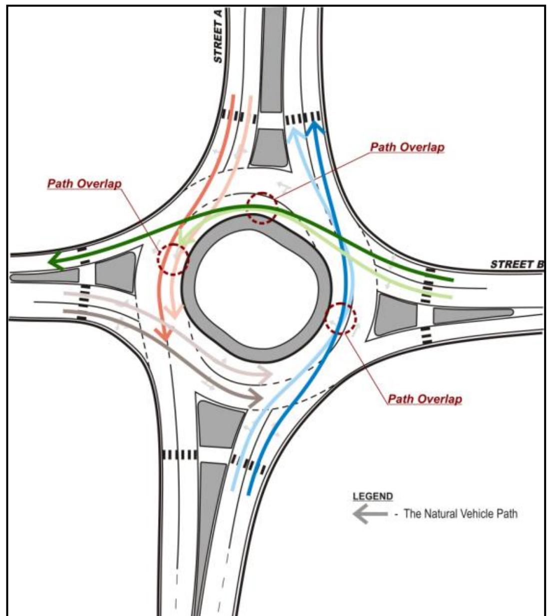


**Figure 3: Natural Vehicle Paths Through the Subject Roundabout**

For the design of the central island, FHWA guidelines suggest a circular shape. A circular shape central island with a constant radius circulatory roadway helps to maintain constant speeds for vehicles navigating the roundabout. Irregular shaped central islands can make roundabouts more difficult to drive and can promote higher speeds on straight sections and reduced speeds on curved sections. The differential in speeds can make it harder for entering vehicle to judge the speed and acceptability of gaps in the circulating traffic of the roundabout. The existing multilane roundabout has an irregular shape, somewhat oval, (refer to Figure 1 for the schematic layout). This central island design may be one reason for failure to yield collisions being the dominant collision type at this location.

*Sight Distance*

Stopping sight distance is the distance along a roadway required for a driver to perceive and react to an object in the roadway ahead of them and to brake and come to a complete stop before reaching the object. It is important that the proper sight distance is available within and on the approaches to the roundabout. Existing stopping sight distance conditions were evaluated at the roundabout[iii]. The minimum stopping sight distances were determined by the posted approach speeds and measured circulating speeds based on FHWA methodology[iv]. Forward intersection sight distance is the distance required for a driver entering the roundabout without the right-of-way to perceive and react to conflicting vehicles that are already negotiating the roundabout. Forward sight distance at the entry of a roundabout is typically satisfied by providing adequate stopping sight distance on the approach to the roundabout. Based on visual inspection, the existing roundabout configuration provides adequate forward intersection sight distance, stopping sight distance on the circulatory roadway, and approaches.

*Vehicle Speeds*

Maintaining appropriate vehicular speeds through the roundabout is a key factor in safety. A roundabout should reduce the overall speed of vehicles entering the intersection, while maintaining a consistent speed for all movements, allowing traffic to safely interact. Speed data at the subject roundabout was collected in the field for the p.m. peak and free flow conditions[v]. This data was used to determine the existing speed vehicles were traveling on the approaches to the multilane roundabout, entering the roundabout, and circulating within the roundabout.

Speeds of vehicles approaching the intersection were measured at a distance of approximately 300 feet from the yield line. The average approach speeds were equal to or less than the posted speeds, showing that a majority of vehicles are slowing down as they approach the intersection.

The overall speeds associated with the use of the multilane roundabout were consistent with the design parameters of the FHWA design guidelines. The average vehicle traveling through this roundabout is traveling at acceptable speeds. The speed differential between entering speeds and circulating speeds are within standards. The largest differential (5 mph) is between vehicles entering the roundabout in the northbound direction and vehicles that are circulating the central island.

**Collision and Conflict Analysis**

Historic data was analyzed to determine trends and characteristics of collisions at the roundabout. Only collisions occurring after the roundabout came into operation were considered for the analysis resulting in a collection period of approximately 13 months. During this period there were eight reported collisions, two of which resulted in bodily injury. No fatalities were reported. Based on the eight collisions during the 13 month collection period this intersection has a collision rate of 1.25 collisions/MEV, which may indicate there is a safety issue with this location and warrants further investigation. This rate was calculated using vehicle volumes collected during the p.m. peak. Prior to the installation of the roundabout the intersection operated as a 4-way stop controlled intersection, and had collision rate of 0.34 collisions/MEV based on collision data collected for the three years prior to the construction of the roundabout.

Based on the reported collision data, the most frequent collision type was approaching vehicles that failed to yield right-of-way to vehicles already circulating in the roundabout (five occurrences reported), which also happens to be the most common collision type associated with roundabouts[vi]. The second most common collision type was vehicles that failed to obey the lane assignments (two occurrences reported). In cases when there are run off the road incidents, and fixed object collisions involving only one vehicle, no accident report is made. To determine if this might be a problem, repair orders for this location were requested, and there have been two separate occurrences when yield signs needed to be repaired or replaced. There was no additional information relating to the cause of the damage or the location of the signs that were replaced.

Traffic conflict analysis involves the observation and recording of traffic conflicts (near-miss collisions) and reporting observations. This information is used to supplement the collision reports to provide a more comprehensive understanding of physical and behavioral conditions. A traffic conflict is defined as a point in time when two vehicles approach the same space that requires one or both vehicles to take evasive action (braking, swerving or accelerating) to avoid a collision.

Traffic conflicts were observed[vii] from 2:30pm to 6:30 pm on a weekday, when vehicle volumes are greatest. Observed conflicts were recorded by location, conflict type and risk of collision. Risk of collision is a subjective measure of the collision potential and is based on the human response to the event and the observer's perception of the amount of control demonstrated by the driver in the situation.

There were 18 observed conflicts during the four hour observation period, nine of which were vehicles performing illegal lane changes. Eight of these illegal lane changes were vehicles in the inside circulating lane (left-turn only) exiting the roundabout in the westbound direction. When the circulating vehicle is in the inside circulating lane it would appear that the entering vehicle would be clear to proceed into the roundabout. However, as the entering vehicle started to enter the roundabout, it had to brake to avoid hitting the vehicle that was exiting the roundabout from the inside lane. This was observed eight separate times with varying severity. A photo of the conflict is shown to the right, Figure 4.

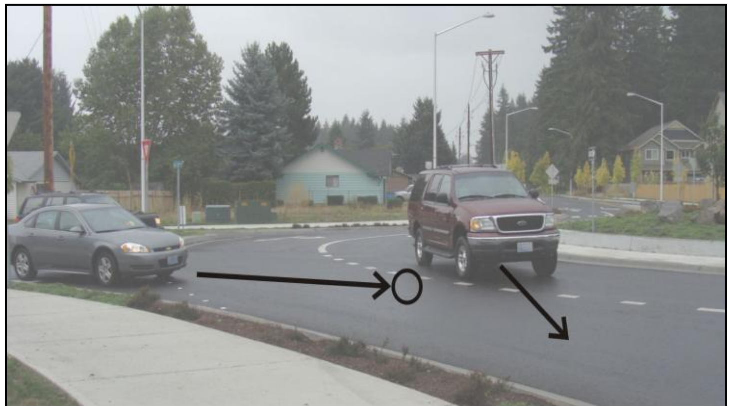

**Figure 4: Photo of a Vehicle Exiting from the Center Lane**

The second most common conflict was failure to yield right-of-way by entering vehicles, which occurred seven times. Five of these were executed by vehicles entering the roundabout in the eastbound direction and two were by vehicles entering in the northbound direction. These did not appear to be the result of vehicles traveling too fast, but rather due to driver error.

The conflict analysis supports the collision reports documented by law enforcement, verifying that failure to yield and drivers not obeying the lane designations are resulting in sideswipe collisions occurring on a more frequent basis than would normally be expected.

**Human Factors**

Human factors at an intersection play a key role in operation and safety of traffic flow. Negotiating a roundabout, much like a stop controlled intersection, is a demanding maneuver and a driver must assimilate information, make a decision, and execute the desired action. The tasks the drivers are required to make when traveling through a roundabout are similar to those at any other type of controlled intersection. These tasks are based on driver tasks discussed in FHWA Task Analysis of Intersection Driving Scenarios[viii]. Key task associated with negotiating an intersection are as follows:

- Monitor/adjust speed and maintain lane position
- Be aware of other vehicles, pedestrians, and bicyclists
- Recognize signs and pavement markings
- Slow down and/or stop to yield right of way

- Search for path guidance
- Select the proper lane

Human behavior while negotiating an intersection depends on the amount of information that is provided to the driver, such as signing and striping. The striping for this roundabout is consistent with MUTCD guidelines, providing fishhook style lane control markings. Signing varies slightly from the current MUTCD guidelines. Fishhook lane control signs are provided on all approaches, except at the time of the study the southbound approach sign was missing. Also, “One-way” directional arrow signs are used along the central island, whereas the current MUTCD suggests the directional chevron traffic signs.

During the observation period, drivers were observed slowing down and looking for circulating traffic, but proceeded to enter the roundabout in spite of a circulating vehicle being present. Based on the sight distance analysis previously discussed, there is more than sufficient sight distance to see approaching vehicles.

Additional observations were made of vehicles changing lanes illegally. Several of these were drivers disregarding lane designations and exiting the roundabout from the inside circulating lane, as was shown in Figure 4.

Drivers were also observed driving in both lanes, along the center line, especially in free flow speed conditions. Drivers frequently cut corners when negotiating around the roundabout in the outside lane, as shown in Figure 5. This can be attributed to the natural path of vehicle shown in Figure 2. Drivers are entering the roundabout in the right position and exiting the roundabout in the right position so are under the impression they are negotiating the roundabout correctly. However, due to the original trajectory drivers are drifting out of their designated lanes.

**Figure 5: Vehicle Cutting a Corner**

## DIFFERENCES FROM THE DESIGN CONCEPT

Based on the analysis and observations covered in the previous sections of this report, there were three differences from the design concept to the as-constructed roundabout that were identified as potential reasons for the surprising number of collisions associated with the new roundabout. The three key differences were excessive vehicle path overlap, the shape of the central island, and the permanent signing and striping.

The original design concept had differing approach designs, which provided more deflection and minimal potential for vehicle path overlap. However, as discussed previously, the as-constructed roundabout has significant path overlap problems. The reason for the change is unknown, but could have been caused by restricted right-of-way or expensive property takes.

The oval shape of the central island also differs from the original concept, which employed more of an ellipse. The irregular shape may make it harder for entering vehicles to judge the speed and acceptability of gaps, because the straight edge sections can promote higher speeds. The shape also impacts circulating vehicles, by requiring them to make turn corrections and adjust speeds while negotiating the roundabout.

The missing lane control sign can make it difficult for motorists unfamiliar with the roundabout to determine what lane they need to be in. However, it is unclear why the sign is missing. Additionally, the spiraling lane striping on the circulating roadway does not originate from the central island as a smooth curve with consistent radii, which potentially creates irregular travel paths.

## RECOMMENDATIONS AND NEXT STEPS

Based on a review of the existing conditions, improvements were identified that have the potential to improve the safety performance of the roundabout. Some of the improvements focus on the geometric design of the roundabout and suggest altering the existing geometry to conform to current MUTCD and FHWA guidelines. Other recommendations focus on the human factors and address methods of changing driver behavior.

**Geometric Solutions:**

- Modify entry radius of the splitter islands by either modifying curbs and/or striping to provide increased deflection that is tangential to the central island, reducing path overlap, and maintaining consistent speeds throughout the roundabout.
- Modify the shape of the central island to a more consistent inner circle creating a smooth curve with a constant radius. This can be achieved with curbs or striping; however, curbs would serve as a more effective treatment.
- Install the missing lane control sign on the southbound approach.

- Consider restricting the eastbound and westbound entries to one travel lane, which provides adequate intersection performance under existing traffic volumes. This can be achieved with curbs or striping, which could be removed at the time additional travel lanes are necessary.

**Driver Behavior:**

- Educational outreach, providing additional information to the community on how to navigate roundabouts
- Increased law enforcement at this location to encourage proper use of the roundabout

Although there are indications that improvements could be made to the safety and operation of the subject roundabout, it is difficult to determine what effect the newness of the roundabout is having. The next step in the safety analysis process is to collect additional collision data, and determine if the number of occurences is increasing, decreasing, or remaining steady.

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[i] *Roundabouts: An Informational Guide* (FHWA-RD-00-067), Chapter 6.
[ii] *Roundabouts: An Informational Guide* (FHWA-RD-00-067), Section 6.4.3.
[iii] Field review of the study area conducted by DKS Associates on September 16th and 18th, 2009.
[iv] *Roundabouts: An Informational Guide* (FHWA-RD-00-067), Section 6.3.9.
[v] Speed data collected by DKS Associates on September 16th and 17th, 2009.
[vi] *Roundabouts: An Informational Guide* (FHWA-RD-00-067), Section 5.3.2, Exhibit 5-12.
[vii] Observations made by DKS Associates on September 16th, 2009.
[viii] *Task Analysis of Intersection Driving Scenarios: Information Processing Bottlenecks* (FHWA-HRT-06-033).