Report No. UT- 04.10

EVALUATION OF FOUR RECENT TRAFFIC AND SAFETY INITIATIVES

Volume I: Developing Guidelines For Roundabouts

FINAL REPORT

Prepared For:

Utah Department of Transportation Research and Development Division

Submitted By:

Brigham Young University
Department of Civil & Environmental Engineering

October 2005

UDOT RESEARCH & DEVELOPMENT REPORT ABSTRACT

1. Report No. UT – 04.10	**2. Government Accession No.**	**3. Recipients Catalog No.**
4. Title and Subtitle **EVALUATION OF RECENT TRAFFIC AND SAFETY INITIATIVES, VOLUME I: DEVELOPING GUIDELINES FOR ROUNDABOUTS**	5. Report Date June 2004 **6. Performing Organization Code**	
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9. Performing Organization Name and Address Brigham Young University, Civil & Environ. Eng. Provo, UT 84602	**10. Work Unit No.** **11. Contract No.**	
12. Sponsoring Agency Name and Address Utah Department of Transportation 4501 South 2700 West Salt Lake City, UT 84119-5998	**13. Type of Report and Period Covered** Final Report, February 2003 – June 2004 **14. Sponsoring Agency Code**	

15. Supplementary Notes
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16. Abstract
Roundabouts have become increasingly popular in the United States in the past ten years. UDOT has recently installed three roundabouts on its state highways (Park City, Lehi, and Bloomington). Requests for installation of roundabouts replacing traditional intersections are expected to grow. However, UDOT does not have specific guidelines or criteria to judge whether roundabouts would be appropriate for the requested sites. The intent of this project was to summarize the key issues concerning roundabouts and develop a preliminary draft of design guidelines and policies that could be used for the implementation of a roundabout instead of some other form of intersection.

Only a few state DOTs had design guidelines on roundabouts at the time of the study. US experiences have not been adequate for creating solid, universal design and analysis guidelines on roundabouts and at the time of the study, a multi-year NCHRP study has just started. The leading software packages used for the design, analysis, and simulation of roundabouts are originated in other countries, such as RODEL (United Kingdom) and aaSIDRA (Australia), where roundabouts have been in existence for many years and in numbers. The former is empirical based on thousands of roundabouts and the latter is based on the gap theory. Engineers do not agree on the best methodology for analysis, and therefore, various software packages with different methodologies exist. The HCS and Synchro 6.0 software programs have gap-based models and their analysis capabilities are not at the level of sophistication as the foreign counterparts.

The NCHRP study (NCHRP) 3-65 Applying Roundabouts in the United States is about to be completed at the time of the publication of this report and it is recommended that this report be referenced.

17. Key Words Roundabout, Performance, Design, Safety, Guidelines	**18. Distribution Statement** No Restrictions. Available from: Utah Department of Transportation Research Division Box 148410 Salt Lake City, Utah 84114-8410 Brigham Young University Department of Civil and Environmental Engineering 368CB Provo, Utah 84602

19. Security Classification (For this report)	**20. Security Classification (For this page)**	**21. No. of Pages**	**22. Price**
None	None		

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ACKNOWLEDGEMENTS

This research was made possible with funding from the Federal Highway Administration, the Utah Department of Transportation and Brigham Young University.

Special thanks to the following people at the Utah Department of Transportation (UDOT). Additional thanks to everyone else at UDOT who helped the researchers to complete this study.

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1. INTRODUCTION

Roundabouts have become increasingly popular in the United States in the past ten years. UDOT has recently installed three roundabouts on its state highways (Park City, Lehi, and Bloomington). Requests for installation of roundabouts replacing traditional intersections are expected to grow. However, UDOT does not have specific guidelines or criteria to judge whether roundabouts would be appropriate for the requested sites. The intent of this project was to summarize the key issues concerning roundabouts and develop a preliminary draft of guidelines that could be used for the implementation of a roundabout instead of some other form of intersection.

1.1 Historical Background of the Modern Roundabout

The modern roundabout is a form of intersection control with one directional circulating flow around a central island. Its predecessor, the traffic circle, also called gyratory or rotary, was first installed in 1905 in New York City. This early design was not well received in the United States and was soon declared to be an ineffective form of intersection control by most traffic engineers (Oregon 1998). Despite its weaknesses, various European nations continued to implement traffic circles, changing and altering the design in order to improve the performance. In the mid 1960s England introduced two fundamental changes that now define the modern roundabout (Arizona 2003). These elements are:

- Yield control at all entries
- Geometric design that promotes slow and consistent speeds

Table 1.1 presents these and the other significant differences between the traffic circle and the modern roundabout (Adapted from Oregon 1998).

Table 1.1 The Traffic Circle and The Modern Roundabout

	Traffic Circle	Modern Roundabout
Priority and Operation	Entering traffic has the right-of-way. (Circulating traffic must yield) Conflict resolved through weaving.	Circulating vehicles have the right-of-way. (Entering traffic must yield) Conflict resolved through gap acceptance.
Traffic control	Stop signs, signals or no control on entry.	Yield control on all entries. No control on circulatory roadway.
Deflection	Tangential entries on some circles. Straight path through roads on some circles. (Allows higher speeds on major route)	No tangential entries, no through roads. All entering traffic is deflected. (Forces lower speeds on all routes)
Parking	Parking permitted on some larger circles.	No parking is allowed on central island or inside the roundabout.
Pedestrian Access	Pedestrian access is allowed on some central islands.	Pedestrian access is allowed only across the legs, behind the yield line.
Splitter Island	Optional.	Required.
Turning Movement	Some circles allow left turns prior to the central island without having to circulate.	All vehicles circulate around the central island.
Flares	No flares, lanes not added at entry.	Lanes added at entry through flaring. (Allows increased capacity at intersection only, while not increasing the number of lanes on approaches)

Throughout Europe and the United States traffic circles have been retrofitted to the modern roundabout design. Figure 1.1 shows a traffic circle on State Route 28 near Ulster, New York that was retrofitted with a modern roundabout in 2000. In the photo, the traffic circle encompasses the much smaller modern roundabout (Arnold 2000).

Figure 1.1 A Traffic Circle Retrofitted with a Modern Roundabout.

The advances in design and operation have prompted a resurgence of roundabout implementation worldwide. France is leading this movement with an estimated 15,000 roundabouts in operation and an installation rate of 1000 per year (NCHRP 1998). Within the last ten years roundabout usage has increased in the United States. Nonetheless implementation has been relatively slow with less then 300 modern roundabouts in operation. The primary reasons for hesitation are: the failure of the traffic circle, a skeptical perception of performance and safety, lack of state guidelines and a fear of disapproval from politicians and the public (Arizona 2003).

1.2 Key Features of the Modern Roundabout

There are a variety of roundabout designs being implemented worldwide. One form of roundabout, commonly called a "mini", is not suited for state routes. Mini roundabouts are intended for traffic calming in low-speed urban areas. The majority of the operational and proposed roundabouts in the United States are considered "normal" modern roundabouts exhibiting the key features illustrated in Figure 1.2 (Washington 2002). The definitions of selected key features are given below. (See the draft guidelines found in Appendix A for more thorough definitions).

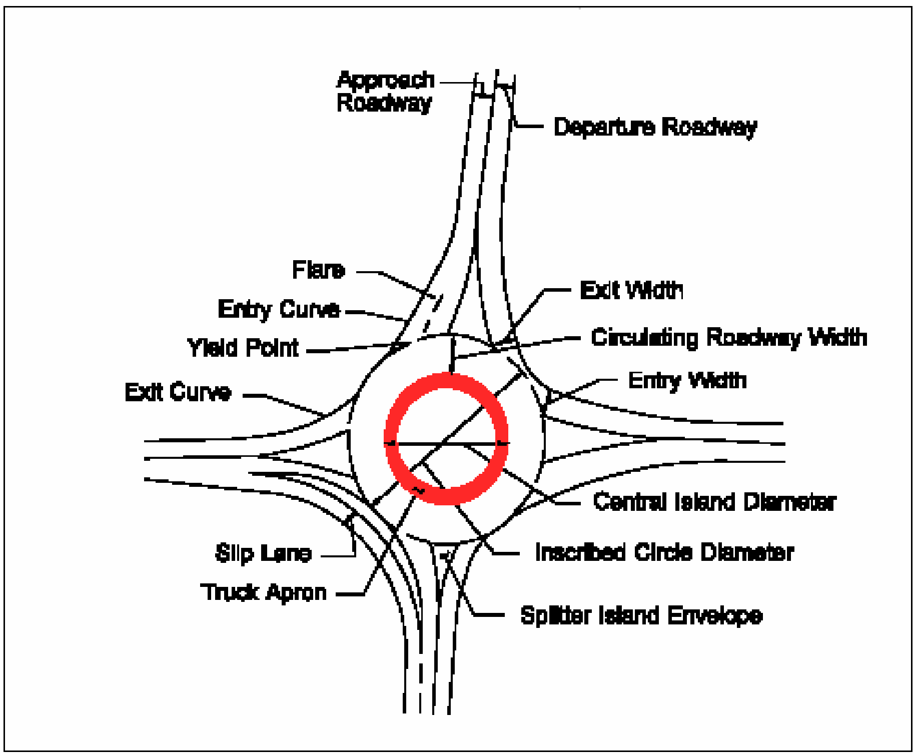

Figure 1.2 The Key Features of the Modern Roundabout.

- Circulatory Roadway – the curved path used by vehicles to travel in a counter clock-wise direction around the central island.

- Central Island – the raised area inside the circulatory roadway used to control vehicular speeds through deflection.
- Truck Apron – the mountable portion of the central island used to provide additional clearance for oversized vehicles.
- Splitter Island – the raised area separating the entry and exit lanes on all legs used to separate entering and exiting traffic, deflect entering traffic, reinforce one-way circulation, provide pedestrian refuge, and provide a place to mount signs.
- Flare – the widening of the approach to increase capacity.
- Slip lane or Bypass lane – a separate lane used to accommodate intersections with excessive right turn movements.

1.3 Scope of Study and Report Organization

Numerous international and national studies have been conducted concerning the implementation of the modern roundabout (see Chapter 2). The intent of this study was to summarize the key roundabout issues as they pertain to Utah's distinctive needs. The following tasks outline the methodology employed to accomplish this goal:

Task 1: Examine and summarize the available roundabout literature
Task 2: Conduct field observations of the three existing UDOT roundabouts and the roundabout located in front of UVSC (the UVSC roundabout is included because of its high volume and close proximity to a state route)
Task 3: Identify the key design considerations associated with roundabout implementation.
Task 4: Evaluate the existing software packages used for analysis and simulation
Task 5: Develop a draft of guidelines
Task 6: Prepare a report of findings
Task 7: Conduct training meetings to UDOT and contract employees to inform them of the results of the study

This report is the product of Task 6, "Prepare a report of findings." Task 7 will be conducted by members of the research team in the near future. The chapters that follow summarize Tasks 1 through 5. Chapter 2 provides a summary of key literature resources, including the seven state roundabout guidelines that have been published as of May 2004. Chapter 3 presents field observations for the UDOT roundabouts located in Lehi, Park City, Bloomington, and the roundabout located in Orem in front of UVSC. Chapter 4 presents the key design considerations associated with roundabout implementation. Chapter 5 describes the computer software packages currently being used for design, analysis, and simulation of roundabouts. Chapter 5 includes the results from the analysis of the Lehi roundabout using the various software packages. Chapter 6 explains the methodology employed to develop the draft guidelines and draft policy. Chapter 7, the concluding chapter, presents a summary of the research findings and recommendations Appendix A is the draft of the Guidelines and Design Standards for roundabouts and Appendix B is the draft of the Policies and Procedures.

2. SUMMARY OF LITERATURE SEARCH

There are hundreds of international articles, reports and studies providing information concerning the design, operation and benevolence of the modern roundabout. In the United States, on the other hand, roundabout implementation is relatively new and therefore the literature is often limited and at times contradictory. Nonetheless there are a number of resources that can be of benefit for states preparing procedural guidelines. Of particular interest are the roundabout guidelines that have been published by other state DOTs (as of May 2004 states with official roundabout guidelines included: Maryland, Florida, Oregon, New York, Pennsylvania, Washington, Missouri, and Kansas). Likewise, the Federal Highway Association's publication, *Roundabouts: An Informational Guide*, merits special attention. These guidelines and other key publications that may have specific relevance for the state of Utah are summarized below.

2.1 International Sources

- Australia - *Guide to Traffic Engineering Practice, Part 6: Roundabouts,* AUSTROADS, 1993.
  Although there are hundreds of international reports dealing with the modern roundabout, this report is one of the oldest and has been the most influential on American designs.

- England - Transportation Research Laboratory, *The Design of Roundabouts. State of the Art Review,* Mike Brown, Department of Transportation. London. HMSO, 1995.
  A thorough examination of the development of the modern roundabout and the various alternative methods of implementation today.

- France – *Carrefours Giratoires: Evolution des Caracteristiques Geometriques,* Ministere de l'Equipement, du Logement, de l'Amenagement du Territoire et des Transports, Documentation Technique 44, SETRA, 1997.
  This French design guide contains specific information that may benefit Utah because it deals with rural conditions. The French developed a separate design guide addressing urban conditions, called CETRA.

2.2 National Sources

- FHWA - *Roundabouts: An Informational Guide,* Federal Highway Administration, 2000.
  The foremost American source, one that nearly all other sources have turned to for reference. In fact, it is this report that has motivated state DOTs to formulate guidelines. It is a national guide intended for the general public, policy-makers, planners, analysts, and designers. The FHWA prepared this comprehensive guide to provide information about all modern roundabouts, from small mini-roundabouts to large freeway interchange roundabouts. It provides valuable information covering policy considerations, planning, operation, safety, geometric

design, traffic design, landscaping and system considerations. However, notwithstanding its breadth and depth, this guide does not offer specific guidelines and criteria that states can implement as fixed requirements or warrants.

- TRB - *Highway Capacity Manual,* Transportation Research Board, 2000.
The roundabout section of the HCM presents an alternative to the foreign analytical methodologies. This "American" methodology is based on gap-acceptance principles. It is admittedly still under development and at this point is only applicable to single-lane roundabouts with circulating flow of less than 1,200 vehicles per hour. Some states have rejected this methodology due to low number of sample test sites.

- TRB – Flannery, Aimee, and Tapan K. Datta, *ModernRoundabouts and Traffic Crash Experience in United States*, Transportation Research Board Annual Meeting, Washington D.C. Report 1553, 1996.
The authors collected and examined traffic crash data for various roundabouts throughout the United States. Statistical analysis was performed to determine if roundabouts reduced crash frequencies for those sites. The conclusion was a reduction of accident rates in the range of 60 to 70 percent.

- NCHRP - *Modern Roundabout Practice in the United States, A Synthesis of Highway Practice,* National Cooperative Highway Research Program, Synthesis 264, 1998.
This synthesis is a comprehensive summary of current practices of modern roundabouts in the United States. It presents the results of a survey conducted over all DOTs in the United States and Canada. These results illustrate the perception and use of roundabouts today. It further examines the current state guidelines and various international guidelines. The report addresses safety, capacity, pedestrian and bicyclist concerns and suggests a methodology for determining appropriateness.

- NCHRP - *Applying Roundabouts in the United States – Interim Report,* National Cooperative Highway Research Program, 2003.
This report is part of an ongoing project seeking to develop methods of estimating the safety and operational impacts of U.S. roundabouts and refine the design criteria used for them.

- ITE – Technical Council committee 5B-17, *Use of Roundabouts*, ITE Journal, February 1992, pp. 42-45.

- Insurance Institute for Highway Safety – *Crash Reduction Following Installation of Roundabouts in the United States.* March 2000.
This report is based a study of 24 intersections in 8 states. The results suggest that in certain situations the modern roundabout can be safer than other forms of intersection control.

2.3 State Reports

- MDOT – *Roundabout Design Guidelines,* The Maryland Department of Transportation, 1995.
  This was the first state roundabout guide. It closely follows the Australian design guide listed above. It suggests appropriate and inappropriate use of roundabouts, it recommends the SIDRA software for analysis and it provides information for both single-lane and multi-lane implementation.

- FDOT - *Florida Roundabout Guide,* The Florida Department of Transportation, 1998.
  This guide is recognized for its detailed section addressing roundabout justification and appropriateness. It is a comprehensive guide dealing with a variety of issues however it concentrates on single-lane roundabouts. This guide follows the Australian guide listed above. It presents a comparative review of SIDRA and RODEL, concluding that SIDRA is more appropriate for analysis.

- *Roundabout Design Guidelines,* Ourston and Doctors, 1995.
  This guide was prepared for Caltrans but was never published as a state guide. Ourston has used this guide for numerous roundabouts throughout the country. It follows the British methodology and recommends ARCADY and RODEL for analysis. The guide is noteworthy for addressing geometric design, from mini-roundabouts to large four-lane roundabouts. It includes specific design requirements for bicycles and pedestrians. It does not address signage.

- ODOT - *Modern Roundabouts for Oregon,* The Oregon Department of Transportation, 1998.
  This lengthy study examined the available roundabout guides (Australia, Maryland, Florida and Ourston) and supplemented the findings with recent studies and recommendations for Oregon's specific needs.

- NYSDOT – *Highway Design Manual Chapter 26: Roundabouts,* The New York State Department of Transportation, 2001.
  These guidelines for the state of New York are still considered just a draft. They rely heavily on the FHWA guide.

- PennDOT – *Guide to Roundabouts,* The Pennsylvanian Department of Transportation, 2001.
  Pennsylvania's guide is designed to assist in the decision phase of roundabout consideration. The guide provides a questionnaire that helps the

- WSDOT – *Design Manual, Roundabouts, Section 915,* The Washington Department of Transportation, 2001.
  This section of Washington's Design Manual distinguishes six roundabout categories and then provides specific guidelines for each. The six categories, which are based on environment, number of lanes, and size, are: Mini

roundabouts, Urban compact roundabouts, Urban single-lane roundabouts, Urban double-lane roundabouts, Rural single-lane roundabouts, and Rural double-lane roundabouts.

- MoDOT - *Project Development Manual, Section 4-05,* The Missouri Department of Transportation, 2002.
  This is Missouri's recently developed state guide. Its development relied heavily on its predecessors. It suggests an initial capacity check should be done using the HCM method, but that detailed analysis be performed according to the gap acceptance method and the aaSIDRA software. The guide presents a set of mandatory design elements that a designer must address, allowing flexibility and ensuring thoughtful, rigorous analysis. The guide requires that designers follow a three-stage justification process. The first stage, "Appropriateness," acts as an initial filter to quickly screen out inappropriate implementation. The second stage, "Operational Feasibility" and the third stage, "Comparative Performance," require more detailed examination of feasibility and efficiency. The guide is only applicable for single-lane roundabouts.

2.4 Selected Newspaper Articles

- *Modern roundabouts may be used in your area,* The Daily Herald, October 28, 1996.
  This article was written after the unveiling of Utah's first modern roundabout on Seven Peaks Boulevard in 1996. It presents a few interesting statistics and cost comparisons. Its greatest value is how it introduces this novelty to an inexperienced community.

- *Provo City – Community Update,* From the Office of the Mayor, February 2000.
  This community message from Provo City's Mayor addresses the increased use of roundabouts in Provo. Mayor Billings begins explaining why this alternative has been chosen, citing safety, cost, and traffic control efficiency. He concludes with instructions on how to use a roundabout. This is an interesting example of the type of public education that so much of the scholarly literature insists is required to make roundabouts effective.

- *If Summit County Gets Its Way, Roundabouts Could Get Rolling,* The Salt Lake Tribune.
  This article was written while the Park City roundabout (the first on a state road) was still just an idea. It examines the arguments for and against roundabout implementation. The article claims that the main objection is a fear to try new things. It makes a comparison to the roundabouts of Avon, Colorado saying that public opinion was initially in opposition there as well but now the roundabout has high acceptance.

3. FIELD OBSERVATIONS

Field observations were conducted for the UDOT roundabouts located in Lehi, Park City, Bloomington, and the roundabout located in Orem in front of UVSC during the summer of 2003. Observations were made during the AM Peak, PM Peak and Off-Peak hours. General observations and some possible problems are summarized below.

3.1 Lehi

Description

The Lehi roundabout is located at the junction of State Route 73 and 500 West. This intersection is five blocks west of Lehi's central business district. The intersection services most of the local residential traffic of west Lehi. This is the major corridor to the communities west of Lehi, namely Eagle Mountain and Saratoga Springs. There is a very busy Maverik gas station located northwest of the roundabout with access points very close to the circulatory road. There is no speed limit posting on the roundabout and therefore one would assume that the speed limit upon approach continues through the roundabout.

- The south leg has relatively little traffic flow. Southbound traffic leads to a residential area. Exiting and entering is single laned with a 25 mph speed limit. There is not a pedestrian crosswalk.

- The east leg services higher volumes of traffic, much of which is westbound through traffic. A railroad crossing is located about 150 yards from the roundabout. The leg is single laned in both directions with a 30 mph speed limit. There is a pedestrian crosswalk with a mountable splitter island.

- The north leg has relatively little traffic. However this leg services more traffic than the south leg and in the evening the north leg services a considerable amount of traffic. This leg allows access to the Maverik gas station located on the northwest corner. The leg is single laned in both directions with a 25 mph speed limit. There is a pedestrian crosswalk with a mountable splitter island.

- The west leg services high volumes of traffic. This leg receives traffic exiting the Maverik. Eastbound traffic desiring to enter the Maverik legally should use the roundabout and then enter by way of the north leg, however many vehicles use the tail end of the splitter paint markings as a turning lane to enter prior to the Maverik. The leg is single laned in both directions. The speed limit is posted at 30 mph, however there is a school zone sign that reduces the speed limit to 20 mph when flashing (See Figure 3.1). There is not a pedestrian crosswalk.

Figure 3.1 School Zone Reduce Speed When Flashing Sign.

General observations

- AM Peak – Peak occurs around 8:00 am. The majority of the flow travels west to east. Eastbound queuing begins around 7:00 am and continues until around 8:45 am. The queue is rolling traffic and rarely results in stopped traffic (See Figure 3.2). On the observation day a train crossed the east leg resulting in gridlock in the roundabout (See Figure 3.3).

Figure 3.2 Lehi AM Peak, Queued Rush Hour Eastbound Traffic on The West Leg.

Figure 3.3 Lehi AM Peak, Eastbound Queue Due to Train Crossing.

- Off Peak – There seems to be light but consistent traffic throughout the day. Much of the traffic travels east-west or west-east. Occasionally pedestrians navigate the roundabout, often en route to the Maverik or the Lehi city center.

- PM Peak – Peak occurs around 6:00 pm. The majority of the traffic is traveling east to west, but high volumes also travel west to east.

Possible problems/concerns

- The roundabout is not marked with a speed limit sign and therefore many drivers would assume that the speed limit through the roundabout is the same as that of their approach speed limit. The FHWA guide considers the 30 mph excessive. The guide suggests 20 mph limits for urban single lane roundabouts.

- The sign shown in Figure 3.4 warns approaching drivers of the roundabout. The FHWA guide suggests that this sign can be confusing. The FHWA and the MUTCD recommend the sign found in Figure 3.5.

Figure 3.4 Current Roundabout Ahead Sign in Lehi.

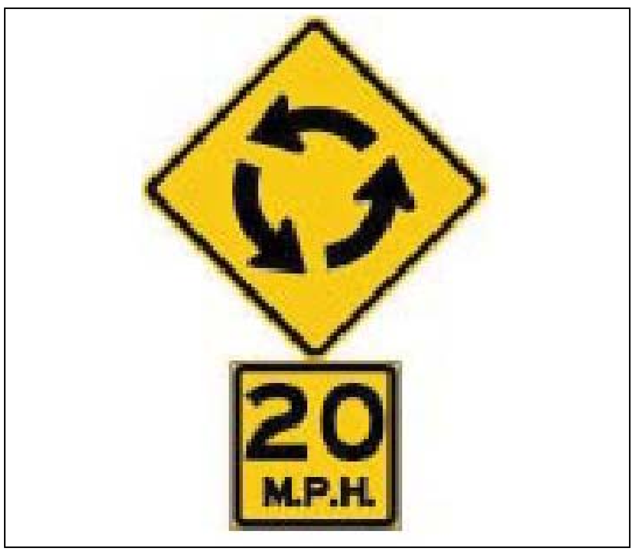

Figure 3.5 MUTCD Recommended Roundabout Ahead Sign.

- The lack of pedestrian crosswalks on the south and west leg make it difficult for a high percentage of pedestrians to reach the Maverik from the south. During the observation, periods many pedestrians braved the heavy traffic by crossing without a pedestrian crosswalk (See Figure 3.6 and 3.7).

Figure 3.6 Pedestrian Crossing West Leg to the Maverik Gas Station.

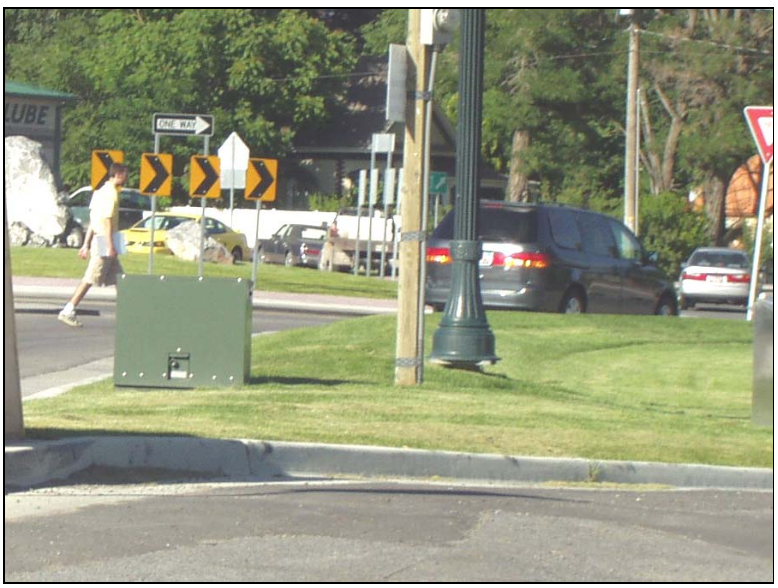

Figure 3.7 Pedestrian Crossing Diagonal from the Maverik Gas Station Southeast to the Residential Area Down.

- The close proximity of the railroad crossing may prove to be problematic in the future. The train halts all east-west traffic the same as it would for any other intersection type, however the north-south traffic is impeded because of the traffic jam caused by the roundabout (See Figure 3.3 and 3.8).

Figure 3.8 North-South Traffic Blocked Due to Train Crossing on the East Leg.

- The Maverik exit/entrance on the west leg is dangerous. Exiting traffic turning left may have difficulties finding an acceptable gap. Entering traffic from the west constricts the traffic flow approaching the roundabout (See Figure 3.9).

Figure 3.9 Eastbound Vehicle Attempting Left Turn Into the Maverik Gas Station.

3.2 Park City

Description

The Park City roundabout is located at the junction of State Route 224 and Marsac Ave. The roundabout speed limit is 15 mph.

- The west leg is restricted to transit traffic only (See Figure 3.10 and 3.11). The leg is single lane entering and exiting with max speed 25 mph. There is a brick pedestrian cross walk beyond the splitter island.

Figure 3.10 Southbound, View of West Leg.

Figure 3.11 West Leg Transit Only Sign.

- The south leg runs up a fairly steep hill. About 50 yards up the hill, on the right is a major parking lot for Old Town Park City. On the left, about 10 yards up the hill, Ontario Street intersects the south leg. Exiting the roundabout is single laned and the north bound approach is single aned; however, the entrance flares to double lane to allow right turns without completely entering the roundabout. Approach and exit speed is 20 mph. This leg leads to a primarily residential area. There is a brick pedestrian crosswalk with a mountable splitter island (See Figure 3.12).

Figure 3.12 South Leg, Different Materials for Pedestrian Crosswalk, Mountable Splitter Island.

- The east leg is single laned but the westbound approach flares to two lanes to allow right turns without entering the roundabout. For both directions the speed limit is 25 mph. There is a brick cross walk, but there is no sidewalk on the north side (See Figure 3.13).

Figure 3.13 East Leg. Pedestrian Crosswalk without Refuge Leading to Nowhere.

- The north leg carries the greatest volume of traffic. About 50 yards north of the roundabout, Swede Alley intersects from the west. This T-intersection prohibits left turns, forcing traffic to use the roundabout as a U-turn (See Figure 3.14). This leg has two lanes entering and exiting with speeds of 25 mph. The speed limit increases to 45 mph about 150 yards north of the roundabout. There is not a pedestrian crosswalk.

Figure 3.14 Junction Swede Alley and SR 224. Prohibited Left Turn, Use Roundabout Sign.

General observations

- AM Peak – Peak occurs around 8:45 am. The majority of the flow travels North to East or East to North. There are a significant number of large trucks with trailers traveling in these same directions. There is relatively little pedestrian and bicycle traffic. The majority of the pedestrians seem to be walking for exercise and predominately travel East-West, and East-South to the residential areas.

- Off Peak – There seems to be moderate traffic throughout the day, volumes much like the AM Peak Hour. The majority of the flow seems to be traveling East-North. There are a significant number of large trucks traveling in these same directions. There are more pedestrian and bicyclists navigating the roundabout during the off peak. Many of the pedestrians only cross the west leg. This is because many of the pedestrians are traveling between the parking lot above the roundabout and the transit station, the Old Town corridor, or the pathway northeast of the roundabout. Many bicyclists travel South to East or South to North. There maybe a mountain bike trail that terminates somewhere up the south hill above the roundabout.

- PM Peak – Peak occurs around 5:00 pm. The majority of the traffic travels north bound. However, a significant portion of the traffic comes from Swede Alley and is forced to travel south toward the roundabout, navigate the roundabout as u-turn and then travel north (See **Description**, above). There are a significant number of pedestrians and bicyclists traveling paths similar to the off peak pattern.

Possible problems/concerns

- Vehicles exiting the south exit and desiring to make an immediate left up the hill on Ontario Street, may have difficulties getting through the oncoming north bound traffic. Furthermore, the delay and blockage associated with this movement may interfere with the operation of the roundabout.

- The speeds of southbound traffic are fairly fast, for this reason vehicles that enter from Swede Alley occasionally queue. During the PM peak high volumes use this path to exit the Old Town. During the PM peak observation period a few drivers illegally and dangerously made a left turn rather then using the roundabout as a U-turn.

- Pedestrians traveling between the walking path on the northwest corner and the east leg are frustrated to find that there is not a pedestrian cross walk across the north leg. During the observation periods a few pedestrians did not have the patience to walk the long distance around the roundabout and opted to cut across the roundabout

- The pedestrian crosswalk on the east leg does not lead to a sidewalk (See Figure 3.13).

3.3 Bloomington

Description

The Bloomington roundabout is a roundabout-teardrop interchange for Interstate 15. There is a six leg roundabout on the west side of the interstate and a four leg teardrop on the east side of the interstate. The roundabout services the southbound interstate traffic, a frontage road called Pioneer Road, and Brigham Road that runs perpendicular to the interstate. The teardrop services Brigham Road and the northbound interstate traffic. The roundabout was installed to accommodate the increased traffic generated by a newly constructed Wal-Mart. There is relatively little pedestrian traffic in the area.

- The north-east leg of the roundabout is the off ramp for southbound interstate traffic, so traffic cannot exit the roundabout on this leg. There is a speed reduction to 35 mph sign located on the interstate prior to the off ramp as shown in Figure 3.15. Closer to the roundabout, there is a directional information board, a "Yield to Roundabout" sign, and a roundabout ahead sign/speed reduction to 20 mph sign as shown in Figure 3.16.

Figure 3.15 Interstate-15 Off Ramp Warning Sign Leading to the North East Roundabout Leg.

Figure 3.16 Directional Information Board, "Yield to Roundabout" Sign, and Roundabout Ahead/Speed Reduction to 20mph Sign.

- The north-west leg of the roundabout is the single laned. It is the north extension of Pioneer Road.   There is a roundabout ahead sign/reduce speed to 20 mph, and a "Yield to Roundabout" sign. This leg accommodates much of the Wal-Mart traffic.

- The west leg of the roundabout is single laned. It is the west extension of Brigham Road.

- The southwest leg of the roundabout is double laned. It is the south extension of Pioneer Road.

- The southeast leg of the roundabout is the on ramp for southbound I-15, so there is only exiting traffic on this leg.

- The east leg of the roundabout is double laned. It is the east extension of Brigham Road. Brigham Road passes under the interstate into the teardrop on the other side.

- The south leg of the teardrop is the off ramp for northbound I-15. This leg does not allow vehicles to exit the teardrop.

- The east leg of the teardrop is the east extension of Brigham Road. About 20 yards from the teardrop there is an entrance into a truck stop (see Figure 3.17)

Figure 3.17 View of the Teardrop and the Truck Stop.

- The north leg of the teardrop is the on ramp for northbound I-15. This leg does not allow vehicles to enter the teardrop. There is a right-turn bypass lane for westbound traffic from Brigham Road (see Figure 3.18).

Figure 3.18 The Right-Turn Bypass Lane on the North Leg of the Teardrop

General observations

- AM Peak – Peak occurs around 7:00 am. The majority of the flow enters and exits from the interstate. During the observation period, traffic was very light.

- Off Peak – Typically light traffic. On Saturdays, the off-peak can have higher volumes because of Wal-Mart traffic.

- PM Peak – Peak occurs around 5:00 pm.

Possible problems/concerns

- The roundabout is double laned but does not have pavement markings indicating this. This can possibly be a problem when a large vehicle, which requires both lanes to navigate the roundabout, crowds out other vehicles.

- The roundabout has six legs indicating the existence of frequent merge operations within the short distances of the entry and exit legs. This will be problematic when traffic demand increases. Merge operations is one source of capacity reduction at a roundabout.

- The steep downhill approach from east at the tear-drop roundabout is a concern as manifested by a number of tire lanes indicating the difficulty following the slip ramp alignment.

- The short distance between the tear-drop roundabout and the entry to a nearby truck stop on the east side may become a bottleneck of this area when the traffic on the east approach and the trucks coming off the northbound I-15 wanting to enter the truck stop cross each other in this short distance.

3.4 UVSC

Description

The UVSC roundabout is located in front of Utah Valley State College at the intersection of College Drive and 800 West. SR 265 crosses 800 West with a signalized intersection about 300 yards south of the roundabout. Although this roundabout is not located on a state route, it was visited to identify possible problems and concerns. The phase cycle of the traffic signal at the intersection of University Parkway and Sandhill Road is about 150 seconds.   The roundabout experiences light traffic in the summer and high volumes in the school year from September to April. All four legs have two approach lanes. There is no posted speed limit.

- The west leg services almost exclusively campus traffic. It has two approach lanes with a 25 mph speed limit. There is a pedestrian crosswalk; however, it does not cross the splitter island. For this reason, the crosswalk is marked with a safety barrel to provide a refuge point for the high volume of pedestrians using this crosswalk (See Figure 3.19).

Figure 3.19 West Leg, Safety Barrel Marking Pedestrian Crosswalk.

Figure 3.20 South Leg, Junction with SR 265, 5 Lanes Exiting off the Roundabout.

- The south leg intersects SR 265 and is the main access point to the campus and therefore it services the highest volumes traffic. The entrance is two laned. The exit flares to five lanes (See Figure 3.20).

- The east leg has a bypass lane from SR 265. The approach flares to side to create transit bay. This UTA stop services Routes 801, 802, 811, 830, 831, and 862. There is a pedestrian crosswalk with a mountable splitter island.

- The north leg services short-term parking and faculty parking. There is no posted speed limit. There is no pedestrian crosswalk.

General observations

- AM Peak – Peak occurs around 8:45 am. The majority of the flow enters and exits from the South leg. During the observation period traffic was very light. It is expected that peak flows will occur between 7:30 and 9:00 am during the school year.

- Off Peak – Light traffic. Pedestrians cross the east leg in high volumes.

- PM Peak – Peak occurs around 5:00 pm. The majority of the traffic exits the south leg. Often the bays at the signalized intersection of SR 265 queue back into the roundabout.

Possible problems/concerns

- On the south leg, the 5 lanes that meet SR 265 often queue. If the queue is greater then 13 cars it impedes the operation of the roundabout. This especially occurs in the right turn bay leading to I-15 (See Figures 3.21 and 3.22). This may become a problem in the future or during peak flows when school is in session.

Figure 3.21 South Leg, Queue in Right Turning Bay Nearly Impeding Roundabout Operation.

Figure 3.22 South Leg, Queue in Right Turning Bay Nearly Impeding Roundabout Operation.

- The UTA pullout on the right side of the westbound approach is not striped with paint, which might confuse traffic intending to turn right (See Figure 3.23).

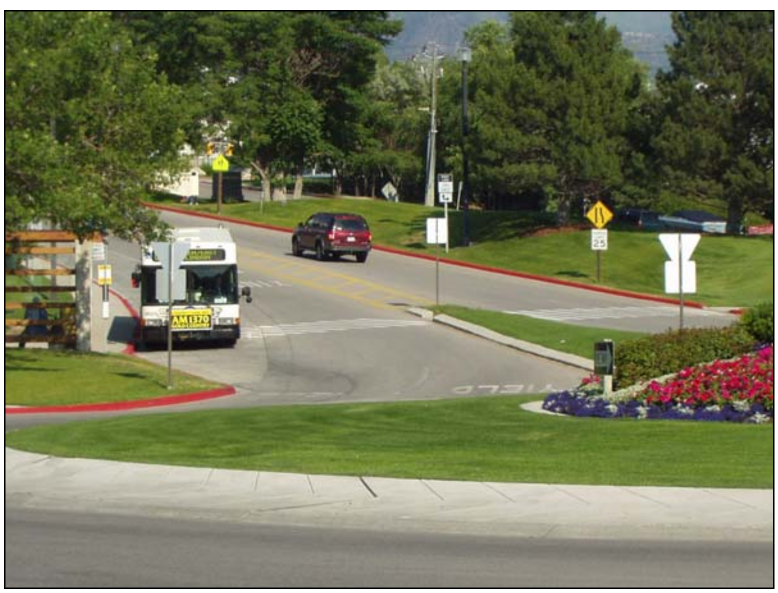

Figure 3.23 East Leg, UTA Pullout Close to Roundabout Possibly Confusing Vehicles Turning Right.

- The lack of pedestrian cross walks across the south and north legs causes difficulties for pedestrians. Many pedestrians attempt to cross diagonally across the roundabout (See Figure 3.24).

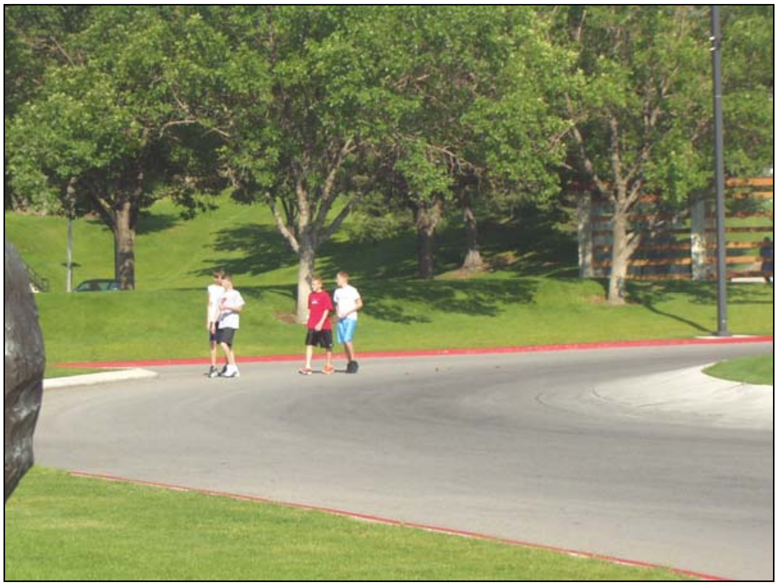

Figure 3.24 Pedestrians Crossing Diagonal Across the Roundabout.

Figure 3.25 Pedestrians Prohibited Sign, Unclear and Confusing for Pedestrians Needing to Cross the Street.

- The sign prohibiting pedestrians to enter the roundabout area might be considered confusing and unclear to many pedestrians (See Figure 3.25). There is no sign directing pedestrians to an acceptable path. On the northeast corner there is no sidewalk or any indication where a safe path can be found.

3.5 Field Observations Summary

The four roundabouts described above seemed to be efficiently servicing the vehicular demand required of them at the time of the observations. However, a few things could be done to improve their over all performance.

- First, the signage is not completely consistent and sometimes confusing. For example, the Roundabout Ahead signs are not uniform.

- Second, all four roundabouts could be made more pedestrian friendly. None of the roundabouts have pedestrian crossings on all legs, and all the roundabouts have confusing pedestrian warning signs that do not properly direct the pedestrians.

- Third, it should be noted that the railroad crossing that is near the Lehi roundabout poses problems because of the high volumes of traffic that the roundabout is expected to service and a possible operation of a UTA commuter train in the future.

- Fourth, it should be noted that the Bloomington roundabout, the only two lane roundabout observed, is effectively a single lane roundabout when a large truck is using it. This should be considered when capacity is determined for roundabouts that service a high volume of heavy vehicles.

- Finally, traffic entering to and exiting from business establishments on the approach legs of roundabouts may cause both capacity and safety problems. The potential problems were observed at the Lehi roundabout and the Bloomington roundabout.

4. DESIGN CONSIDERATIONS

Research and experience agree that when a roundabout is properly designed and implemented it is a superior form of intersection control. This chapter presents an overview of the key design considerations for the proper use of a roundabout. Many of the advantages and disadvantages will be presented, a checklist for appropriateness will be outlined, and safety issues will be addressed.

4.1 Advantages and Disadvantages

Modern roundabouts vary in size and features, each with its unique advantages and disadvantages. Table 4.1 presents some of the advantages and disadvantages for a "normal" roundabout that has been appropriately implemented (Adapted from Oregon 1998).

Table 4.1 Advantages and Disadvantages of Roundabouts.

Category	**Advantages**	**Disadvantages**
Safety	-There are a reduced number of conflict points compared to uncontrolled intersections. -Slower operational speeds yield less severe and fewer accidents at intersections. -Slower through speeds because of deflection reduce accidents on legs.	-Since roundabouts are unfamiliar to the average driver in the US, there is likely to be an initial period where accidents increase. -Signalized intersections can preempt control for emergency vehicle, but roundabouts may not be able to.
Capacity	-Traffic yields rather than stops, often resulting in the acceptance of smaller gaps. -For isolated intersections, roundabouts should give higher capacity/lane than signalized intersections due to the omission of lost time (red and yellow) at signalized intersections. -Intersections with a high volume of left turns are better handled by a roundabout than multi-phased traffic signal.	-Where a coordinated signal network can be used, a signalized intersection will increase the overall capacity of the network. -Signals may be preferred at intersections that periodically operate at higher than designed capacities.
Delay	-Overall delay will probably be less than for an equivalent volume signalized intersection (this does not equate to a higher level of service). -During the off-peak, signalized intersections with no retiming produce unnecessary delays to stopped traffic when gaps on the other flow are available. -Reduced delay results in less fuel consumption and less pollution.	-Drivers may not like the geometric delays that force them to divert their cars from straight paths. -When queuing develops, entering drivers tend to force into the circulating streams with shorter gaps. This may increase the delays on other legs and the number of accidents.
Cost	-In general, less right-of-way is required. -Maintenance costs of signalized intersections include electricity, maintenance of loops, signal heads, controller, timing plans (roundabout maintenance includes only landscape maintenance, illumination, and occasional sign replacement). -Accident costs are low due to the low number and severity of accidents.	-Roundabout construction costs may be higher than for four-way stop locations. -In some locations, roundabouts may require more illumination, increasing costs.

Table 4.1 Continued.

Category	**Advantages**	**Disadvantages**
Pedestrians	-A splitter island provides a refuge for pedestrians that will increase safety. -Pedestrians need only check one direction of traffic before crossing.	-A splitter island may cause difficulty to people using wheelchairs if the path is not flush with the pavement. -Roundabouts may increase delay for pedestrians waiting for acceptable gaps to cross. - Longer paths increase travel distances.
Bicyclists	-The lower speeds should improve safety for bicyclists.	-Tight dimensions of roundabouts create an uncomfortable feeling to bicyclists. -Because of unfamiliarity there may be initial frustration and possibly an increased number of accidents.
Aesthetics	-The center island and splitter islands provide opportunity to landscape, decorate, and/or erect monuments. -Without signalization the intersection is free of traffic poles and hanging traffic lights. -Reduced delay results in less fuel emissions.	-Roundabouts may require more signs than signalized intersections.
Public Transit	-Reduced delay decreases travel times for transit riders who are confined to specified routes. (Private motorists have more freedom to avoid signalized queuing)	-Roundabouts may interfere with bus stop locations. -Roundabouts may require more distance from rail crossings.

4.2 Appropriateness

Most of the state guides have a preliminary section that addresses appropriateness. This checklist of situations allows an initial filter before detailed analysis is performed. The following three sections, compiled from the various guides and other literature, list the conditions under which roundabouts *may be, may* NOT *be*, or *are* NOT appropriate.

Conditions under which roundabouts *may be* appropriate

- Intersections with high left-turn flows.
- Intersections with high U-turn flows.
- Four-way stop intersections, particularly when neither road is to have priority.
- Y and T intersections.

- Intersections with unusual geometry.
- Intersections with more than four legs.
- Intersections where traffic signals are not warranted.
- Intersections with periodically changing traffic patterns.
- High accident intersections, including rural roads with outstanding left turn accidents and high-speed arterials with outstanding left turn accidents.
- Intersections with high delay, particularly when the delay occurs in off-peak periods or when the delay occurs on minor streets that cross high volume streets.
- Intersections where the majority of activity is turning.
- Low or medium volume intersections.
- Locations where signalization is limited by other conditions ie. lack of space for equipment, remoteness, etc.
- Locations where queues created by signalization cause operational or safety problems, i.e. diamond interchanges, intersections near rail lines, bridges, tunnels, etc.
- Locations with closely spaced intersections.
- Locations where road character changes, i.e. rural to urban, divided to undivided, high speed to low speed.
- Locations where traffic growth is predicted to be high.
- Locations where future traffic flows are uncertain or changeable.
- Intersections that could have urban design or aesthetic importance.

Conditions under which roundabouts *may* NOT *be* appropriate

- Intersections at the top or bottom of a steep grade.
- Locations with right-of-way limitations.
- Locations with heavy pedestrian or bicycle traffic.
- Locations with numerous children, elderly, and disabled users.
- Locations near emergency facilities that frequently require the ability to preempt traffic, such as hospitals or fire stations.
- Intersections where traffic flows are unbalanced and therefore some approaches would experience undue delays.
- Locations near railroad crossings.
- Intersections with significant traffic that might have trouble negotiating the roundabout, such as oversized trucks, or vehicles with long trailers.

Conditions under which roundabouts *are* NOT appropriate

- Locations with grades more than 4%.
- Locations with physical/geometric complications that make it impossible/uneconomical to construct a roundabout.
- Routes where large vehicles will frequently use the intersection and sufficient space is unavailable.
- Locations with nearby bottlenecks that would routinely back up into the roundabout.

- Isolated intersections within a coordinated network.
- Roadways with reversible lanes.
- Locations where a bus stop must be at the intersection.
- Locations where the ADT total for all approaches exceeds 20,000 vpd for single-lane roundabouts.
- Locations where the ADT total for all approaches exceeds 40,000 vpd for double-lane roundabouts.

4.3 Safety Issues

Research agrees that the modern roundabout can be a safe intersection alternative. In 1981, the British Department of Transportation suggested that, "Roundabouts are normally the safest form of at-grade junction over a wide range of entry flows and approach speeds." (NCHRP 1998) In the United States, such definitive conclusions are yet to be made. Nonetheless, various studies throughout the United States have demonstrated that roundabouts deserve consideration for their safety benefits. The most noteworthy domestic studies relating to roundabout safety are listed below.

- Organization: Insurance Institute for Highway Safety
  Date: March 2000
  Location/Methodology: Crash data from various roundabouts around the country.
  Results/Conclusions: 39% reduction in total crashes, 76% reduction in injury crashes, estimated 90% reduction in fatal or incapacitating crashes.

- Organization: National Cooperative Highway Research Program
  Date: 1998
  Location/Methodology: A survey questionnaire was sent to all US DOTs, each province in Canada, and 26 US municipalities. Information was received for 28 operational roundabouts on state routes. This is an estimated two thirds of total operational state roundabouts at the time of the study. Crash statistics were received for 11 of these roundabouts.
  Results/Conclusions: For small to medium roundabouts there was a 51% reduction in total crashes and 73% reduction of injury crashes. A few larger roundabouts exhibited increased Property-Damage-Only crashes however this was more than offset by a reduction at the other roundabouts.

- Organization: National Cooperative Highway Research Program
  Date: August 1997
  Location/Methodology: Examination of five roundabouts in Maryland
  Results/Conclusions: A 30% reduction in crash severity from an average cost of $120,000 before the roundabout to $84,000 after the roundabout.

Reasons for greater safety

1. *Fewer and less severe vehicular conflict points*

Figure 4.1 illustrates that by converting all turning movements to right turns roundabouts decrease the number of conflict points by 75% from 32 to 8 (FHWA 2000). Accident severity at an intersection is determined by the speed and the angle of impact. Accordingly, crossing conflicts or left-turns are the most severe type of conflict. Roundabouts eliminate crossing left-turn conflict points. The left-turn of a roundabout greatly reduces the number severe injuries and fatalities. The remaining merging and diverging conflict points have safer angles and involve the best-protected parts of the vehicle. Furthermore, the reduction of speed imposed by deflection decreases the potential and severity of accidents. Finally, since roundabouts do not rely on signalized controls, drivers tend to be more defensive through the intersection. On the other hand, signalized intersections often allow drivers to become complacent and unaware of other drivers who may be violating the control.

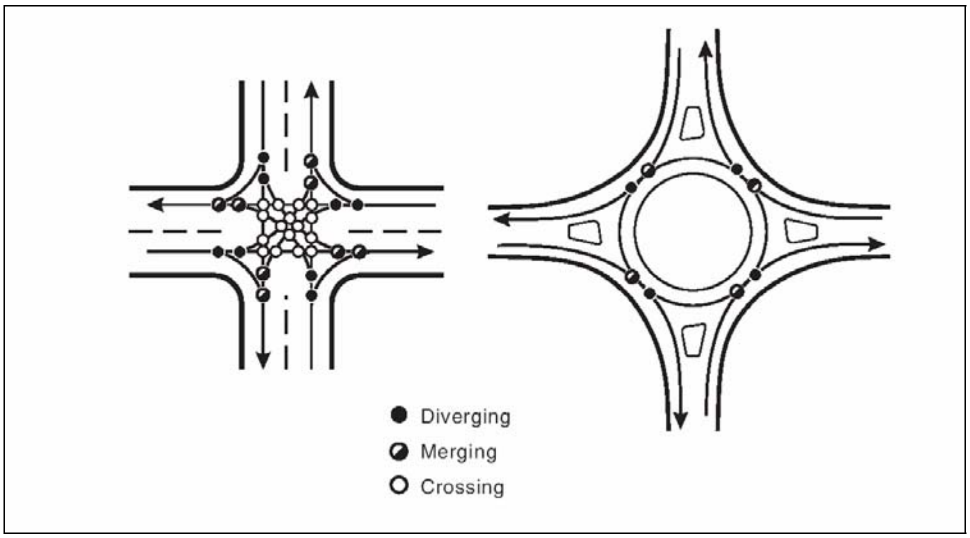

Figure 4.1 Vehicle/Vehicle Conflict Point Comparisons for Intersections With Single-Lane Approaches.

2. *Lower speeds*

The geometric form of the roundabout imposes lower speeds compared to other intersection types. The curved entry, circulating pathways and over all deflection of movement, force the driver to lower their speeds to navigate the intersection. Furthermore, traditional intersections provide greater opportunity for control violations and signalized intersections encourage drivers to accelerate to “beat the red light”.

3. Simplicity of decision making

Drivers navigating roundabouts do not have as many conflict points to preoccupy their movement. Regardless of the number of approaches, the entering driver need only consider the front-left quadrant of the visual sphere. Drivers within and exiting are only required to heed the right half of their visual sphere. Drivers navigating a traditional intersection, on the other hand, must heed traffic from the left, the right and opposing at all times of the turning movement.

4. Increased Pedestrian Safety

Although most sources concede that further studies ought to be performed, there is consensus that for intersections with low vehicular volume, a roundabout can provide increased safety for pedestrians. This is in part due to the lower speeds and the simplicity of the driver's decision making. Additionally, as Figure 4.2 illustrates, roundabouts reduce the number of conflict points faced by a pedestrian. Furthermore, the splitter islands provide refuge for pedestrians and permit them to cross one direction of traffic at a time. However, pedestrians must walk longer distances and their crossing paths are indirect compared to regular intersections.

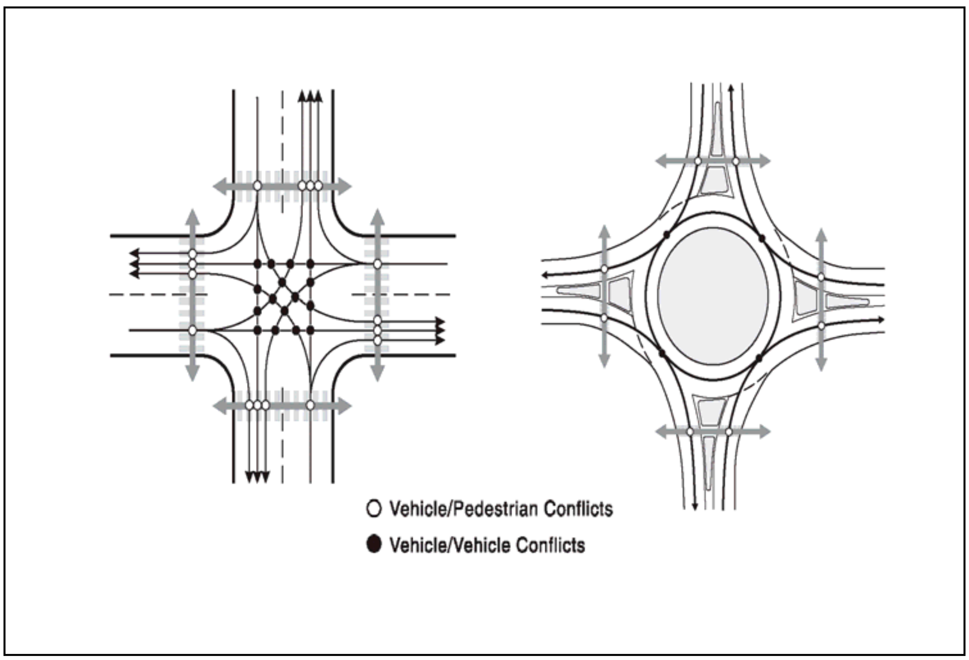

Figure 4.2 Vehicle/Pedestrian and Vehicle/Vehicle Conflict Point Comparisons for Intersections with Single-Lane Approaches.

Safety items requiring further consideration

1. *Pedestrian and bicyclist provisions*

The increased pedestrian safety discussed above is only valid if the roundabout is properly designed and implemented. In practice, pedestrians and bicyclist are not given sufficient consideration. In fact it has been found that many roundabouts do not provide pedestrian crossings on all four legs (see Lehi, Park City, Bloomington, and UVSC in Chapter 3). There are varying degrees of bicycle safety measures all of which are intended to eliminate operational confusion for the bicyclist. The safest design involves an exclusive bicycle lane. None of the roundabouts in Utah provide an exclusive bicycle lane.

2. *Visually Impaired Pedestrian Safety*

Further study should be performed concerning visually impaired pedestrians. It has been noted that visually impaired pedestrians may have difficulty (1) locating the cross walks because of the unfamiliar design, (2) determining gap acceptance without the aid of audible signal due to the disruptive and possibly confusing sound of circulating traffic, (3) locating the splitter island for a mid-crossing refuge. The suggested possible remedies for these problems include, respectively, implementation of defining landscaping; locating cross walks further away from the circulating road, and unique surface material for the splitter island.

5. SOFTWARE EVALUATION

This chapter examines the leading software packages used for the design, analysis, and simulation of roundabouts. Engineers do not agree on the best methodology for analysis, and therefore, various software packages with different methodologies exist. This chapter provides a brief introduction to a few leading design/analysis packages.

Likewise, there are a variety of simulation software packages. The widespread use of simulation in traffic analysis has encouraged software developers to incorporate roundabout analysis into the packages. Limited analysis can be accomplished on the leading simulation packages. This chapter will provide a brief introduction to two simulation packages.

The software packages presented below will be used to examine the roundabout on State Route 73 in Lehi. Traffic data, including delay data, was collected and used for comparison of the delay calculated by the software packages.

5.1 Design/Analysis Software

Capacity is the primary concern during roundabout design and analysis. Capacity is influenced by:

- the circulating flow that conflicts with the entry flow
- the overall geometry.

Two methods for predicting capacity have been developed over the years. In the early 1960s, engineers at the UK Transport Research Laboratory produced a methodology based on the probability of a vehicle entering the roundabout for the probable gap size provided by the circulating flow. It was soon noted that the capacity predictions from the gap method did not match observed capacities, so the British researchers abandoned the gap method and began to develop empirical formulas for predicting capacity. Other countries, mainly Germany and Australia, did not give up on the gap methodology. The gap method and empirical formula method have been advanced considerably in the past four decades.

The most popular software packages use one of these two capacity prediction methods.

- RODEL – empirical formula method
- aaSIDRA – gap method
- HCS – gap method
- SYNCRHO 6.0 – gap method

Each program requires different input and produces different output. Table 5.1 shows the primary input for each program and Table 5.2 shows the possible output.

Table 5.1 Input for Roundabout Analysis

	RODEL	aaSIDRA	HCS	Synchro 6.0
Entry Width	X			
Entry Radius	X			
Entry Angle	X			
Flare Length	X	X		
Lane Width	X	X		
Central Island Diameter	X	X		
Circulatory Roadway Width		X		
Grade	X	X		
Turning Flows	X	X	X	X
Confidence Level Of Flows	X			
Saturation Flow		X		
PCU Factor	X			
Peak Hour Factor		X	X	X
Approach Speed		X		
Lane Utilization Percentage		X		
Critical Gap Size		X[1]	X[2]	
Follow-Up Time		X[1]	X[2]	

1 Can be given as input or calculated by the program
2 The software provides default values

Table 5.2 Output from Roundabout Analysis

	RODEL	aaSIDRA	HCS	Synchro 6.0
Capacity	X	X	X	X
Delay Values	X	X		
Queue Values	X	X		
Level Of Service	X	X		
Delay Costs	X	X		
Travel Time Data		X		
Operating Costs		X		
Fuel Consumption		X		
Pollution Data		X		

The RODEL software is the world leader for the empirical method. Its calculations are based on extensive empirical data collected from at-capacity roundabouts throughout Great Britain. The program operates in two modes. Mode 1 is for design and Mode 2 is for analysis. In Mode 1, the user inputs volumes and a target measure of performance. The output is a set of preliminary geometries. In Mode 2, these geometries are used as input to produce the output shown in Table 5.2. Through iteration the user can determine the optimal geometries for the desired capacity. This method relies on geometries more than the other software packages. The methodology is identical to another program called ARCADY (RODEL 2000).

The aaSIDRA software is the most popular program using the gap method. The software was first developed in Australia but it has been used for hundreds of roundabouts in the United States. It is suitable for single-lane and multi-lane roundabouts with up to eight legs (Akcelik & Associates 2003).

HCS is a computer program for the calculations of the Highway Capacity Manual (HCM). Roundabout analysis is limited in the HCM and HCS. Circulating flows and gap theory are used to produce a range of possible capacities for each leg of the roundabout (HCS 2003).

The Synchro 6.0 software utilizes the logic of the HCM for analysis. The advantage with Synchro 6.0 is that it can be linked to SimTraffic for simulation. Note in Table 5.1 that Synchro 6.0 does not allow the user to adjust the critical gap size and follow-up times (Husch and Albeck 2003). Synchro 6.0 can analyze only single-lane roundabouts while SimTraffic can simulate multi-lane roundabouts.

5.2 Simulation Software

The two leading simulation packages for roundabouts are:

- SimTraffic
- VISSIM

SimTraffic is a well-used US simulation software. The input is entered into Synchro and then simulated in SimTraffic. The simulation and analysis is very simple. The developers admit that further work needs to be done to make the simulation more robust. Nonetheless the simulation provides nice presentation possibilities and an analysis comparable to other software packages (Husch and Albeck 2003). SimTraffic can simulate multi-lane roundabouts although Synchro itself can analyze only one-lane roundabouts.

VISSIM is certainly the more expensive of the two programs, but it offers features that many claim make the simulation superior. These features include: connectors rather than nodes (this allows geometric representation of the components of the roundabout), routing decision capabilities, priority rules (this allows a more realistic description of the gaps), and reduced speed zones which can account for reduced speed for geometry. Furthermore, VISSIM offers 3-D simulation which can be very effective for presentation to decision makers (VISSIM 2004).

5.3 Case Study: Lehi Roundabout

The software packages introduced above were used to examine the roundabout on State Route 73 in Lehi. The geometric input was taken from the As-Built drawings.

Traffic volume input was collected Friday, March 19, 2004 for the AM Peak flow between 7:30 am to 8:30 am.

Capacity is the only output common to RODEL, aaSIDRA, Synchro, and HCS. Table 5.3 presents the predicted capacity from these programs for the Lehi roundabout. Note that when the default values for critical gap size and follow-up time are used with the HCS program, then the HCS and Synchro is identical. The RODEL and aaSIDRA predictions are within the prediction range produced by HCS and Synchro. For the east-west legs aaSidra predicted a greater capacity, while for the north and south legs RODEL predicted a greater capacity.

Table 5.3 Capacity Prediction (vph) for the Lehi Roundabout

	East Bound	West Bound	North Bound	South Bound
Actual Flow	745	374	82	163
RODEL (50% confidence level)	1124	1000	688	883
aaSidra	1697	1275	587	862
HCS/Synchro	1047 - 1259	972 - 1176	524 - 671	829 - 1018

The input that was collected March 19th was used to simulate the roundabout in Synchro and VISSIM. Figures 5.1 and 5.2 are screen shots of the simulation for Synchro and VISSIM, respectively.

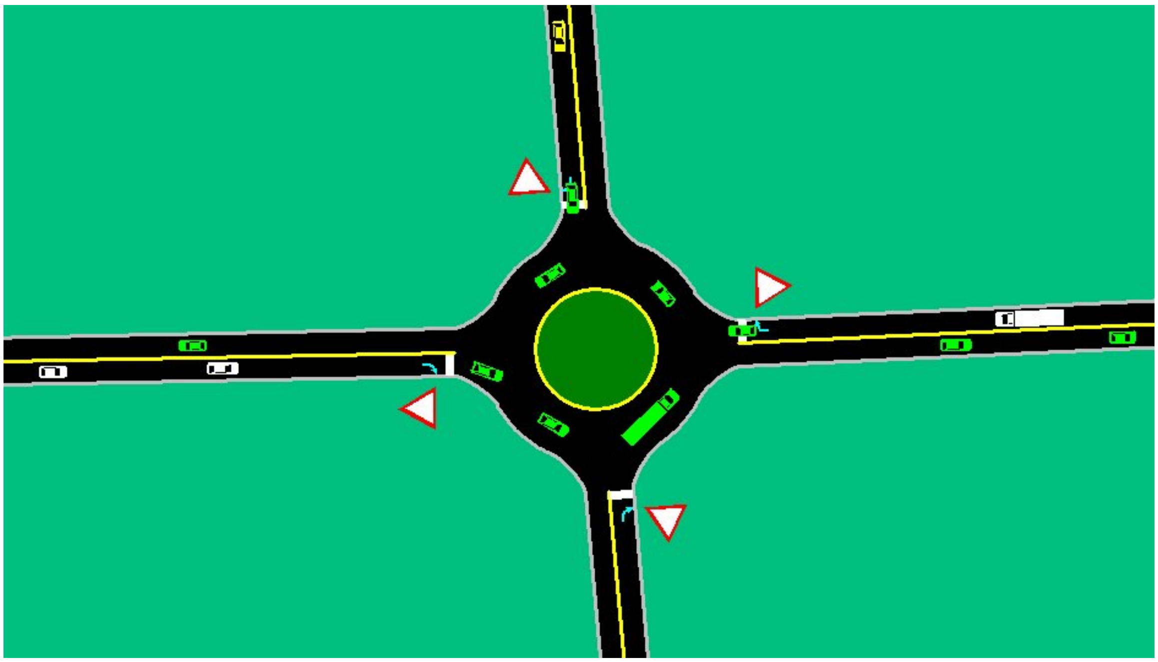

Figure 5.1 Screen Shot of Synchro Simulation of the Lehi Roundabout

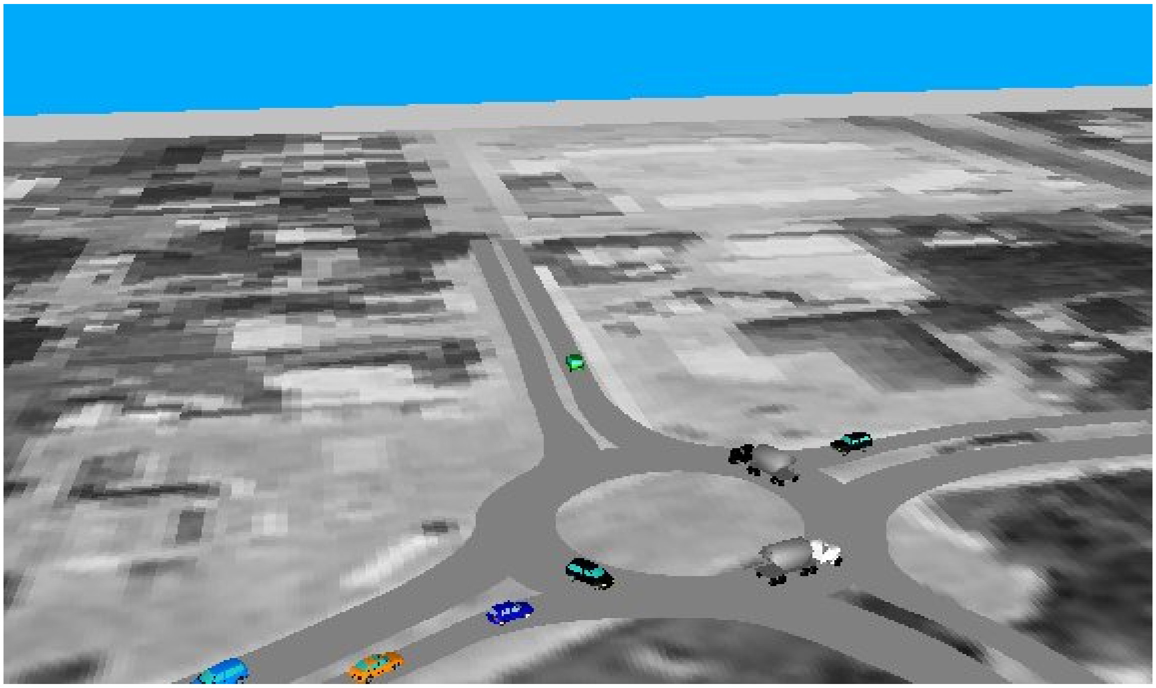

Figure 5.2 Screen Shot of VISSIM Simulation of the Lehi Roundabout

The simulation was used for analysis. Since the two programs use random number seeding, 10 simulations were performed with each software package. Table 5.4 presents the average values along with the standard deviation for the 10 executions. Note that the approach delay from SimTraffic and VISSIM were slightly different while stop delay and average stops per vehicle values from SimTraffic and VISSIM were quite different. In VISSIM not much stopping is recorded as vehicles try to enter the roundabout and most of the delay was caused by slow down on the approach. No judgment should be made at this point; further in-depth studies are recommended for comparing the performance of these software programs. The evaluation of delay at roundabouts in the field is difficult to accomplish.

Table 5.4 SimTraffic and VISSIM Output for Base Volumes

	EB	WB	NB	SB
	Delay (sec/veh)			
Synchro	6.3 (0.3)	4.5 (0.3)	6.5 (1.1)	2.7 (0.3)
VISSIM	4.8 (0.4)	2.9 (0.4)	3.1 (1.0)	1.5 (0.2)
	Stop Delay (sec/veh)			
Synchro	1.4 (0.2)	1.0 (0.2)	5.2 (1.1)	1.2 (0.3)
VISSIM	0.03 (0.05)	0.01 (0.03)	1.05 (0.18)	0.08 (0.11)
	Stops (per veh)			
Synchro	0.16 (0.05)	0.20 (0.04)	0.63 (0.05)	0.28 (0.04)
VISSIM	0.03 (0.01)	0.01 (0.01)	0.10 (0.05)	0.02 (0.02)

Average from 10 executions (Standard Deviation)

5.4 Summary

The different analysis may or may not produce comparable results. The user of the software programs need to be familiar with the characteristics and limitations of software programs. There is much debate concerning the appropriateness of the two methods. Many engineers argue that the empirical method cannot be properly employed in the United States because there is relatively little U.S. data available and U.S. drivers have different characteristics than European drivers. Other engineers argue that the gap method does not produce reliable results for certain capacities. At the time of this writing (the summer of 2005) the NCHRP is conducting an extensive study on roundabouts and their analysis methods to determine a standard for the United States (NCHRP 3-65: Applying Roundabouts in the United States). The currently available U.S. packages for roundabout analysis, HCS and Synchro 6.0 (SimTraffic), currently use the gap method but the developers are waiting to improve their packages based on the findings from the NCHRP study.

The simulation packages evaluated in this study are both based on gap analysis and relatively easy to use. However, they are not identical; for instance the way delay data are collected between the two simulation software is different from each other. SimTraffic collects at fixed locations, i.e., the downstream end of a link. Hence, the performance of the circular roundabout portion are combined with the performance data of downstream link; there is no way to separate these two. VISSIM offers more flexible approach and the user can define which part of the segments he/she wants to collect performance data. Most U.S. engineers are already familiar with Synchro; hence, SimTraffic is advantageous for this reason. However the limitations of these programs must be understood as they interpret their analysis results. One drawback of VISSIM is that it is considerably more expensive than the Synchro and SimTraffic combination. One drawback of these software is that Synchro simply mimics the Highway Capacity Manual analysis method and SimTraffic is not much flexible for obtaining MOEs.

6. DEVELOPMENT OF GUIDELINES

This chapter discusses the development of the Draft Guidelines and Design Standards and the Draft Policies and Procedures published as attachments to this final report. The information concerning existing guidelines from other states will be reproduced as it was presented in Chapter 2. The methodology and a description of the draft documents will be described.

6.1 Existing Guidelines of Other States

- MDOT – *Roundabout Design Guidelines*, The Maryland Department of Transportation, 1995.
  This was the first state roundabout guide. It closely follows the Australian design guide listed above. It suggests appropriate and inappropriate use of roundabouts, it recommends the SIDRA software for analysis and it provides information for both single-lane and multi-lane implementation.

- FDOT - *Florida Roundabout Guide,* The Florida Department of Transportation, 1998.
  This guide is recognized for its detailed section addressing roundabout justification and appropriateness. It is a comprehensive guide dealing with a variety of issues however it concentrates on single-lane roundabouts. This guide follows the Australian guide listed above. It presents a comparative review of SIDRA and RODEL, concluding that SIDRA is more appropriate for analysis.

- *Roundabout Design Guidelines*, Ourston and Doctors, 1995.
  This guide was prepared for Caltrans but was never published as a state guide. Ourston has used this guide for numerous roundabouts throughout the country. It follows the British methodology and recommends ARCADY and RODEL for analysis. The guide is noteworthy for addressing geometric design, from mini-roundabouts to large four-lane roundabouts. It includes specific design requirements for bicycles and pedestrians. It does not address signage.

- ODOT - *Modern Roundabouts for Oregon,* The Oregon Department of Transportation, 1998.
  This lengthy study examined the available roundabout guides (Australia, Maryland, Florida and Ourston) and supplemented the findings with recent studies and recommendations for Oregon's specific needs.

- NYSDOT – *Highway Design Manual Chapter 26: Roundabouts,* The New York State Department of Transportation, 2001.
  These guidelines for the state of New York are still considered just a draft. They rely heavily on the FHWA guide.

- PennDOT – *Guide to Roundabouts*, The Pennsylvanian Department of Transportation, 2001.

Pennsylvania's guide is designed to assist in the decision phase of roundabout consideration. The guide provides a questionnaire that helps the

- WSDOT – *Design Manual, Roundabouts, Section 915,* The Washington Department of Transportation, 2001.
  This section of Washington's Design Manual distinguishes six roundabout categories and then provides specific guidelines for each. The six categories, which are based on environment, number of lanes, and size, are: Mini roundabouts, Urban compact roundabouts, Urban single-lane roundabouts, Urban double-lane roundabouts, Rural single-lane roundabouts, and Rural double-lane roundabouts.

- MoDOT - *Project Development Manual, Section 4-05,* The Missouri Department of Transportation, 2002.
  This is Missouri's recently developed state guide. Its development relied heavily on its predecessors. It suggests an initial capacity check should be done using the HCM method, but that detailed analysis be performed according to the gap acceptance method and the aaSIDRA software. The guide presents a set of mandatory design elements that a designer must address, allowing flexibility and ensuring thoughtful, rigorous analysis. The guide requires that designers follow a three-stage justification process. The first stage, "Appropriateness," acts as an initial filter to quickly screen out inappropriate implementation. The second stage, "Operational Feasibility" and the third stage, "Comparative Performance," require more detailed examination of feasibility and efficiency. The guide is only applicable for single-lane roundabouts.

6.2 Methodology and Description of Draft Documents

The development of the draft guidelines found in Appendix A relied heavily on the guides of other states. The guides of Maryland, Florida, and Oregon were created prior to the publication of the FHWA guide. The other guides are based on the FHWA guide. Some guides, such as those of Arizona and New York, are elaborate documents that detail roundabout issues. However, the majority of the guides are short documents that act as a supplement to the FHWA guide. In these guides the reader is encouraged to consult the FHWA guide. The draft guidelines for Utah are intended to be a supplement to the FHWA guide as well. The draft guidelines resemble those of Washington and Missouri.

The draft guidelines are not a rigid set of rules. The designer is given flexibility with roundabout design and implementation. This flexibility encourages the designer to think proactively. The guidelines simply support and supplement the framework already established by the FHWA guide and the other standards and regulations of the UDOT.

The draft guidelines begin by providing the reader brief description of the modern roundabout. This assures that the designer is familiar with the terminology of the guidelines. Next there is a discussion concerning the appropriateness of roundabout implementation. This is presented early in the document to get the reader thinking about the feasibility and suitability of a roundabout at the location in question. This is followed by a brief explanation of capacity analysis in which the reader is told to consult the FHWA guide. The next two chapters present geometric and operational design standards that must be met.

The draft policy is intended to be the legal document that compels the designer to adhere to the UDOT roundabout guidelines. The draft policy outlines the procedure for implementation and delineates the responsibilities of each entity throughout the process.

7. Conclusion

This chapter presents a summary of the study, findings from the literature search and field observations, and recommendations for further study.

7.1 Summary of the Study

Roundabouts have become popular in the United States in the past ten years. Roundabouts have been especially popular in cities in the state of Utah. UDOT has recently installed three roundabouts on its state highways, but UDOT does not have specific guidelines or criteria to judge whether roundabouts would be appropriate for the requested site. The objectives of this study were the followings.

- Evaluate existing UDOT’s roundabouts (three roundabouts at the time of this writing) and some of the roundabouts constructed by local communities to identify factors affecting their performances
- Analyze existing roundabouts and conduct literature search to develop geometric and traffic constraints that will constrain the installation of roundabouts, including the existence of bicycles, pedestrians, the handicapped, and the elderly and children
- Conduct literature search and summarize the sign and marking practices for roundabouts
- Produce a set of guidelines and design standards used for selecting a roundabout instead of a regular intersection and a sample of policies and procedures

These objectives were met by the tasks conducted in the study. In the next subsections study findings and recommendations are presented.

7.2 Findings

There are hundreds of international articles, reports and studies providing information concerning the design, operation and benevolence of the modern roundabout. In the United States roundabout implementation is relatively new and therefore the literature is often limited and at time contradictory. NHCRP has been studying roundabouts as this study was underway. The NCHRP 3-65 Applying Roundabouts in the United States is near completion as this final report is being prepared. This NCHRP study will undoubtedly provide more definitive directions for design, analysis, and implementation of roundabouts in the United States.

Several state departments of transportations were found to have their roundabout design guidelines, from simple to elaborate ones. The Maryland DOT’s roundabout design guidelines were the first state roundabout guide. Other states DOT that have their own guidelines include Florida, Oregon, New York, Pennsylvania, Washington, and Missouri. The development of the guidelines and design standards, including sign and marking guidelines, of this study relied upon the information found in:

- FHWA. *Roundabouts: An Informational Guide*,
- Washington State DOT. *Design Manual, Section 915: Roundabouts*,
- Missouri DOT. *Project Development Manual*,
- Arizona DOT. *Roundabouts: An Arizona Case Study and Design Guidelines, Final Report 545*,
- AASHTO. *A Policy on Geometric Design of Highways and Streets*, and
- FHWA. *MUTCD Millennium Edition – Proposed Revision No. 2.*

The draft guidelines and design standards and a draft document for policies and procedures were prepared and included in the Appendix to this report; these documents can be used as stand alone documents.

As for the evaluation of the existing roundabouts, roundabouts in Lehi, Park City, Bloomington (owned by UDOT), and the main entrance to Utah Valley State College were visited and observed for their geometric and traffic conditions. Chapter 3 summarizes the findings of each roundabout in detail. In general, several issues exist that would require UDOT engineers' attention at these roundabouts. One of the issues is access to business establishments near the roundabouts. Both Lehi and Bloomington roundabouts have the entry and exit of a gas station very close to the roundabouts; entries and exits to these gas stations are located in the flared sections of roundabouts and turning into and out of these gas stations are hazardous and potentially become the source of capacity reduction of the roundabouts. Another major concern is lack of concern for pedestrians. During the field observations, several pedestrians were seen to cross the legs that did not have a pedestrian path, simply because those legs are close to their dwellings. As for traffic demands on roundabouts, future land use patterns of the areas surrounding the roundabouts need to be carefully evaluated at the time of the design, as well as the current land use patterns and traffic demands for the roundabouts. Once the lands surrounding the roundabouts are developed, it would be extremely difficult to widen the roundabouts.

As for the analytical and design software, RODEL and aaSIDRA appear to be most comprehensive and capable to reflect design features such as flare length and central island angles (see Table 5.1 for software feature comparison). RODEL is empirical and aaSIDRA is based on the gap acceptance concept. Two software programs, HCS and Synchro, produced in the U.S. are both based on the gap acceptance concept. Both software programs can analyze roundabouts with only one lane in the circular path. Compared to RODEL and aaSidra, they are inflexible and limited.

Two simulation software programs that are available to UDOT engineers, SimTraffic and VISSIM, were tested in this software. Both programs can handle multi-lane roundabouts. Entering data for SimTraffic is straight forward and done through Synchro; hence, the program still lacks the flexibility and simulation power of VISSIM. VISSIM provides the user more control than SimTraffic in the extraction of performance results such as delays and travel times. Due to the ease of data input, SimTraffic can be used to get the feel of what might happen to the roundabout under design. However, for an in-depth analysis, use of VISSIM is recommended.

7.3 Recommendations

The Guidelines and Design Standards for Roundabouts (Appendix A) and Policies and Procedures for Roundabouts (Appendix B) developed in this study are draft and require modifications as needed as new data on design, operation, and maintenance of roundabouts becomes available. These documents will function as stepping stones for better application of roundabouts. In order to further improve these documents, the following actions are recommended:

- Continually monitor the performance of UDOT owned roundabouts to see if they meet the current and future traffic demands,

- Develop a database to continually monitor crash types and severities and locations of occurrence because the severity level of roundabout related crashes may be lower but the number of crash occurrences may not decrease,

- Distribute the Guidelines and Design Standards for roundabouts among the UDOT engineers and seek feedback from design and field engineers of the region offices,

- Revise as needed the draft Policies and Procedures prepared by this study,

- Review NCHRP 3-65 Applying Roundabouts in the United States when it becomes available and incorporate new knowledge found in its report into the Guidelines and Design Standards, and

- Continue evaluating the capability of software programs that are capable to analyze and simulate roundabouts.

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