HIGH SPEED APPROACHES AT ROUNDABOUTS

Prepared For:

East West Partners
California Department of Transportation
Transportation Research Board

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EAST WEST PARTNERS
CALIFORNIA DEPARTMENT OF TRANSPORTATION
TRANSPORTATION RESEARCH BOARD

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INTRODUCTION

BACKGROUND

The mobility of the car and the seemingly endless development of suburban areas has created the infamous "commute" to bring people back and forth to work from more remote areas to the downtown areas of local cities and towns. This journey usually occurs on two or four lane state highways and high capacity arterial roadways built specifically to carry traffic from regional areas to local downtown districts. These roadways are typically designed for high speed and efficient movement of vehicles at 45 miles per hour or greater. However, as the local economy and population continues to grow, so does the need for minor roadways and intersections along these highways and arterials.

As a cause and effect, the quick and efficient movement of traffic along these higher capacity roadways is hindered with an increasing number of conflicting turning movements, stop signs, and traffic signals, which create the legendary stop/go/slow-down/speed-up/stop/go motions of traffic along a former "easy-to-travel" roadway. As a result of these additional crossroads, peak hours as well as off-peak travel times experience a substantial increase in unnecessary delay. The principal example of this is when you have stopped for a red light at a traffic signal at a minor cross street along a state highway in early morning or later afternoon hours. There are no cars in front of you, no cars behind, and no cars on either side of you. You sit there letting time lapse and wait for the light to change its color to green.

These enforced pauses throughout the day are unnecessary, increasing in number, and could be eliminated by purging this enforced flow-control from intersections by the use of modern roundabouts. By merely *slowing* traffic down at a more consistent pace, the end results are being proven throughout the world to provide faster overall travel times for all movements. The capacity problems of not slowing traffic down is actually the threat of fast moving vehicles along the major corridor conflicting with the minor roadway vehicles. By slowing down all traffic movements, this threat is substantially reduced, if not eliminated, where major and minor vehicular movements as well as pedestrians can coexist and interact safely. Urban planning and transportation engineering are learning the many benefits of slowing all traffic versus stopping selected phases of traffic movements. The modern roundabout, coupled with good design and additional geometric and non-geometric design measures such as proper lighting and landscaping, are the traffic control devices of choice for intersections in most countries throughout the world. The United States has gained recognition of these statistics and facts converting old traffic circles, stop controlled, and signalized intersections to modern roundabouts with additional design measures.

Without opening another box of topics regarding driver behavioral characteristics and the conflicts between traffic behavior and social behavior, another concept worth noting is to place the control back into the drivers and pedestrians using the intersections and allow the priorities to be sorted out more efficiently based on a self regulating traffic control device with fewer conflict points, such as the modern roundabout. This creates fewer driver and pedestrian decisions with potential conflicts traveling at relatively the same rate of speeds to substantially reduce driver perception errors and vehicular crashes. This situates the drivers and pedestrians into the actual environment they are approaching and within a better-controlled condition. The roadway becomes part of the surrounding area, driver behavior is driven by eye contact with simply left priority, and the road is in harmony with its multifunctional purpose of vehicles, cyclists, and pedestrians.

Modern roundabouts provide this type of environment and safe interaction between road users. The modern roundabout is a self-regulating traffic control device. The self-regulating environment is controlled by the roadway and intersection layout, geometry, and character of the surrounding roadway widths, curves, medians, lighting, and landscaping to regulate the speeds where slower speeds are required. This includes the removal of many typical roundabout signs and the overall reduction in traffic signs along the roadway with only a few, highly efficient signs implemented. These concepts have been implemented throughout the world in various places such as Great Britain, the Netherlands, France, and a small number of locations in the United States to name a few. However, very little research seems to be available in North America regarding the safety and operational performance after implementation. It can be speculated that these roadway and intersection models are functioning so efficiently and positively that no further research has been necessary to study post conditions.

The "wide nodes - narrow roads" concept has existed for decades and is slowly gaining recognition in North America. The "nodes" are modern roundabouts that are replacing both stop controlled and signalized intersections throughout the world for years, more recently in the United States and Canada. However, it is important to note that these circular intersections are modern roundabouts and not the older non-conforming traffic circles from the previous century. Modern roundabouts conform to British guidelines and have statistically superior operational and safety performance of other types of intersections due to key design features not discussed in this document. In general, the two key features that represent modern roundabouts are YIELD at entry and deflection. A third feature, entry *flare*, is used on high capacity roundabouts to transition between the wide nodes and narrow roads.

In summation, the rising need of traffic control devices in sprawling suburban and rural areas, which are predominantly connected by higher speed roadways, as well as the rising awareness of the benefits of modern roundabouts has raised the common question in North America of whether roundabouts are appropriate at intersections with high speed approaches.

PURPOSE

This report identifies and evaluates the *perceived* concern of placing modern roundabouts on roadways or corridors with high-speed approaches (45 miles per hour or greater). The report takes an engineering standpoint of analyzing several roundabout case studies with high speed approaches found in North America. In short, this report answers the question of whether modern roundabouts are appropriate at intersections with high-speed approaches based on safety research. This report also provides recommendations and mitigation measures for high-speed conditions that are crucial to the safety performance of modern roundabouts.

In particular, the need for this *High Speed Approaches At Roundabouts* report is project driven by two proposed roundabouts on State Route 89 North in Truckee, California that are located along a rural high-speed corridor with approach speeds at or greater than 45 miles per hour, depending on the roadway segment. The two roundabouts are part of the Grays Crossing Development with East West Partners (EWP) in which a higher level of traffic control at the intersections of State Route 89 North / Donner Pass Road and State Route 89 North / Alder Drive-Prosser Dam Road is required (currently stop controlled) due to the surrounding area growth and change in roadway configurations. The Town of Truckee has had a number of projects proposed and developed in the immediate area to these intersections that have increased the traffic volumes and turning movements substantially in the recent few years. Local developments as well as a number of future proposed projects have pushed the need for additional intersection improvements at these specific locations, which now meet a number of signal warrants.

In the fall of 2004, RTE was contacted by EWP and the Town of Truckee to perform two conceptual roundabout designs in conjunction with signal warrant analyses at the intersections of SR 89 / Donner Pass Road and SR 89 / Alder Drive. The results of the analyses indicated that both the AM and PM peak hour conditions met signal warrants under both existing and future conditions.

This *High Speed Approaches At Roundabouts* report has been prepared to identify and present appropriate mitigation measures for high speed concerns, then roundabouts could be designed with additional safety mitigation measures incorporated into the final Plans, Specifications, and Estimates (PS&E) documents for the project.

In addition, the Transportation Research Board and the National Roundabout Subcommittee have requested this *High Speed Approaches At Roundabouts* report be published for presentation and use at the 2005 International Roundabout Conference in Vail, Colorado. It is the intent of the author of this report to present and publish this report to assist in the understanding and future approval of roundabouts located along high-speed corridors and roadways.

OBJECTIVES

This *High Speed Approaches At Roundabouts* report has five main objectives:

1. Evaluate perceived concern of high-speed approaches at roundabouts by demonstrating that roundabouts along high-speed roadways are appropriate and can function well.
2. Present safety statistics and data from resources worldwide with high-speed approaches at roundabouts.
3. Conduct and document case studies of existing modern roundabouts in North America with high-speed approaches.
4. Demonstrate & document geometric design treatments or major elements of design currently used for high-speed approaches at roundabouts throughout the world.
5. Recommend additional non-geometric design measures for high-speed approaches at roundabouts.

ORGANIZATION

Roundabouts & Traffic Engineering (RTE), with assistance from Ourston Roundabout Engineering, researched available data from case studies of roundabouts with respect to safety and high-speed approaches. It is known that very few of these studies exist or have been completed on any issue regarding roundabouts in the United States. Therefore, RTE sought worldwide resources and contacts in the United States, Canada, Great Britain, France, Germany, the Netherlands and Australia, to obtain reports that contain operational safety information at roundabouts that are located along high speed corridors or roadways. As anticipated, crash data was available for very few existing roundabouts along high-speed roadways. A comparative analysis of roundabouts versus signals along high-speed and low-speed roadways was also assembled from available sources and literature.

This documentation contains the following pertinent information regarding roundabout operating characteristics:

- Safety research data from various sources such as the Insurance Institute of Highway Safety;
- Case studies at various locations;
- Predicted entry path speed information for several roundabouts;
- Entry and exit speed data information;
- Speeds before and after implementing roundabouts from signals at high and low speeds;
- A summary of research on geometric design characteristics affecting roundabout safety performance; and,
- An assessment of the geometric elements contributing to good safety performance for the sample of roundabout sites examined as part of this study.
- Non-geometric mitigation measure alternatives for high-speed approaches at roundabouts.

The report is organized into the following major sections related to high-speed approaches at roundabouts and other traffic signal and modern roundabout information:

I. Introduction
II. Safety Research & Comparisons
III. Roundabout Case Studies (High Speed)
IV. Conclusions & Design Treatments

The report commences with the background, motive, and purpose of producing this report (above). The next section of the report provides specific safety research information from various agencies such as the Insurance Institute of Highway Safety, U.S. Department of Transportation, Washington Department of Transportation, America Trauma Society, Maryland State Highway Administration, Transportation Research Laboratory (United Kingdom), as well as other roundabout design specialists throughout the globe.

Next, the report presents five case studies of modern roundabouts with high-speed approaches. Specific speed data, entry radii, and accident data (where available) is provided with observations of the research conducted.

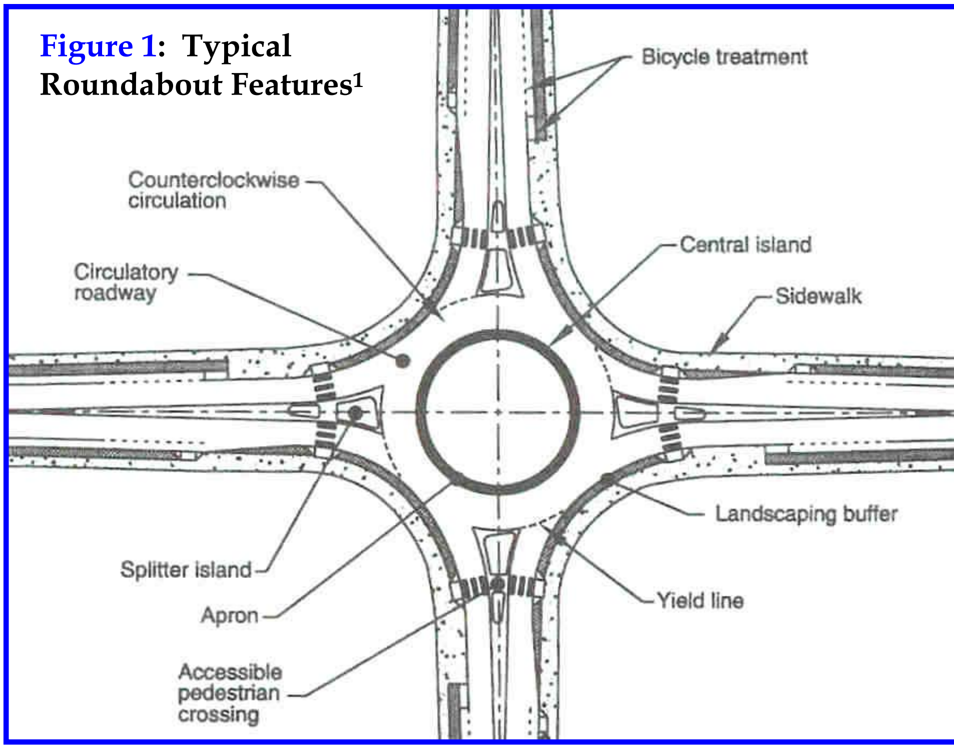
Finally, the study provides conclusions and recommendations on design measures for modern roundabouts with high-speed approaches based on the results of the analyses conducted to date. It is important to note that since limited data is available in North America pertaining to high speeds at modern roundabouts, the extent in which this data could be reported is just as limited. Additional publications and studies should be undertaken in the future at more modern roundabout locations as they are constructed in North America. However, the findings and recommendations within this report provide sound geometric and non-geometric design treatments for high-speed approaches at roundabouts. The case studies and statistics within this document clearly indicate that the existing modern roundabouts located along high-speed corridors are currently functioning well.

SAFETY RESEARCH & COMPARISONS

GENERAL ROUNDABOUT INFORMATION

Modern roundabouts are a type of circular intersection with specific design and traffic control features to control driver behavior. **Figure 1**, shown below, identifies key modern roundabout features[1] required in roundabout design. Some of these features include yield control for entering traffic, channelized approaches, and a geometric design that ensures travel speeds are relatively low and safe. Modern roundabouts are unique from other circular intersections in that they use *splitter islands* (or curved medians) and physical geometry (raised concrete curb) to control and slow the speeds of vehicles entering the roundabout and traveling through the roundabout. The splitter islands help control speeds, guides drivers into the roundabout, physically separate entering and exiting traffic streams, significantly increases intersection safety, deters wrong-way movements, and provides safe pedestrian crossings. Modern roundabouts are designed and sized to accommodate specific design speeds, traffic flows, and large design vehicles or trucks.

Figure 1: Typical Roundabout Features[1]



[1] U.S. Department of Transportation, Federal Highway Administration, *Roundabouts: An Information Guide,* 2000

Roundabouts improve the safety of an intersection through the introduction of a raised island in the center of the intersection and the conversion of all movements through the intersection to right turns thus eliminating vehicle-to-vehicle crossing conflicts.

The horizontal and vertical geometry of a roundabout is crucial to the operation and safety of the roundabout. Since the capacity of a roundabout is dependent on the turning movement volumes at each approach, the capacity analyses for a roundabout (if a higher level of capacity software like RODEL is used) identify the required geometry at entry for the design. However, the capacity analyses only identify some of the recommended geometric design parameters with respect to the capacity. The safety factors of each design's geometry are also primary concerns for the operational adequacy of roundabouts. The "body language" of the roundabout directly relates how comfortable and safe drivers will use the roundabout. The body language of the roundabout must adequately communicate to the driver in order to avoid accident and capacity problems.

The geometric analysis of a roundabout evaluates the geometric parameters that affect roundabout *capacity and safety*. Three particularly important geometric safety parameters are the design of each entry or approach, fast path design speeds, and speed consistency within the roundabout design. In addition, a large part of roundabout design involves specific non-geometric details such as the roundabout's signing, striping, lighting, and landscaping. The design of roundabout entries and exits is an intricate and complicated procedure that involves numerous variables that need to be addressed to ensure a safe design and adequate capacity. Some of these variables include the following:

- Entry Width
- Entry Flare
- Entry Angle
- Entry Radius
- Entry Deflection
- Entry Path Curvature
- Entry Path Overlap
- Entry Speeds
- Fast Path Speeds
- Speed Consistency
- Sight Distance
- Exit Path Overlap
- Entry and Circulating Visibility
- Splitter Island Design
- Exit Lanes and Geometry
- Pedestrian Crossings/Crosswalks
- Maneuverability of Large Trucks
- Vertical Design Parameters

Many other roundabout features are analyzed during a roundabout design, which are not covered in this report. Further detail of these topics would typically be performed and discussed in a roundabout peer review report, a roundabout training seminar, design publication or manual, or a design process report for a roundabout design project.

SAFETY RESEARCH FACTS & STATISTICS

The Insurance Institute for Highway Safety (IIHS) performed a study[2] titled *Crash Reductions Following Installation of Roundabouts in the United States* in 2000 on 24 U.S. intersections that had been converted both signalized intersections and stop-controlled intersections to modern roundabouts. Similarly, the Institute of Transportation Engineers (ITE) also completed a related study[3] in 2002. The U.S. Department of Transportation, Federal Highway Administration (FHWA) also produced *Roundabouts: An Information Guide* in 2000 with safety statistics contained. All of these studies revealed very consistent "before" and "after" results with respect to the safety of modern roundabouts compared to other types of stop controlled and signalized intersections. The following is a brief summary of these results with regard to the extent to which modern roundabout conversions improved the accident safety of the intersections:

- 38 - 40% average reduction in all crash types
- 74 - 78% average decrease in injury accidents
- 90% average decrease in fatalities or incapacitating injuries
- 30 - 40% average decrease in pedestrian accidents (depending on the roundabout location and existing pedestrian volumes)
- As much as a 75% reduction in delay where roundabouts replaced signals

These study results replicate other results of numerous studies conducted on roundabouts in Europe and Australia and provide quantitative evidence that the selection of a roundabout over the more conventional intersection geometrics and traffic control can have significantly positive traffic safety implications. Studies completed in England have revealed that the total number of pedestrian accidents with vehicles at roundabouts is lower than that of other intersection types by 33 to 54 percent. Norway has also indicated in several studies over the years that roundabouts have provided a 73 percent reduction in pedestrian crashes at intersections converted to roundabouts.

The FHWA informational guide on roundabouts states that accident frequency and severity is less for a roundabout than a traffic signal. The uninformed person typically asks why roundabouts are safer than traffic signals. The following bulleted list of items provides these answers as well as further discussions and illustrations below:

- Roundabouts have fewer conflict points for vehicles, pedestrians, and cyclists. The potential for many hazardous conflicts, such as right-angle

[2] IIHS, Status Report, 5/13/2000

[3] ITE Journal, September 2002

accidents and conflicting left turn head-on crashes, are eliminated with modern roundabouts.

- Speeds at roundabouts are significantly lower (average of 22 mph) than other types of crossings, which allows drivers more time to react to potential conflicts.
- There is a lower speed ***differential*** between the users of roundabouts (e.g. vehicles to pedestrians to cyclists) since the road users travel at similar speeds through the roundabout.
- Lower speeds and speed differentials between users of roundabouts significantly reduces the accident severity if an accident occurs.
- Pedestrian crossings at roundabouts are much shorter in distance and entails interruption in only one direction of the traffic stream at a time. Since conflicting vehicles arrive in one direction only to the pedestrians, the pedestrians need only to check to their left for conflicting vehicles. In addition, the speed of the vehicles in the roundabout at entry and exit are reduced with a proper roundabout design.

The following are some facts on traffic signals, red light running, and roundabouts:

1. In 2002, more than 1.8 million intersection crashes occurred throughout the nation. Of those crashes, about 219,000 are due to red light running; resulting in about 1,000 deaths and 181,000 injuries. (*Insurance Institute for Highway Safety, IIHS, and Federal Highway Administration, FHWA, 2003*)

2. A study conducted by the Insurance Institute for Highway Safety (IIHS) in 2003 found that at a busy intersection in Virginia, a motorist ran a red light every 20 minutes. During peak commuting times red light running was more frequent.

3. Researchers at the IIHS studied police reports of crashes on public roads in four urban areas. Of thirteen crash types identified, violating traffic control devices accounted for 22 percent of all crashes. Of those, 24 percent were attributed to red-light-running.

4. According to a survey conducted by the U.S. Department of Transportation and the American Trauma Society, two out of three Americans see someone running a red light at least a few times a week and, at most, once a day. (1998)

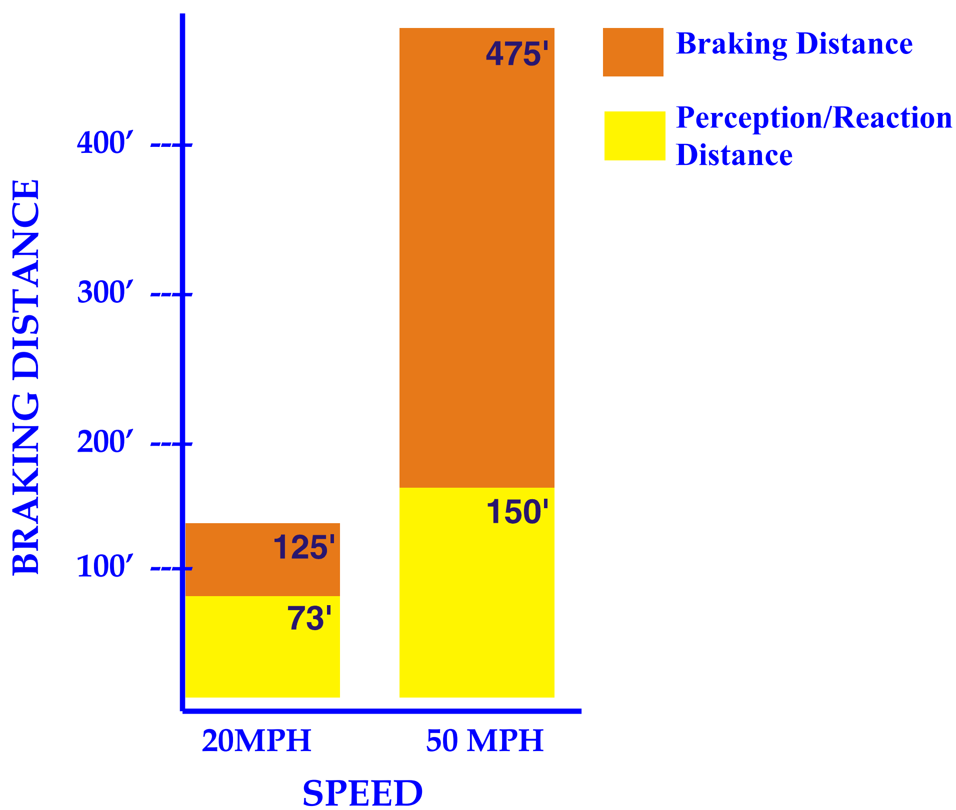
5. One in three Americans knows someone who has been injured or killed in a red light running crash. (FHWA, 2002)

6. Research from the IIHS illustrates far fewer crashes occur at intersections with roundabouts than at intersections with signals or stop signs. Modern roundabouts are substantially safer than intersections controlled by stop signs, traffic signals or traffic circles.

7. Compared to the former traffic circle or rotary, the majority of modern roundabouts have excellent safety performance mostly due to their small diameter, slower circulating speeds, flared approach, deflection, and yield control entrances. Studies from around the world have shown modern roundabouts typically reduce crashes by 40 to 60 percent compared to stop signs and traffic signals. They also typically reduce injury crashes by 35 to 80 percent and almost completely eliminate fatal and incapacitating crashes.

Roundabouts are self-regulating traffic control devices that automatically control driver speeds. These lower speeds at roundabouts, compared to traffic signals, directly relate to intersection safety. To elaborate on this concept, lower speeds on a roadway or at an intersection equate to shorter braking distances. The following bar chart (**Figure 2**) demonstrates a comparison of traffic signals to roundabouts based on braking distance and driver perception/reaction distances for braking.

Figure 2: Braking Distances & Speeds



As mentioned above, since the speeds at roundabouts are significantly lower and there is a lower speed differential between the users of roundabouts, this significantly reduces the accident severity of collisions at roundabouts. The following chart (Figure 3) illustrates the accident severity of collisions at roundabouts versus traffic signals based upon vehicle speeds. As shown in the chart below, roundabouts will have a lower accident severity rate than that of traffic signals. Hence, there will be less injuries and fatalities at roundabouts than signals as well as other types of intersections. The statistics discussed above or the "before" and "after" field studies verify this reality.

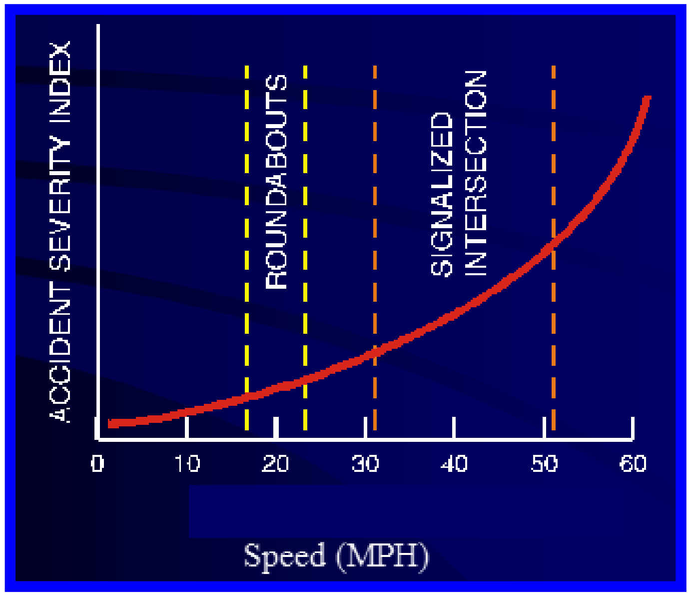


Figure 3: Accident Severity & Speeds
(Courtesy: Mark Johnson)

Another reason why roundabouts are safer types of intersections are the reduced number of conflict points at a roundabout versus a signal. The following illustrations (Figures 4 and 5) show the number of vehicle-to-vehicle (black dots) and vehicle-to-pedestrian (white dots) conflicts at a roundabout and signal.

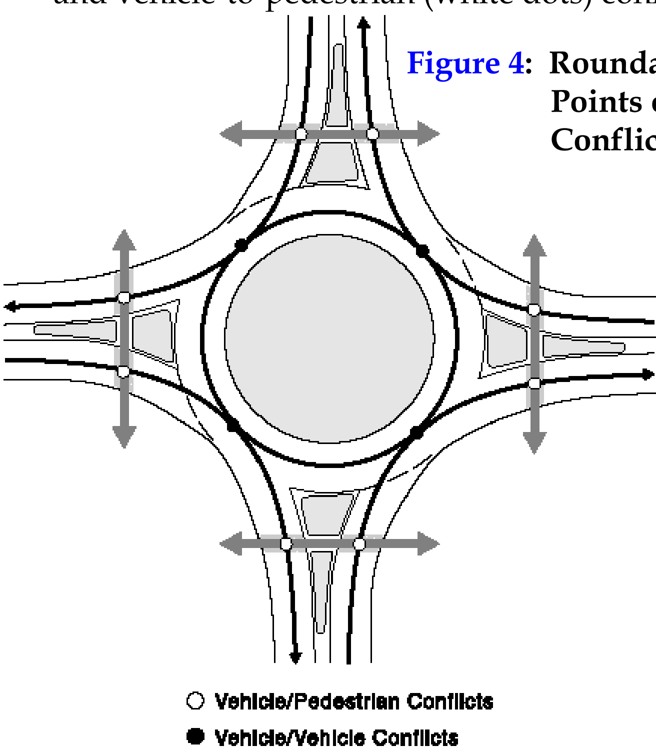


Figure 4: Roundabout Points of Conflict

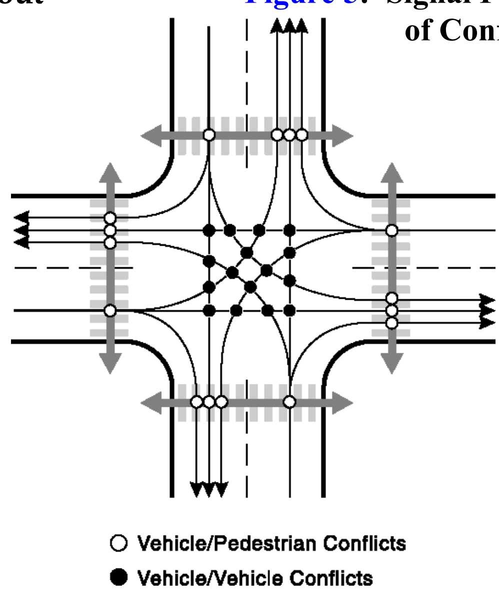


Figure 5: Signal Points of Conflict

As shown above, there are 32 points of conflict at a signalized intersection with only 12 points of vehicular and pedestrian conflicts at a roundabout. This solves the question in a very basic way of why roundabouts are safer than a signalized intersection.

In addition to a significant reduction in traffic accidents, roundabout installation can generate reductions in delays and associated air emissions, improve intersection capacity and pedestrian travel, reduce intersection improvement costs and associated operation and maintenance costs, and can be a key element in improving the visual quality of roadway corridors and town centers.

In general, if roundabouts are designed by a qualified roundabout expert, the modern roundabout will function as a self-regulating traffic control device that offers numerous capacity, safety, and aesthetic benefits to a community or public jurisdiction.

MARYLAND STATE HIGHWAY ADMINISTRATION

Within the later part of the past decade the Maryland State Highway Administration has implemented modern roundabouts to resolve a number of traffic engineering and urban design dilemmas. Edward Myers published a report *Accident Reduction with Roundabouts* with accident statistics at five sites where the Maryland State Highway Administration (MSHA) has installed modern roundabouts. All of the roundabout sites can be classified as high-speed rural locations. The following intersections were analyzed in the study:

1. MD 94 / MD 144, Howard County (Lisbon Roundabout)
2. MD 63 / MD 58-MD 494, Washington County (Cearfoss Roundabout)
3. MD 213 / Leads Road- Elk Mills Road, Cecil County (Leeds Roundabout)
4. MD 2 / MD 408-MD 422, Anne Arundel County (Lothian Roundabout)
5. MD 140/ MD 832-Antrim Blvd., Carroll County (Taneytown Roundabout)

The accident data was gathered three years before as well as three years after the roundabouts were installed. The before and after accident results are shown in the summary **Table 1** below by accident type. The table also shows the reported average annual accidents and the injury crash rates three years before and three years after construction of the roundabouts.

In addition, the report used statistics for average accident costs compiled by the MHSA to determine the average cost per accident at each intersection location in both the before and after conditions. **Table 2** presents a summary of the accident severity comparison of the intersections before and after the roundabouts as reported in the *Accident Reduction with Roundabouts* study.

Table 1: Maryland Before & After Accidents

3 Years Before and After Data for All Roundabouts

	Lisbon Roundabout		Cearfoss Roundabout		Leads Roundabout		Lothian Roundabout		Taneytown Roundabout	
Crash Type	Before	After	Before	After	Before	After	Before	After	Before	After
Angle	23	3	6	2	8	2	13	1	12	0
Rear-End	0	1	1	0	1	0	2	8	2	1
Sideswipe	1	0	0	0	0	1	1	0	1	0
Left-turn	0	1	1	0	1	0	8	0	1	0
Opposite Direction	0	0	0	0	0	0	1	0	1	0
Single Vehicle	0	10	1	0	0	14	0	3	2	2
Overturned	0	0	0	0	0	0	0	1	0	0
Avg. Annual Crashes	**7.4**	**2.3**	**3.0**	**0.67**	**3.9**	**3.2**	**8.2**	**4.1**	**5.3**	**1.25**
Avg. Injury Crashes	**4.3**	**0.53**	**0.78**	**0.29**	**0.78**	**0.29**	**5.4**	**1.25**	**2.8**	**0.42**

Source: Accident Reduction With Roundabouts, Myers *RTE High Speed Approach Tables.xls*

Table 2: Maryland Accident Severity Comparison

3 Years Before and After Data for All Roundabouts

	Number Of Accidents		Average Accident Cost	Total Accident Cost	
Crash Type	Before	After		Before	After
Angle	62	8	$125,971	$7,810,202	$1,007,768
Rear-End	6	10	$80,231	$481,386	$802,310
Sideswipe	2	1	$60,819	$121,638	$60,819
Left-turn	11	1	$95,414	$1,049,554	$95,414
Opposite Direction	1	0	$307,289	$307,289	$0
Single Vehicle	3	20	$59,851	$179,553	$1,197,020
TOTALS	**85**	**40**	**3.0**	**$9,949,622**	**$3,163,331**

Source: Accident Reduction With Roundabouts, Myers *RTE High Speed Approach Tables.xls*

In general, the report states that the MHSA has experienced an overall accident reduction of 59% from an average of 5.56 accidents per year to an average of 2.3 accidents per year. In addition, the reported injury accidents (including fatalities) have been reduced by 80%. All of the intersections experienced a reduction in accident frequency as well as accident severity.

TRANSPORTATION RESEARCH LABORATORY

Specific research taken from the Laboratory Report 1120 by G. Maycock (TRL Limited) and R. H. Hall (Southampton University) show that faster speed roundabouts have a lower crash percentage for entering-circulating and pedestrian crash types. The lower pedestrian crash percentage can be anticipated due to the proportion of pedestrian volumes for faster speed roundabouts to lower speed roundabouts. **Tables 3** and **4** below provide summary results from the TRL study.

Of particular relevance and interest to this *High Speed Approaches at Roundabouts* report is the statistic showing that the accident rate is lower for both small and two-lane roundabouts but higher for conventional roundabouts (roundabouts that do not have a flare in the entry design). The data conveys that smaller roundabouts that have flaring have a much lower crash rate on high-speed roads compared to sites with lower speeds. This would suggest that rural high-speed single lane roundabouts with flaring have superior safety performance over designs with no flare at entry.

The data further indicates that single vehicle crashes are over-represented on high-speed roundabouts. This appears to confirm that the main issue with roundabouts in high-speed conditions is the driver not adjusting to the correct entry speed based on the speed differential between entry speeds and circulating speeds in the roundabout.

In addition, the accident data at all of the different types of roundabouts analyzed show a reduced severity at the high-speed roundabouts versus the low speed roundabouts. This could be accounted by the possibility that drivers are more cautious and conscious of circulating traffic at high-speed approaches at roundabouts.

Table 3: Roundabout Crash Types & Rates

Accidents Statistics By Roundabout Type & Speed

Roundabout Category	Operating Speeds (MPH)	Total # of Accidents	Avg Accident Rate	Percentage By Accident Type: Entering / Circulating	Approach	Single Vehicle	Other	Ped
Small	30 - 40	497	37.1	72.2%	6.6%	7.5%	9.7%	4.0%
	50 – 70	150	28.7	67.3%	8.0%	10.7%	12.0%	2.0%
Conventional (No Flare)	30 - 40	146	21.2	16.4%	18.6%	37.6%	19.2%	8.2%
	50 – 70	193	28.7	24.9%	26.9%	29.0%	17.1%	2.1%
Two-Lane	30 - 40	244	22.5	21.7%	24.2%	24.2%	18.4%	11.5%
	50 – 70	197	22.4	16.8%	29.9%	32.5%	17.8%	3.0%

Source: TRL, LR 1120 *RTE High Speed Approach Tables.xls*

TABLE 4: Roundabout Accident Severity

Crash Statistics By Roundabout Type & Speed

Roundabout Category	Operating Speeds (MPH)	Number of: Sites	Junction Years	Accidents: Fatal	Serious	Slight	Total	Accident Frequency/ Junction/Yr	Severity %
Small	30 - 40	25	113.4	2	86	409	497	4.38	18
	50 – 70	11	53	1	20	129	150	2.83	14
Conventional (No Flare)	30 - 40	11	61.9	3	37	106	146	2.36	27
	50 – 70	11	62.2	0	30	163	193	3.1	16
Two-Lane	30 - 40	14	72.5	1	30	213	244	3.37	13
	50 – 70	12	68.3	0	22	175	197	2.88	11

Source: TRL, LR 1120 *RTE High Speed Approach Tables.xls*

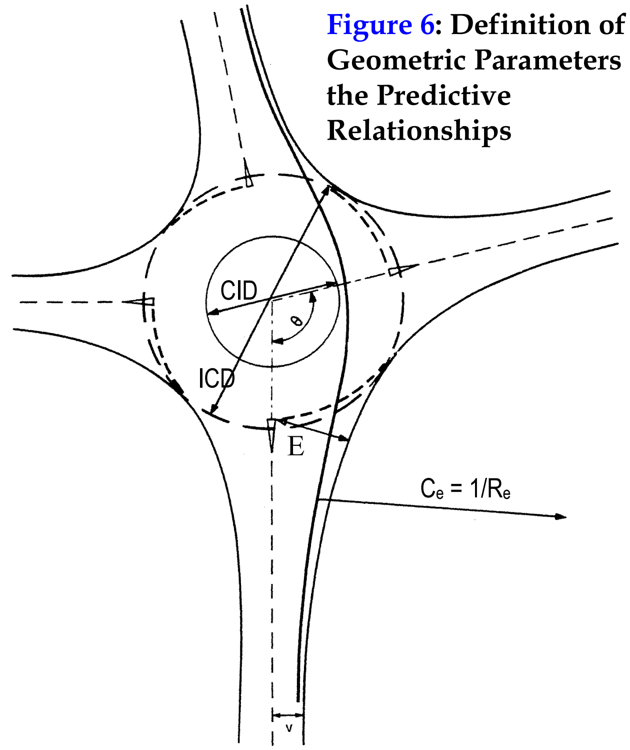


Figure 6: Definition of Geometric Parameters in the Predictive Relationships

Research on Relationships Between Geometric Design & Safety Performance

To further analyze the injury accident data results from above to assist in the justification of using modern roundabouts at high-speed intersection locations, there are links that have been established between a roundabout's physical geometry and injury accidents.[4] Empirical equations have been developed to enable prediction of roundabout crashes for appraisal of existing roundabouts and for use in design. The definitions of the primary geometric parameters in the empirical predictive relationships are shown in **Figure 6**. The costly research undertaken in the early 1980's using four years of data has identified relationships between safety and geometry for a wide range of traffic flows and geometric conditions.

It has been realized over many years of roundabout implementation that the slightest change in a roundabout's geometry (on a scale of inches) can significantly effect and change the type and frequency of accidents at roundabouts. Since it is extremely unlikely that a design change, which would reduce crashes in the U.K., would have the reverse effect in North America. The relationships are expected to prove dependable for predicting the major effects of design changes in North America in a similar manner. With the exception of the prediction model for pedestrians, which is a function of entering and exiting traffic flows, the main accident types dependant on entering flow, circulating flow, and roundabout geometry are:

1. Entry/circulating crashes - a vehicle entering the roundabout collides with a circulating vehicle.
2. Approach crashes involving two or more vehicles approaching the junction. These are sideswipes and rear-end crashes.

[4] Maycock, G. and Hall, R D., Accidents at 4 Arm Roundabouts. TRL LR1120, 1984

3. Single vehicle accidents caused by failure to slow at entry and colliding with street fixtures, the central island, or simply venturing off the roadway.
4. Other Accidents - including motorcyclists or a variety of other relatively infrequent accidents.
5. Pedestrian related crashes, for which no geometric parameters were attributed, are a function of the entering and exiting traffic flows.

The most noteworthy features of the empirically researched accident prediction equations have been illustrated from the extensive data collected on a four-year sample of 84 four-arm roundabouts in the U.K.

Two of the geometric design features identified in the U.K. research on accident-geometry relationships, entry angle and entry path curvature, are significant for roundabouts with high-speed approaches.

- The Entry Path Radius (C_e) - This is the minimum radius taken by a straight-ahead vehicle entering the junction along the fastest possible path. It is typically measured within 165 feet (50 meters) of the junction. Accident frequency varies significantly with Entry Path Radius. Very small values must be avoided. Usually values are large and need to be reduced. The optimum value will depend on the specific entry and circulating flows.

- The Angle Between Arms (θ): Increasing the angle sharply reduces accident frequency. Equally spaced arms are therefore safest. Accordingly, designs with a reduced number of equally spaced arms may be safer. However, this needs to be checked as it may increase the circulating and entry flows on the remaining arms leading to a net increase in accidents.

The U.K. empirical approach to accident prediction has proved successful for the whole range of roundabout sizes from mini-roundabouts up to three and four lane entries in native instances. In North America there are too few roundabouts covering the range of design and traffic flows suitable for development of a safety model; however, the British research can be used reliably in relative terms because it is unlikely that a change, which reduces crashes in the U.K., is going to have the reverse effect in North America. If an accident prediction model can be accurately developed for use in North America, the results between the two models would be relatively similar. There may not be an absolute correlation when compared to traffic signal accident rates in the United States or Canada, but the measure of error would be relatively low for simple comparison purposes.

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION

Prior to considering the use of roundabouts on rural high-speed roadways, the Washington State Department of Transportation made a comparison of collision rates and severity between rural high-speed signalized intersections and urban low-speed signalized intersections. As a result of their studies, they found a significant ***increase*** in injury rates and severity for the rural signalized intersections on high-speed corridors.

A second comparison between roundabouts and traffic signals with high-speed approaches revealed that roundabouts installed elsewhere at high-speed intersections out performed their signalized counterparts by nearly a 50% reduction in injury and fatal crashes. Subsequently, a specific site was used in the analysis to demonstrate a potential 80% reduction in expected crashes after conversion. The site used in this study, Novelty Hill Road Case Study, is documented later in this report under Section III, Roundabout Case Studies.

The accident data compiled for the comparison was derived from various resources and time periods. The signal data was gathered by the Washington State Department of Transportation (WSDOT) accident records and WSDOT traffic counts for a three-year history for the following nine intersections:

- SR 9 / SR 524
- SR 9 / 180th SE
- SR 9 / 176th
- SR 9 / SR 96
- SR 9 / SR92
- SR 9 / 172nd
- SR 9 / SR 531
- SR 522/ Paradise Lake
- SR 522 / Echo Lake

All of the sites have been classified as high-speed signal locations. In addition the WSDOT gathered a ten-year history of a two-way stop controlled intersection located on a high-speed state highway corridor at SR-203 / NE 124th Street in rural King County.

Specific roundabout injury data was used from the Transport Research Laboratory Report 1120, *Accidents At 4-Arm Roundabouts* with six years of accident history for Halesowen, Ellesmere Port, Ellesmere Port (2), Chester, Newcastle, Brockworth, Teesside, Churchstow, Stony Stratford, Longwick, Chester; all of which were reported by Maycock and Hall.

The projected roundabout accident data was reported by RODEL, Limited, using roundabout specialist Barry Crown in the United Kingdom.

It should be noted that the WSDOT document attempts to reconcile differing accident classification methods between the U.S. and the U.K. as follows:

US	Fatal	Disabling Injuries + ½ Evident Injuries	½ Evident Injuries + Possible Injuries
UK	Fatal	Serious	Slight

As shown from the accident definitions below, the U.S. "evident" injury overlaps the U.K. "serious" and "slight" injuries. According to the WSP Manual under Accident Definitions, the U.S. terms above are defined as follows:

> ***Disabling:*** *any injury which prevents the injured person from walking, driving, or continuing normal activities. Examples: severe lacerations, broken or distorted limbs, skull or chest injuries, abdominal injuries.*
>
> ***Evident:*** *any injury other than fatal or disabling at the scene. Examples: broken fingers or toes, abrasion, contusions.*
>
> ***Possible:*** *any injury reported to the officer or claimed by the individual such as momentary unconsciousness, limping, complaint of pain, claim of injuries not evident, nausea, hysteria.*

According to the United Kingdom Transport, the U.K. terms above are defined as follows:

> ***Serious injury:*** *an injury that a person is detained in a hospital as an "in-patient" or injuries such as fractures, concussion, severe cuts, lacerations, and shock where after medical treatment they can leave the hospital.*
>
> ***Slight:*** *An injury of a minor character such as a sprain, bruise, cut or slight shock, which is not judged to need more than roadside attention.*

As a result from the above specified intersection locations and assumptions, the following results were summarized to depict the differences between modern roundabouts and traffic signals located on high speed corridors. **Table 5** below provides the data summary as reported by WSDOT. As a result of these analyses as well as others, the modern roundabout at Novelty Hill Road was constructed and is operating well. The Novelty Hill Roundabout is used as a case study in this report and is illustrated in Section III below.

TABLE 5: Accidents At High Speed Approaches

WSDOT "Injury Accidents Statistics at High Speed Roundabouts vs. High Speed Signals"

Category	Injury Accidents / 100 Million Vehicles: Fatal	Serious	Slight	Total	Number of Sites	Avg Daily Traffic
Roundabouts: 50-70 mph	0.19	3.80	24.70	28.70	11	27,800
Signals: 45-55 mph	0.56	11.80	39.20	51.50	8	20,400
Existing Novelty Hill Road	0.00	29.90	62.30	92.20	1	13,700
Projected Roundabout	0.13	2.54	16.52	19.19		

Source: WSDOT *RTE High Speed Approach Tables.xls*

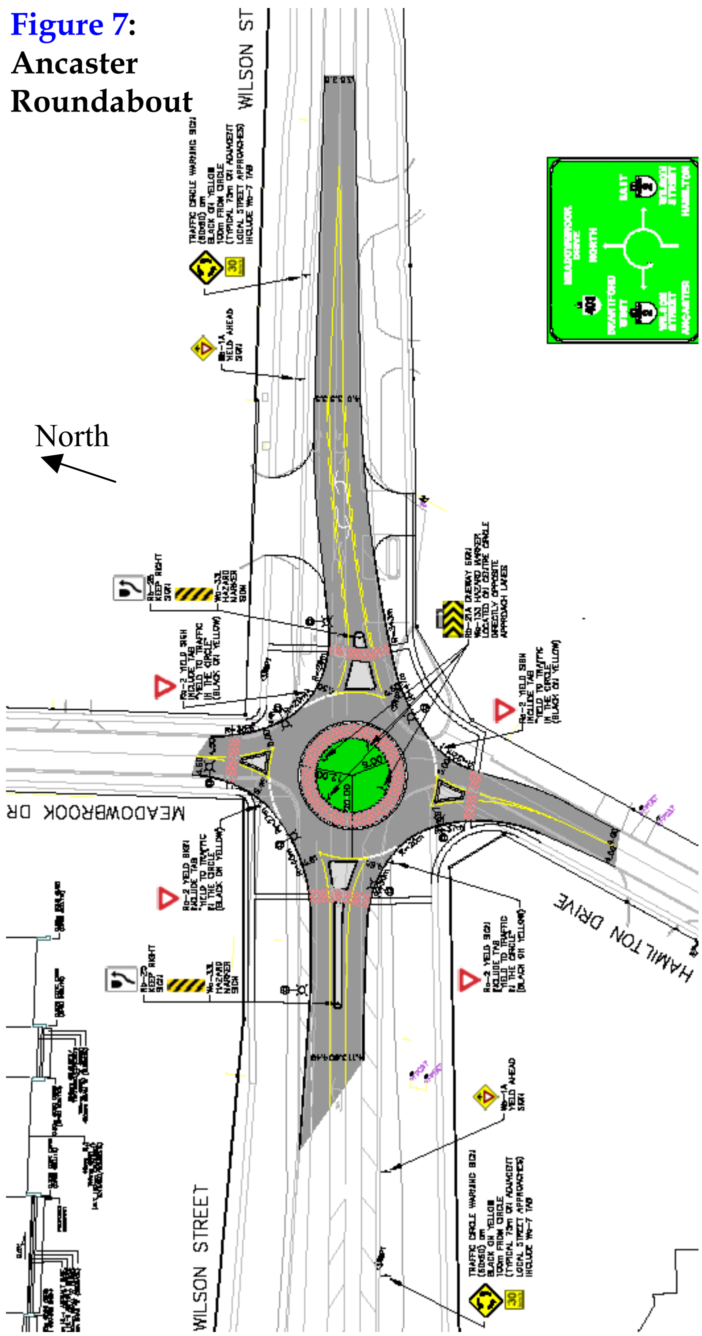
ROUNDABOUT CASE STUDIES

CASE STUDY 1: ANCASTER ROUNDABOUT

The subject intersection is adjacent to the Highway 403 corridor at the west limit of the Village of Ancaster in Hamilton Ontario. The east and west approaches have a posted limit of 60 km/h (37mph) that transitions to 50 km/h east of the intersection Posted speed limits are 50 km/h (31mph) for the north and south approaches. Some design information about the roundabout are as follows:

- ICD Size = 130 ft (40 m)
- Entry Width = 15 ft (4.5 m) EB and WB
- Design Speed = 45 mph (70km/h)

Figure 7: Ancaster Roundabout



The crash history at the intersection prior to installation of the roundabout from 1988 to 2002 indicated 31 crashes of which 10 incidents involved personal injury with a consistent crash type of angle or turning movement crashes. The calculated collision rate for the intersection prior to installation of the roundabout was approximately 0.55 per million vehicles entering based on the existing traffic volumes. The table below (Table 6) illustrates the crashes at the intersection four years prior to the roundabout as well as the crashes since the roundabout opened in 2002. The dates of the roundabout data are shown in the table. Figure 7 above illustrates the implemented design for the Ancaster Roundabout.

Table 6: Ancaster Before & After Collisions

High Speed Case Study on Wilson Street adjacent to Highway 403

Conditions / Year	Total Accidents	Type of Accident: Turning	Angle	Single Veh	Severity: Prop Damage	Injury
Before Roundabout (Jan 1998 - Oct 2002)	7	4	3	0	7	0
After Roundabout (Nov 2002 - Jan 2005)	5*	0	0	5	3	2*

**Note: Injury accidents were single vehicle accidents at night with excessive speed involving alcohol*

Source: ORE/RTE RTE High Speed Approach Tables.xls

These accident results demonstrate a substantial reduction in all crash types except single vehicle crashes where the accidents were high. The total accident results are not at the rate or percentage anticipated for the average roundabout with only a 29% accident reduction. However, the accident reports identified that **all** of the crashes were single motor vehicle accidents (one car only) that occurred at night on the eastbound high-speed approach, two of which were drunk drivers.

Further analyses at the intersection identified that the major contributing factor for the single vehicle accidents was the central island conspicuity due to a lack of landscaping. Providing sufficient landscaping or a physical obstruction for oncoming drivers to make eye contact with is required at modern roundabouts to avoid these types of single vehicle accidents, especially during night time hours. With no central island vegetation, it makes it too easy for drivers to see straight across the circle. Providing proper landscaping for roundabouts is crucial to operational safety. This roundabout's location at the gateway to a town on the edge of a rural area warrants further treatment of landscaping on the central island, roadway, and possibly the splitter island for the rural approach.

Another factor identified in the review of this case study roundabout was the poor visibility of the eastbound entry at night due to a potential lack of illumination. Since lighting levels are within acceptable ranges, it was recommended to landscape the central island and to place some ground level reflectorized markers on either side of the roadway to define and delineate the entry. In the case of this design, the eastbound approach splitter island could not be extended because the adjacent road authority would not permit it. **Figure 8** demonstrates the implemented markers on the eastbound approach. The figure also shows the "see through" problem of the intersection due to the lack of sight-obstructing landscaping.

Figure 8: Ancaster Roundabout with Candlestick Bollards on EB Approach (Note "see through" problem of central island)

Based on the fastest path design of the Ancaster Roundabout under design conditions, the following radii and corresponding predicted speeds (see **Table 7**) were documented before the construction of the roundabout:

Table 7: Ancaster Speed Predictions Before Construction

Based on Design Plan Set Fast Path Speeds
Wilson Street / Meadowbrook Drive / Hamilton Drive

	South		North		West		East	
Design Parameter	R1	R2	R1	R2	R1	R2	R1	R2
Radius (ft)	262.5	73.8	155.8	78.7	175.5	75.5	149.3	85.3
Speed (mph)	30	18	25	19	26	18	28	19

Source: ORE/RTE *RTE High Speed Approach Tables.xls*

Speed studies were recently conducted at the Ancaster Roundabout to determine if the predicted fastest path design speeds prior to construction were accurate and within tolerances at each approach entry, at each exit, and within the circulating roadway of the roundabout. The data from the speed study was then compiled to calculate and identify the average speeds, the 85th percentile speeds, and the highest and lowest speeds at each surveyed point on the roundabout.

The speed study locations at the roundabout are identified in Figure 9 below. The results of this speed study are documented below in Table 8.

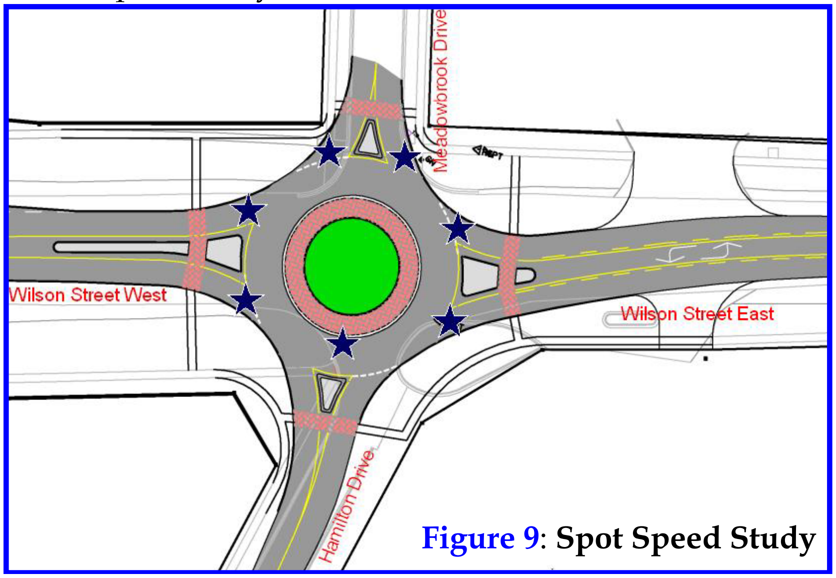


Figure 9: Spot Speed Study

Table 8: Ancaster Speeds After Construction

Based on Actual Measured Speeds Conducted Years After Construction
Wilson Street / Meadowbrook Drive / Hamilton Drive

Speeds (mph)	Wilson East		Meadowbrook		Wilson West		Circulating
	Entering	Exiting	Entering	Exiting	Entering	Exiting	
Average	16	22	19	22	20	25	18
85th Percentile	19	25	22	25	24	28	21
High	25	30	28	34	29	34	27
Low	7	11	7	14	7	14	7

Source: ORE/RTE *RTE High Speed Approach Tables.xls*

The above results show that the actual speeds after construction of the roundabout are lower than the predicted fastest path design speeds. As a result, the roundabout's design and design speeds were not a major contributing factor for the single vehicle crashes. Speed studies were also conducted at the Ancaster Roundabout at six points before and after the roundabout opened to see how the roundabout affects driver behavior and speeds. Figure 10 below shows where the locations of the six points of the speed study were measured along the high-speed corridor of Wilson Street. Figures 11 and 12 show the intersection before and after the roundabout's construction. Figure 13 is an aerial photograph of the roundabout post construction to provide an understanding of the high-speed roadway characteristics, proximity to Highway 403, and identify the relationship of the roundabout to the surrounding rural area transitioning to a suburban area.

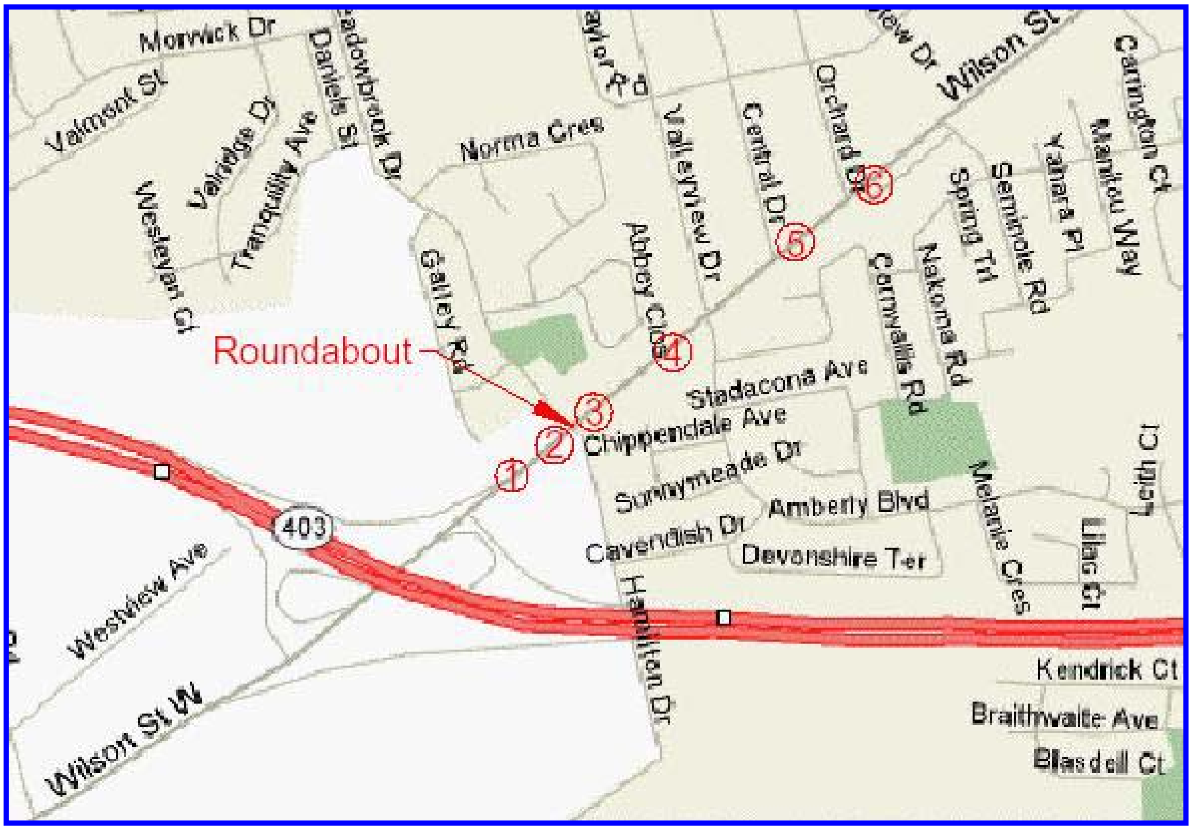


Figure 10: **Six Points of Speed Study (Before & After Construction)**

Figure 11: **Before Roundabout**

Figure 12: **After Roundabout**

Based on the six points surveyed in the speed study before and after construction of the roundabout, it can be concluded that speeds have reduced greatly since the roundabout has opened and that the design is performing as predicted according to entry path measurements. The speeds reported in **Table 9** below provide a summary of the results of the speed survey conducted at 85th percentile calculations.

Figure 13: **Ancaster Roundabout Aerial**

Table 9: Wilson Street Speeds Before & After Construction

Measured Speeds at the Ancaster Roundabout Reported at 85th Percentile
Wilson Street / Meadowbrook Drive / Hamilton Drive

Survey Location	Direction	Before Roundabout	After Roundabout	Change of Speed
Point 1	EB	48	39	-9
	WB	48	36	-12
Point 2	EB	47	26	-21
	WB	48	32	-16
LOCATION OF MODERN ROUNDABOUT				
Point 3	EB	46	28	-18
	WB	50	24	-26
Point 4	EB	44	37	-6
	WB	47	36	-11
Point 5	EB	42	43	1
	WB	43	42	-1
Point 6	EB	42	42	0
	WB	43	41	-2

Source: ORE/RTE *RTE High Speed Approach Tables.xls*

As shown in **Figure 10** and **Table 9**, the modern roundabout is located between survey points 2 and 3. The 85th percentile before and after results of the speed survey along the high-speed roadway of Wilson Street express that the speeds have substantially reduced with the implementation of the modern roundabout.

In summary, this roundabout would benefit from increasing the central island conspicuity and extending the west leg approach splitter island to the deceleration distance appropriate for the high-speed conditions. As explained above, providing proper landscaping is crucial to operational safety. The splitter island extension would increase the side friction as well as create a "tunnel effect" for approaching drivers and would result in slower vehicular speeds.

CASE STUDY 2: CHAMBLY ROUNDABOUT

This case study roundabout intersection is located along Fréchette Boulevard and Anne-Le-Seigneur Boulevard in Chambly, near Montreal, Quebec. This roundabout intersection is classified as having high-speed approaches on this arterial corridor (posted speed = 55 mph, design speed = 65 mph). As the Chambly area continues to grow, suburban sprawl is occurring further south with more residential projects along high-speed commute corridors such as this roadway. There is also a roundabout located at the next cross street to the north of this study intersection along a high-speed curve. The design plans for the two roundabouts are shown on left side of **Figure 14** below.

Speed studies at the new roundabout intersection of Boulevard Fréchette and Boulevard Anne-Le-Seigneur were very recently performed for this *High Speed Approaches at Roundabouts* study since the subject area lends itself to very similar conditions of the two roundabouts being design and proposed by RTE on State Route 89 North in Truckee, California. The design plan for the case study roundabout (Chambly Roundabout) is shown on the right side of **Figure 14**. The fastest paths have been designed on **Figure 14** to provide the predicted speeds of vehicles entering and circulating in the roundabout. The predicted speeds are shown in **Table 10**. Some roundabout design information are as follows:

- ICD Size = 164 ft (50 m)
- Entry Width = 17 ft (5.25 m) on Boulevard Fréchette
- Design Speed = 65 mph (100 km/h)

Speed studies performed on the Chambly Roundabout to compare the predicted speeds in the roundabout design to the actual field conditions measured after the roundabout was constructed. The speeds of vehicles traveling along the high-speed roadway were measured at five locations, as specified below.

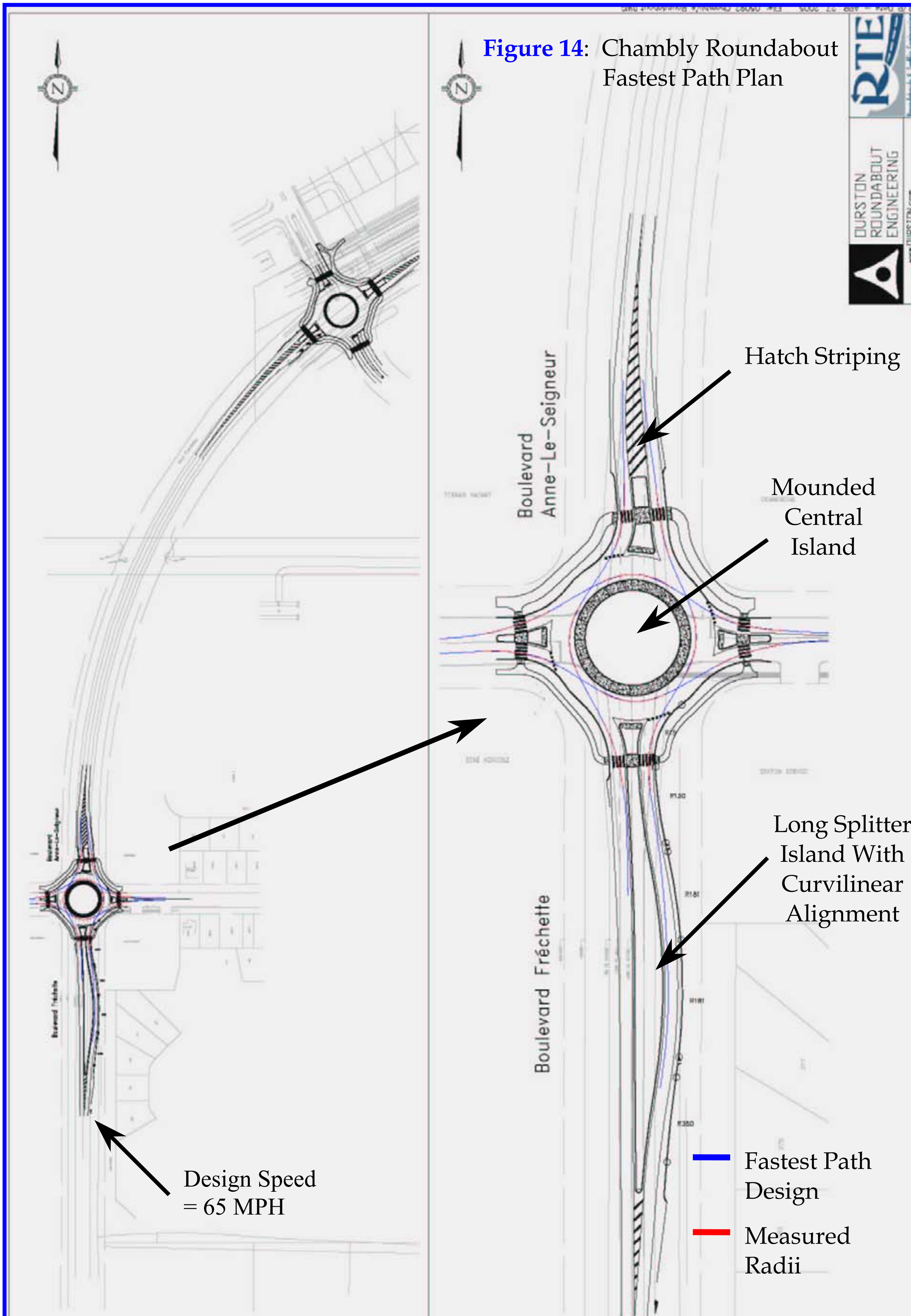


Figure 14: Chambly Roundabout Fastest Path Plan

Table 10: Chambly Speed Predictions Before Construction

Based on Design Plan Set Fast Path Speeds

Fréchette & Anne-Le-Seigneur Boulevard

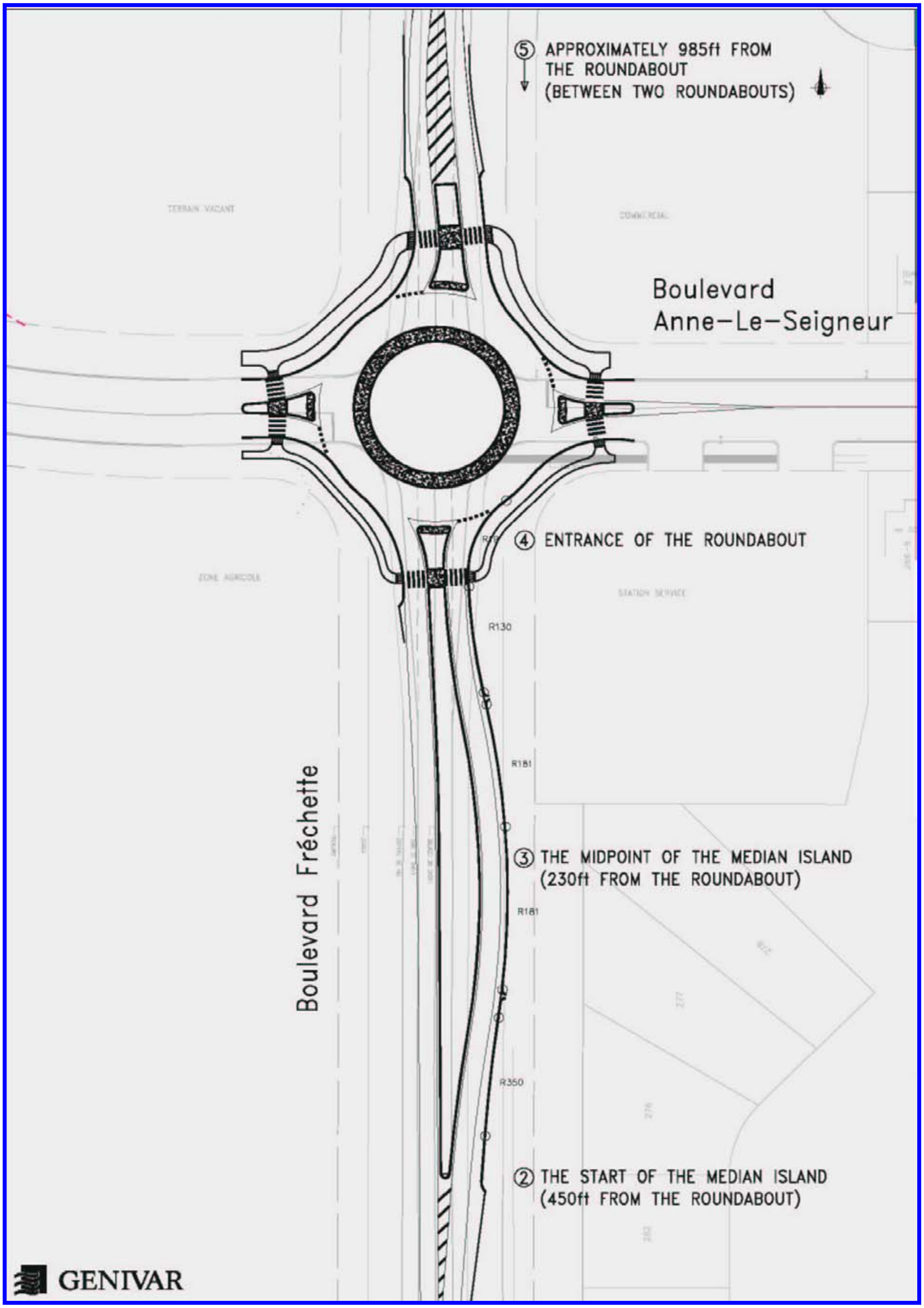
Design Parameter	Southbound		Northbound		Westbound		Eastbound	
	R1	R2	R1	R2	R1	R2	R1	R2
Radius (ft)	137.8	59.1	111.5	68.9	154.2	59.1	144.4	65.6
Speed (mph)	24	17	22	18	25	17	24	17

Source: ORE/RTE *RTE High Speed Approach Tables.xls*

During the speed studies performed on the Chambly Roundabout, the speeds of vehicles traveling along the high-speed roadway were measured at the following five locations:

- Point 1: 1,640 feet (500 meters) from the roundabout.
- Point 2: 450 feet (137 meters) from the roundabout at the beginning of the northbound median island
- Point 3: 230 feet (70 meters) from the roundabout at the midpoint of the median island (second curve)
- Point 4: At the northbound entrance of the roundabout
- Point 5: Roughly 985 feet (300 meters) between the two roundabouts

The points of the speed study are shown graphically in **Figure 15** on the next page. The speed study results are shown in **Table 11** below. As shown in the tables, the actual speeds currently experienced at the roundabout are lower than the predicted fastest path speeds. Even though the posted speed limit is 55 miles per hour (mph), the 85th percentile speeds prior to the roundabout are 63 mph and the average speeds are 58 mph (survey point 1). However, the channelized effect of the long northbound splitter island (survey point 2) shows a drop in speeds with an 85th percentile at 45 mph and an average speed of 39 mph. By the time drivers arrive at the entry of the roundabout, the speeds are lower than the fastest path speeds predicted in design. The speeds between the roundabouts also considerably dropped with an 85th percentile speed of 41 mph (below the posted speed limit of 55) and an average speed of 39 mph. These are positive results. It should be noted that no accident data was analyzed or available. **Figures 16**, **17** & **18** illustrate the implemented Chambly Roundabout design.



⑤ APPROXIMATELY 985ft FROM THE ROUNDABOUT (BETWEEN TWO ROUNDABOUTS)
Boulevard Anne-Le-Seigneur
④ ENTRANCE OF THE ROUNDABOUT
R130
R181
③ THE MIDPOINT OF THE MEDIAN ISLAND (230ft FROM THE ROUNDABOUT)
R181
R350
② THE START OF THE MEDIAN ISLAND (450ft FROM THE ROUNDABOUT)
Boulevard Fréchette
GENIVAR

Table 11: Chambly Speeds After Construction

Calculations Based on Actual Measured Speeds

Survey Location	Average Speed	85th Percentile Speed	Highest Speed	Lowest Speed	Posted Speed
Point 1	58	63	69	45	55
Point 2	39	45	54	26	55
Point 3	29	32	38	21	55
Point 4 (Entry)	**13**	**16**	**20**	**8**	55
LOCATION OF MODERN ROUNDABOUT					
Point 5	37	41	45	26	45

Source: ORE/RTE *RTE High Speed Approach Tables.xls*

Figure 16: NB Approach

Figure 17: WB Approach

Figure 18: NB Approach Oncoming

CASE STUDY 3: NOVELTY ROUNDABOUT

This case study intersection is located along State Route 203 (Carnation-Duvall Road) at NE 124th Street in the Snoqualmie River Valley in rural King County, Washington. Carnation-Duvall Road NE (SR-203) is a state highway that follows the east bank of the Snoqualmie River from SR 202 in Fall City to US 2 east of Monroe. NE 124th Street is a minor arterial that crosses the Snoqualmie River and connects the West Snoqualmie Valley Road NE in the west to Carnation-Duvall Road NE (SR-203) and Duvall in the east. Please refer to **Figure 19** for the roundabout design plan conceptual layout and **Figure 20** for a vicinity map of the Washington area where the Novelty Roundabout is located.

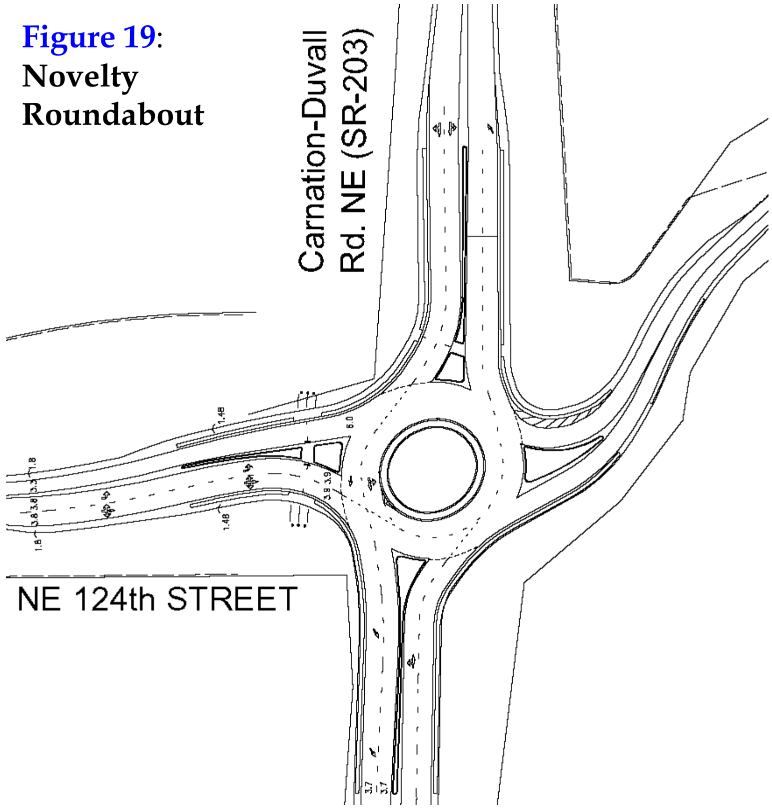


Figure 19: **Novelty Roundabout**

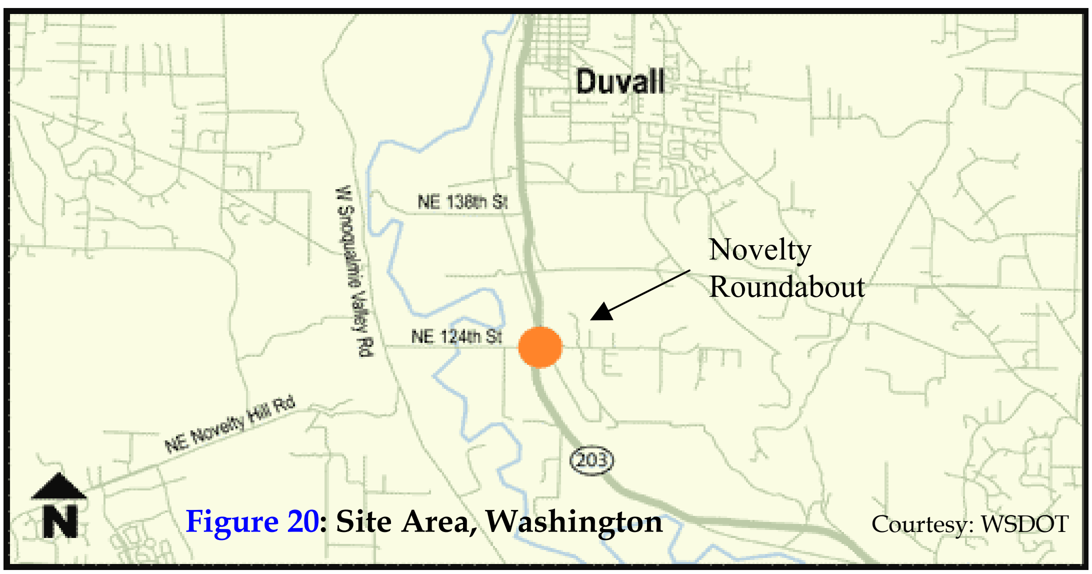


Figure 20: **Site Area, Washington**

The site conditions are rural and mountainous with high-speeds along SR 203 and NE 124th Street. The existing rural stop controlled intersection location was experiencing a high amount of high-speed crashes in which WSDOT needed to remedy. The submitted roundabout design above (**Figure 19**) was admired by the WSDOT engineers, but later discarded by the safety reviewers since it was **perceived** that "*roundabouts are unsafe on high speed roads*." As a result of this high-speed concern, WSDOT requested high-speed crash comparisons between traffic signals and modern roundabouts installed in the U.K. Although there are many roundabouts located along high-speed roadways implemented in the U.K. with an abundance of crash data available, there are very few traffic signals still remaining in the U.K. that have not been converted to roundabouts. Hence, the comparisons could not be made strictly from U.K. data. However, WSDOT decided to compare local state traffic signal crash history data on high-speed roadways to the crash history data at modern roundabouts found in the U.K. with high-speed approaches. The results of this comparison were reported in Section II (Safety Statistics and Comparisons) of this report.

In summary, as a result of the data, the roundabout was reinstated for design. **Figure 20** is a rendering of the roundabout design concept prior to construction. **Figure 21** illustrates a portion of the intersection prior to implementation of the roundabout. **Figure 22** shows another portion of the intersection near construction of the roundabout in August of 2004. Finally, **Figures 23** and **24** present the completed roundabout without landscaping yet installed in October of 2004.

Figure 20: **Roundabout Rendering Prior to Construction**

Figure 21: SR 203 Before Construction

Figure 22: Near the Start of Construction

Figure 23: Northbound View of Roundabout as of October 2004

Figure 24: Southbound View of Roundabout as of October 2004

Based on the design plans for the Novelty Roundabout, the entry radii and fastest path speeds are shown in Table 12 below. Washington State Department of Transportation staff as well as the State Patrol Office has indicated that there have not been any reports of collision problems at the intersection within the past six months. Since the roundabout is operating well, WSDOT has no plans to conduct any speed studies. This suggests that the early reports of safety performance indicate improvements over the previous type of intersection control.

Table 12: Novelty Roundabout Speed Predictions

Based on Design Plans Fastest Path Speeds

SR 203 / NE 124th Street

Design Parameter	Southbound		Northbound		Westbound		Eastbound	
	R1	R2	R1	R2	R1	R2	R1	R2
Radius (ft)	400.2	229.7	308.4	177.1	52.5	219.8	141.6	134.5
Speed (mph)	36	27	32	25	17	27	25	22

Source: ORE/RTE *RTE High Speed Approach Tables.xls*

CASE STUDY 4: TOWNLINE ROUNDABOUT

This case study is a three-way or "T" intersection with the north and south approaches on Townline Road and the east approach on Can-Amera Parkway in Waterloo, Ontario. The existing posted speed limit on both roads is 60 km/h (37 mph). The 85th percentile speeds on the approaches are approximately 70 km/h (44 mph) on Townline Road and 75 km/h (47 mph) on Can-Amera Parkway. The site conditions are rural with relatively high-speeds along both roadways. The previous stop controlled intersection location was experiencing a high amount of high-speed crashes. Based on the fastest path design plans, the predicted speeds on the Townline Road approaches of the roundabout are reported in **Table 13**. The actual measured speeds of the roundabout were obtained and calculated with respect to the highest, lowest, 85th percentile, average, and standard deviation of the data for all approaches at the roundabout. **Table 14** provides a summary of the results. The submitted roundabout design is shown in **Figure 25**.

Table 13: Townline Predicted Speeds

Based on Design Plans Fastest Path Speeds
Townline Road / Can Amera Parkway

Design Parameter	Southbound R1	Southbound R2	Northbound R1	Northbound R2
Radius (ft)	252.6	157.5	305.1	114.8
Speed (mph)	30	24	32	21

Source: ORE/RTE *RTE High Speed Approach Tables.xls*

Table 14: Townline Speeds After Construction

Based on Actual Measured Speeds Conducted After Construction
Townline Road / Can-Amera Parkway

Speeds (mph)	Northbound Entering	Northbound Exiting	Westbound Entering	Westbound Exiting	Southbound Entering	Southbound Exiting
Average	16	25	20	26	16	24
Standard Deviation	3	4	5	4	4	3
85th Percentile	20	30	25	30	21	27
High	23	37	29	34	26	30
Low	11	16	3	14	11	19

Source: ORE/RTE *RTE High Speed Approach Tables.xls*

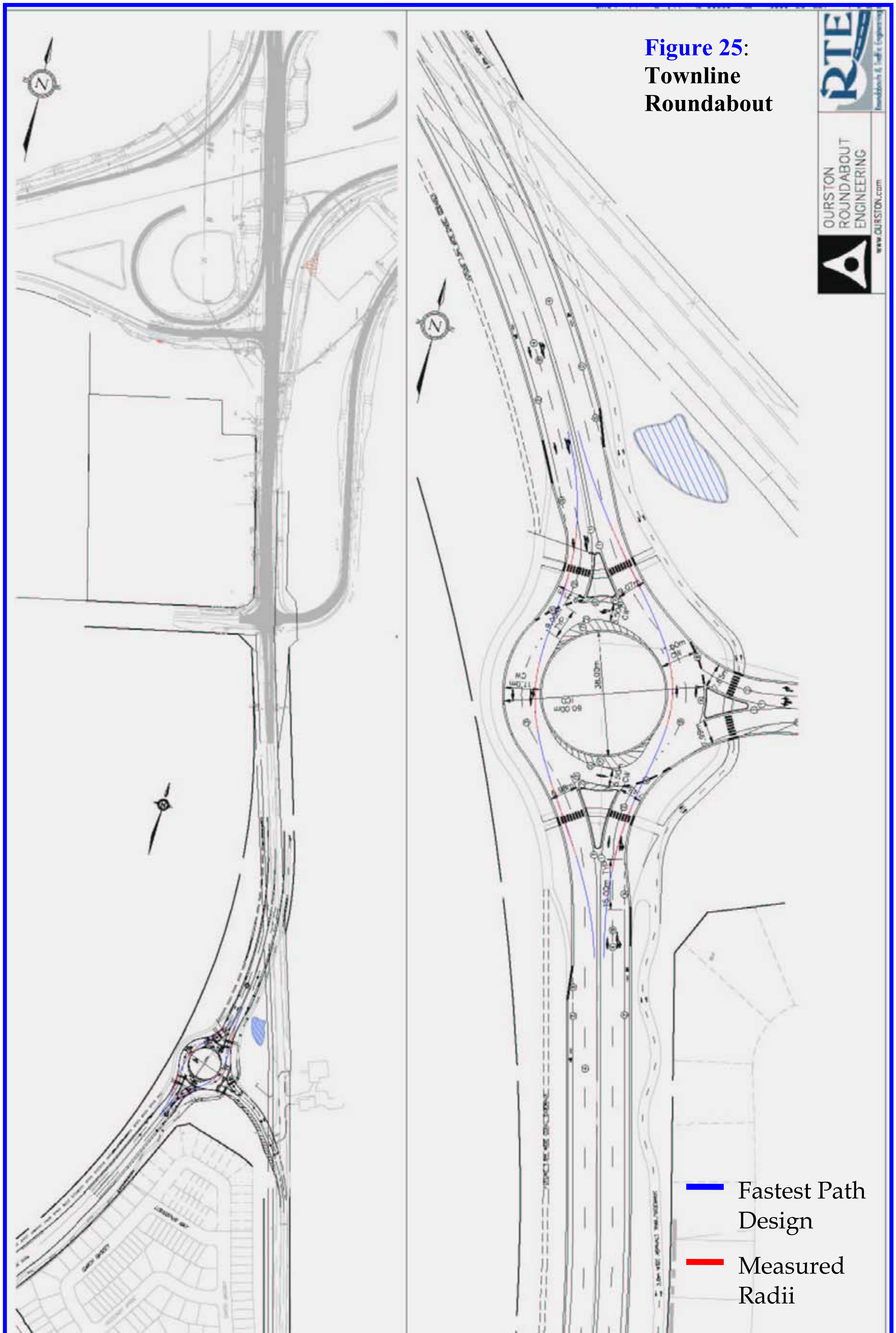


Figure 25: Townline Roundabout

As shown in the tables above, the measured speeds at the roundabout are slightly less than the predicted design speeds. These are positive results. Another noting factor with this rural high-speed roundabout are the implemented sign designs. The signs at the multi-lane Townline Roundabout aid in detecting the presence of the roundabout ahead, deciding on the correct entry lane to use, and slowing to an appropriate speed. Signs at multi-lane roundabouts also aid in deciding on the correct exit to use. The photos in Figures 26 and 27 are good examples of proper signing at modern roundabouts.

Figure 26: **Correct Maptype Sign**

Figure 27: **Correct Exit Sign**

For more information about recommended signing procedures for modern roundabouts, a publication was recently written by Phil Weber with ORE and Scott Ritchie with RTE for the Transportation Research Board that provides an eight step signing procedure for modern roundabouts, the introduction of new signs for North America such as the map-type sign, and guidance on the placement location of advanced warning signs at roundabout approaches.[5]

CASE STUDY 5: M-53 ROUNDABOUT

Specific crash or speed data at the M-53 Roundabout were unobtainable since the project was still under construction; however, it is worth noting the project as another implemented roundabout currently functioning well on high-speed roadways in North America. The roundabout is located at 18 ½ Mile Road in Sterling Heights and the M-53 Freeway (Van Dyke Freeway) in Macomb County, Michigan. On May 12, 2004, a partnership was formed between MDOT, the Road Commission for Macomb County and the City of Sterling Heights to widen

[5] Roundabout Signing Guide, A Recommended Practice, 1st Edition, Scott Ritchie, P.E., Roundabouts & Traffic Engineering and Phil Weber, P.Eng. Roundabouts Canada, 2005

18 ½ Mile Road between Mound and Van Dyke, construct a roundabout at 18 ½ and Van Dyke, and create direct access from 18 ½ to the M-53 Freeway.

The two by three lane roundabout has on and off-ramps to the M-53 Freeway with all of its approaches classified as high-speed roadways. The roundabout opened in December of 2004 and remaining construction will be completed in July 2005. **Figure 28** is an aerial photograph and map of the surrounding area. **Figure 29** illustrates the conceptual roundabout design that was implemented. The east and south legs connect to the M-53 Freeway (70 mph) and the other legs connect to arterials (45 mph).

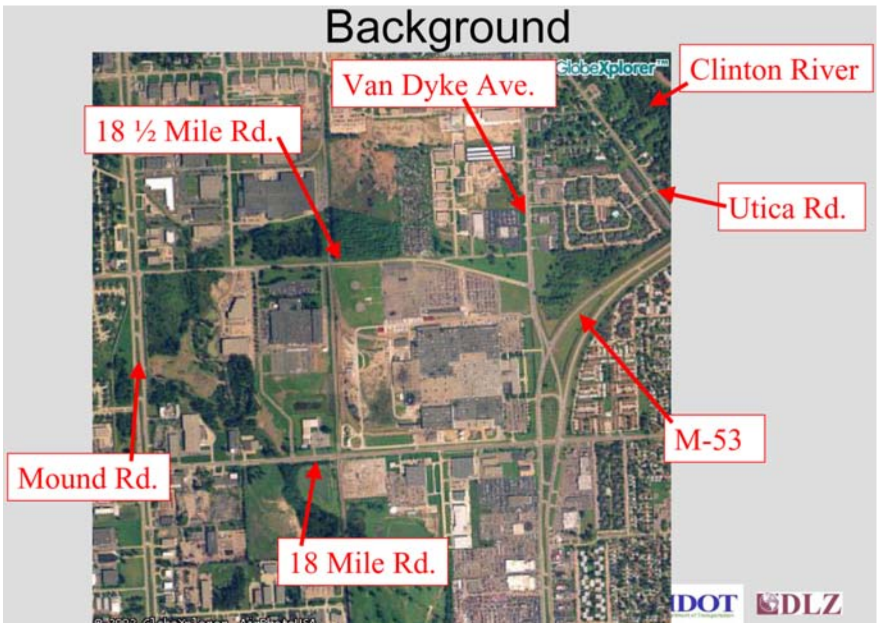


Figure 28: Surrounding Roadways and Map (Courtesy: MDOT)

The M-53 Project was inaugurated to increase safety and promote mobility in the rapidly growing and congested Macomb County area. The $16.8 million dollar project at Van Dyke Avenue and 18 ½ Mile Road includes the construction of the new M-53 Freeway ramps, a southbound M-53 bridge over the new ramps to access Van Dyke Avenue, upgrading the Mound Road intersection at 18 ½ Mile Road, and constructing a modern roundabout at the intersection of 18 ½ Mile Road, Van Dyke Avenue, and the M-53 entrance/exit ramps.

MDOT has placed a mobile video surveillance camera at the northeast quadrant of the intersection (freeway located to left), which has limited access to the public for safety purposes. **Figures 30** through **34** show images of the roundabout functioning during off-peak hours to illustrate the design, high-speed roadways, and its well functioning traffic at the roundabout's entries and exits. Metro Region Engineer Greg Johnson states, "The project will benefit residents and commuters alike by reducing congestion and improving safety between Mound Road and Van Dyke Avenue by widening 18 ½ Mile Road and constructing the roundabout."

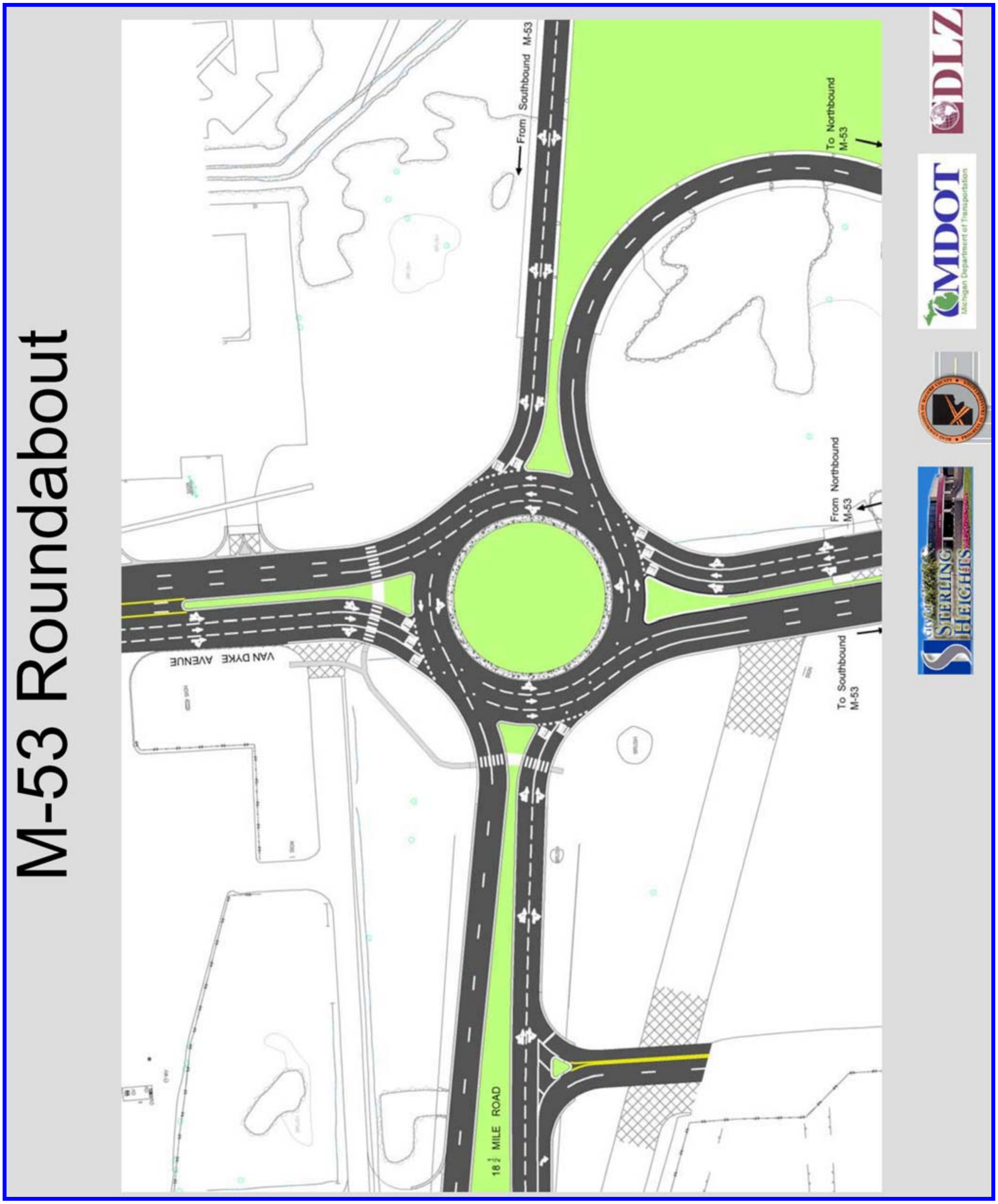

M-53 Roundabout
From Southbound M-53
To Northbound M-53
From Northbound M-53
To Southbound M-53
VAN DYKE AVENUE
18 ½ MILE ROAD
DLZ
MDOT
Michigan Department of Transportation
Sterling Heights

Figure 30: SB M-53 Ramp

Figure 31: SB M-53 Ramps

Figure 32: NB M-53 Ramps

Figure 33: 8 ½ Mile Road

Figure 34: Van Dyke Avenue Approach

All of the entries at the M-53 Roundabout are high-speed approaches. The roundabout design accommodated the multi-lane high-speed approaches with proper roundabout design principles such as:

- Well designed entry angles (phi angle)
- Proper entry radii for deflection based on fastest path design
- Adequately sized roundabout diameter and placement of the circle
- Appropriate entry lane widths for adequate side friction as well as truck maneuverability
- Tangential entry lanes for reduced entry path overlap
- Proper exit radii with large values for speed consistency

In addition the roundabout design incorporated additional non-geometric design high-speed mitigation measures such as:

- An increased number of chevrons on the central island
- Advanced warning maptype signs,
- Asphalt in the circulating roadway instead of concrete as shown on the approaches of the roundabout. This increases the effectiveness of the striping and pavement arrows in the circulatory roadway for added driver comprehension and safety.
- Repeated thermoplastic arrows and markings
- Visible crosswalks

As this triple lane roundabout configuration in Michigan begins to receive higher traffic volumes and local drivers learn to utilize the facility with increasing driver comfort, speed studies should be conducted for additional analyses in the future.

CONCLUSIONS & DESIGN TREATMENTS

STUDY CONCLUSIONS

This report has provided case studies and statistics of hundreds of roundabouts studied by recognized world leaders in the roundabout consulting profession as well as other organizations and jurisdictions throughout the globe. All of the statistics and case studies have one common and obvious conclusion: the modern roundabout is proving to be a superior traffic control device versus any other intersection control type. As stated in the introduction of this report, the modern roundabout, coupled with good design practices and additional geometric and non-geometric design measures such as proper signing and landscaping, are the traffic control devices of choice for intersections in most countries throughout the world. Modern roundabouts have been proven to provide the safest at grade intersection type for interaction between road users. The modern roundabout is a self-regulating traffic control device that creates a controlled environment by proper geometric design of roadway widths, curves, medians, lighting, signing, striping, and landscaping designed to regulate traffic speeds.

The case studies in this report and the other documented studies acknowledged modern roundabouts on roadways with high-speed approaches as effective with a proper design. It should be noted that a competent roundabout design specialist designed all of the case studies represented in this report. The installation of a roundabout will not always result in a safe, accident or speed reducing intersection if an inadequate design is implemented. Examples of modern roundabouts completed with unsafe geometric elements are briefly shown below. In short, this report resolves the concern of whether modern roundabouts are appropriate at intersections with high-speed approaches based on quantified and qualified safety research and well-performing roundabout designs already constructed. We have concluded the following from this review of the application of roundabouts to high-speed intersections:

- Statistically, roundabouts are the most appropriate control for intersections with high-speed approaches.

- There is not yet sufficient statistical evidence of a correlation between the geometric design of high-speed approaches to roundabouts and the resulting safety performance in North America. This is primarily due to the fact that there is little data currently available. However, several geometric design treatments are commonly used in other countries that show promise in rural high-speed conditions.

- There are statistically proven relationships between roundabout geometry and safety performance from Great Britain, the trends of which would not be to the contrary in North America.

- Several roundabouts examined for their speed characteristics and safety performance are showing early signs of positive safety performance in North America. These case studies and sites all have several common elements:

    - Entries are visible to drivers from a safe stopping distance;

    - The entries are designed so that the speeds corresponding to the fastest entry paths are consistently low and correlate well with the predicted entry speeds. Entry speeds are also reduced sufficiently to promote yield at entry by being comparable to circulating traffic speeds; and,

    - There are early indications that extending the diverter or splitter islands to a distance equal to the deceleration length from approach speed to entry speed is an appropriate treatment for high-speed approaches.

    - Properly landscaped central islands with adequate use of trees, rocks, and other noticeable obstructions that prevent driver "see through" is one of the most important and effective mitigation measures to reduce accidents.

Advance signage combined with a visible driving situation with appropriate landscaping and a well-illuminated intersection all contribute to the good safety performance currently being observed at roundabout sites.

HIGH SPEED DESIGN TREATMENTS

This section demonstrates geometric design treatments or major elements of design currently used for high-speed approaches at roundabouts throughout the world.

Since approach speeds are higher in rural areas than urban or local streets and drivers generally do not expect to encounter speed interruptions when approaching rural high-speed intersections, we have examined guidelines from various agencies to describe the geometric considerations for rural high-speed conditions. The measures described herein are aimed at mitigating the effects of high speeds on intersection safety using modern roundabouts. Several of the case studies above exhibited these characteristics.

Experience with other types of intersections indicates that there are four basic demands of a safe intersection design. These basic tenets of intersection safety are made practical and gain significance through the range of design elements.[6]

1. Clarity of the situation for approaching drivers
2. Visibility between road users
3. Comprehensibility of traffic operations
4. Space for the largest permitted vehicles

The primary safety concern in high-speed context is clarity of the driving situation, that is, to make drivers aware of the roundabout with ample distance to comfortably decelerate to the appropriate speed. Therefore, roundabout designs should follow these general principles:

- Only provide the ***minimum*** stopping sight distance at the entry point of a roundabout based on approach operating speeds. Do not provide an ample amount of clear sight view of other approaching drivers to allow too fast of entry speeds.

- Align approach roadways and set vertical profiles to make the central island conspicuous with appropriate landscaping and sight blocking amenities.

- Splitter islands should extend upstream of the yield line to the point at which entering drivers are expected to begin decelerating - a minimum length of 200 feet is recommended.

- Use landscaping on extended splitter islands and roadside to create a tunnel effect for approaching vehicles.

- Provide roadway illumination in transition to the roundabout.

- Use signs and markings effectively to advise of the appropriate speed and path for approaching drivers.

[6] Mark Lenters, P. Eng., Safety Auditing Roundabouts, prepared for presentation at the 2005 Transportation Research Board Conference on Roundabouts Vail, Colorado

The consequences of an inconspicuous central island and/or splitter islands is mainly loss of control crashes as motorists unfamiliar with the roundabout are not given sufficient visual information to see the central island and roundabout geometry to elicit a change in speed and path. Roundabout landscaping designs in the central island should adequately block the through sight distance of an approaching driver so that the driver sees a physical obstacle in the roadway.

In addition to the above, for safety, it is crucial to provide sufficient deflection in the design of a roundabout's entry approach. The concept is to slow vehicles down ***before*** they reach the yield line, not as they reach it, and not after they have entered the roundabout. If the entry is overly tangential, then vehicles tend to arrive at the conflict point too fast, leading to unnecessary crashes between entering and circulating vehicles. Conversely, if the entry path curvature is too tight, as with perpendicular or sharply curved entries, then there is a rise in single vehicle crashes resulting from loss of control on the approach to the roundabout.

When considering the effects of entry path curvature, it should be recognized that approach-related single-vehicle type of crashes associated with perpendicular or sharply deflected entries tend to be higher speed and result in more severe injuries. Thus, conventional design with nearly perpendicular entries is undesirable at high-speed rural intersections where it is important to reduce speed with approach and entry geometry that gives the driver sufficient guidance as to appropriate entry speed in addition to the obvious visual clue of a central island barrier. Entry path curvature is vital to establishing natural paths for multi-lane roundabout entries to prevent overlap of parallel streams of traffic upon entry. The illustrations below depict examples of too much deflection (**Figure 35**) and insufficient deflection (**Figure 36**).

Figure 35: An Over-deflected Entry
(But good use of landscaping on the splitter island prior to entry)

Figure 36: Insufficient Entry Path Curvature
(This layout also suffers from an entry path overlap creating safety and capacity issues)

The conditions shown in **Figure 35** control the speed of entry, but are prone to approach type crashes such as rear end, side swipe, and single vehicle crashes if entering traffic flow is higher using both travel lanes. This condition can lead to overlap of the paths of two entering vehicles upstream of the entry. **Figure 36** depicts a condition that is prone to entry circulating crashes and overlap of the paths of two entering vehicles in the roundabout. Tight entry radii coupled with insufficient entry path curvature produces a combination of crash results. Although this roundabout was recently completed in 2004 on US Highway 6 in Avon, Colorado, the designer did not recognize the multiple problematic issues such as crash related safety hazards, capacity reducing geometry, and high approach speeds.

Speeds on roundabout approaches and in the roundabout can be lessened with subtle design changes. In **Figure 37**, the fastest path R1 value is 177 feet, which translates to about 26 miles per hour. In **Figure 38**, the R1 value is 135 feet, which translates into an approach speed of 24 miles per hour. This is a reduction of nearly 2 mph in the fastest path design of the roundabout's approach. This is achieved by tightening the radii on the approach and by providing a slight deflection on the approach in the magnitude of feet and inches. The deflection on the approach forces drivers to slow their vehicle before coming into the roundabout. An alternative to this treatment is to enlarge the inscribed circle diameter, though this is not always feasible when property is constrained. Enlarging the roundabout diameter also increases circulating speeds which have a negative effect on adjacent approaches with slower entering speeds.

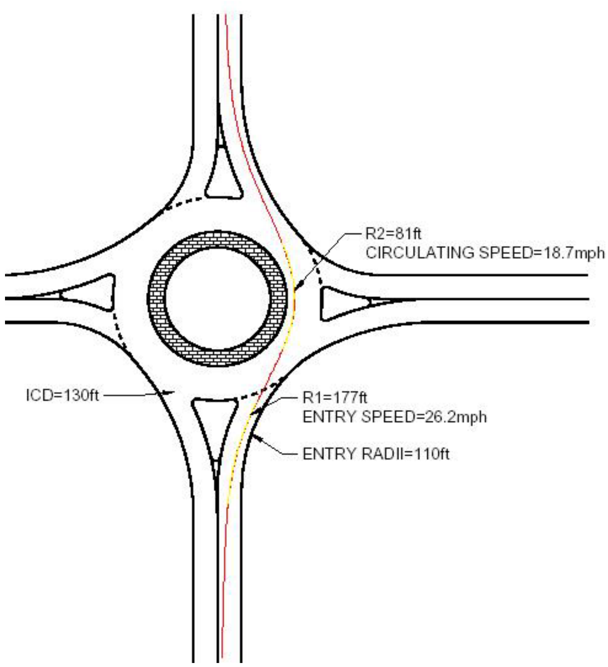


Figure 37: **Fastest Path**

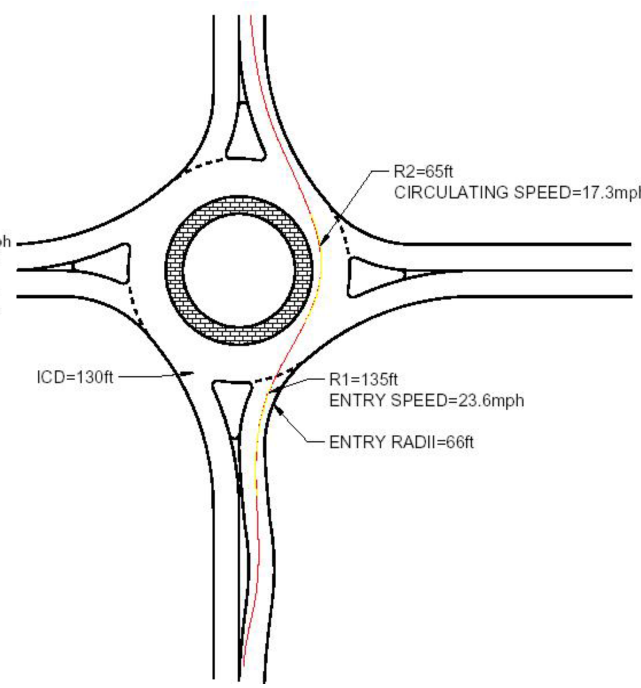


Figure 38: **Fastest Path with Minor Design Modifications**

There are two alternative design treatments for splitter island design aimed at mitigating the effects of high rates of speed of traffic approaching a roundabout. The first is to size the length of the splitter island according to the deceleration distance, or the distance over which the speed reduction between the approach speed (posted) and the entry speed (20 mph) occurs. For example, the calculated difference between a 50 mph approach speed with a 20 mph entry speed is 30 mph. This would correspond to a deceleration distance and a splitter island length of 300 feet for this high-speed approach.[7] The practical side of this design concept is a physical point of obstruction or clue for drivers to begin reducing speed at the end of the splitter island bull-nose. An illustration of this treatment is shown in Figure 39 with the completed design implemented in Figure 40.

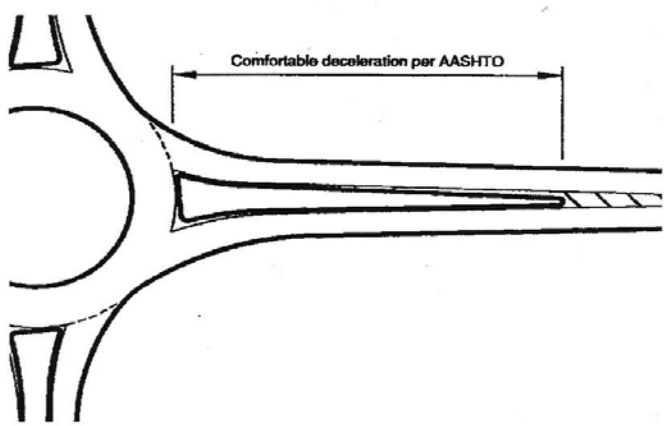


Figure 39: Splitter Island Extension

Figure 40: Splitter Island Extended

Correspondingly, driver behavior characteristics show that drivers use the beginning an urban section or roadway to begin to reduce their speed. If a roundabout designer uses the same idea above to determine the length of curb and gutter on a typical rural approach to a roundabout, the driver will comfortably begin to reduce speed in the same location. Therefore, a splitter island extension in high-speed conditions and an extension of an urban cross-section in the rural context of high-speed approaches are practical mitigation measures for roundabouts as well as conventional intersections.

[7] AASHTO Manual, Exhibit 2-25

An Australian research team[8] developed a method to achieve speed reduction using successive curves on the approaches to decrease the approaching rear-end vehicle crash rate and the entering-circulating and exiting-circulating vehicle crash rates. They investigated extending the splitter island but with a series of inflection curves or increasing radius to transition speeds from the background posted limit to the desired entry speed.

Although renowned roundabout design specialists in the U.K. caution against using such methods due to increased approach accidents at or prior to entry, studies still need to be conducted to verify this type of Australian design. The risk associated with this high-speed mitigation measure is that decreasing the radius of an approach curve may increase the single-vehicle crash rate on the curve, particularly when the required side-friction for the vehicle to maintain its path is too high. On multi-lane approaches this may encourage drivers to cut across lanes and increase sideswipe crash rates on the approach curve. Examples of this treatment are illustrated below in **Figures 41** and **42**.

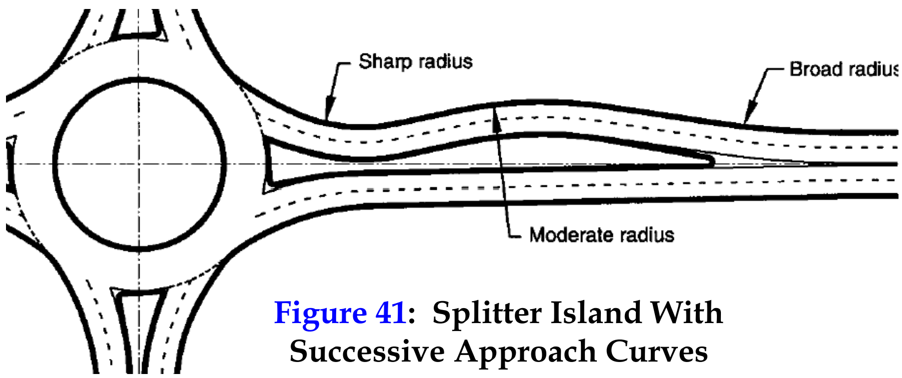


Figure 41: Splitter Island With Successive Approach Curves

Figure 42: Successive Approach Curves Implemented

[8] Queensland Department of Main Roads (QDMR). Relationships between Roundabout Geometry and Accident Rates. Queensland, Australia: Infrastructure Design of the Technology Division of QDMR, April 1998.

The *Relationships between Roundabout Geometry and Accident Rates* study conducted by the Queensland Department of Main Roads (QDMR) in Queensland, Australia, found that for multi-lane approaches, it was determined that shifting the approach roadway approximately 23 feet laterally enables adequate curvature while keeping the curve length to a minimum. The design guidelines derived from that study also provide a set of equations for two and four lane high-speed roads.

For two-lane rural roadways:

$$V85 = 64.37 – 1.21(D), D > 30$$
$$V85 = 60.7, D < 30$$

For four-lane rural roadways:

$$V85 = 64.7 – 1.21(D)$$

Where: V = 85th % speed, mph
D = Degree of curvature, degrees = 5729.58/R
R = radius of curve, feet

However, this Australian research with curvilinear approaches still needs further clarification on the type of crashes considered in the research.

In addition, it should be pointed out that at high-speed approaches at roundabouts, increasing entry radius (R1) may be desirable depending on the circulating volumes conflicting with the particular approach and the circulating speeds of the roundabout. The consideration of a two-lane entry with a short flare length also is a method of making the entry less restrictive. Too much restriction on a high-speed approach appears less safe. If circulating flows are higher, a two-lane approach may be needed regardless. The roundabout diameter (ICD) may also need to be increased slightly with a larger R1 value. The tables identified in the FHWA *Roundabouts: An Informational Guide* requiring small R1 values with smaller ICDs may need revising.

HIGH SPEED NON-GEOMTERIC TREATMENTS

In addition to the elements of geometric design for high-speed approaches mentioned above, there are also numerous other non-geometric design treatments for high-speed approaches at roundabouts that are recommended by RTE. Some of the ***non-geometric*** design treatments for modern roundabouts as well as high-speed approaches at roundabouts are as follows:

- Delineation markers at entry (illustrated above)
- Proper lighting placement before, at, and after the roundabout
- Landscaping the central island properly
- Avoid excessive signing prior to or at entry
- Landscaping the splitter islands prior to entry
- Detached sidewalks with planters
- Landscaping the roadway between the face of curb and sidewalk
- Internally illuminated exit signs (such as in Vail, CO)
- Increased chevron signs on the central island
- Increased chevron sign sizes on the central island
- Effective advanced warning signs (maptype)
- Long hatched areas (pavement markings), opposed to long splitter islands
- Repeated lane assignment arrows
- The use of thermoplastics instead of paint
- Internally illuminated bollards
- Transverse yellow bar markings

The general conclusions from the *non-geometric* design solutions for high-speed approaches at roundabouts listed above can be summed into the following five points:

1. Make the roundabout and the need to slow down clear to the driver at the stopping sight distance point with various treatments such as long splitter islands, extended curbing, transverse yellow bar markings, thermoplastic crosswalk and yield stripes, and long hatching or striping.

2. Make the roundabout very visible during the day with foliage, chevrons, and illuminated bollards. Avoid excessive signing at roundabouts as this hinders the driver's ability to see the roundabout itself, pedestrians, crosswalks, and most importantly the "yield" signs.

3. Make the roundabout very visible during the night with illuminated bollards, illuminated signs (internally or externally), and street lighting.

4. Use much larger U.K. style chevrons. The larger, extended and repeated chevrons are often required for high-speed approaches in other countries.

5. Add side friction on single lane approaches with planters, curbing, trees, splitter islands, or the like.

6. Create a "tunnel effect" for the approaching vehicles with both geometric and non-geometric treatments.

One of the items listed above that the authors of this study highly recommend at all roundabouts that are not found in North America with the exception of a couple recently implemented designs, is the internally illuminated bollard. The U.K. has discovered a 30% reduction in accident rates with the use of the internally illuminated bollard. Although the first mini roundabout in the United States implemented the U.K. style bollard, the authors of this report have been working with manufacturers in the U.K. to develop an internally illuminated bollard that meets the Manual of Uniform Traffic Control Devices (MUTCD) standards. The typical "KEEP RIGHT" sign typically found on medians or splitter islands at roundabouts throughout the U.S. is shown below in Figure 43. An illustration of the newly developed internally illuminated bollard with the MUTCD "keep right" symbol on it is shown below in Figure 44. Figure 45 shows the typical U.K. style bollard implemented.

Figure 43: MUTCD "KEEP RIGHT" sign

Figure 44: Internally Illuminated Bollard with MUTCD "KEEP RIGHT" symbol

Figure 45: U.K. Style Internally Illuminated Bollard

The recommended bollard (Figure 44) for roundabouts in North America is highly durable and flexible for use in any type of conditions, especially in snow country. The bollard is compliant with the MUTCD. In addition, Vail Colorado has implemented internally illuminated arrow-shaped exit signs that are proving extremely useful in winter conditions for increased visibility and safety.

Another item on the list of non-geometric high-speed treatments above not commonly used in North America but used in other countries successfully are transverse yellow bar markings. The Department of Transport Highway, Safety and Traffic Departmental Standard (TD 6/79) which covers the use of transverse yellow bar markings at roundabouts is an appropriate tool for use at high-speed approaches at roundabouts with accident issues due to high speeds. The standards explain the criteria controlling the use of transverse yellow bar markings at roundabouts and provide additional details of the pattern to be laid and material to be used in the design. Studies conducted by the Transport and Road Research Laboratory have shown that transverse yellow bar markings are appropriate contributions to road safety when placed on the approaches of roundabouts where there is a history of speed related accidents. However, only suitable sites and prior authorization of headquarters is required to ensure that the markings are used only at sites with similar characteristics in the TRRL studies. The TRRL criteria are also sensitive to surrounding area conditions and intersections before consideration of use. In general, the bar markings are placed successively with decreased spacing to create the illusion to the driver of an increase in speed despite the fact that the vehicles speed may be decreasing. An illustration of an implemented example of the transverse yellow bar markings at a roundabout is shown in **Figure 46**.

Figure 46: Transverse Yellow Bar Markings at Roundabout Approach

This report does not provide further discussion and design illustrations of all of the possible non-geometric design treatments as the remaining treatments may be found in other available standards and manuals. However, these few key treatments illustrated and listed above are recommended for roundabouts with high-speed approaches (where appropriate). In conclusion, it is recommended that any modern roundabout design have a qualified roundabout expert involved in the geometric design, non-geometric design, and construction process for a project.