CHAPTER 12
DESIGN GUIDELINES FOR MODERN ROUNDABOUTS

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CHAPTER 12
DESIGN GUIDELINES FOR MODERN ROUNDABOUTS

12-1.0 INTRODUCTION

The modern roundabout is a highly refined circular intersection form with specific design and traffic control features. These features – including yield control of entering traffic, channelized approaches, and restrictive geometric curvature and roadway widths – are designed to control travel speeds, facilitate efficient exchange of traffic flows, and minimize the number and severity of vehicle conflicts.

12-1.01 General

Roundabouts have gained solid acceptance among design professionals and road users in recent years by virtue of their operational and safety performance. By those measures, they have proven comparable or superior to conventional intersections in most circumstances. MnDOT policy is to consider modern roundabouts for application on an equal basis with other intersection types.

12-1.02 Purpose and Scope

This chapter is intended to convey MnDOT policy and criteria on the design of modern roundabouts beyond what can be considered a foundational understanding of roundabout design. The intended outcomes are design products conducive to safe and efficient travel, suitable for typical conditions and needs in Minnesota, and consistent with roadway design practice elsewhere in this manual.

The designer should consider the material herein supplemental to the existing body of guidance and study on roundabout design, particularly those references in 12-1.07. The scope of this chapter is particular guidance related to operational analysis, geometric design approach, and detailed treatments specific to the models and methodology that have been designated for use on MnDOT facilities, as well as MnDOT-specific preferences within the generally accepted range of practice.

12-1.03 Evaluation Criteria

In most cases, modern roundabouts compare favorably in safety and operational performance to conventional intersections with stop control or signalized operation. Additionally, roundabouts have comparable initial construction costs and lower life-cycle costs than a traffic signal with similar traffic capacity. For these reasons and others, MnDOT's policy is that modern roundabouts are an intersection design form equal to other traffic control methods in terms of the Department's acceptance and consideration.

In general terms, any intersection – whether in an urban or rural environment – that meets the criteria for additional traffic control beyond a thru stop condition, also qualifies for evaluation as a modern roundabout. Therefore, in any planning process for an intersection improvement where a traffic signal or a 4-way stop is under consideration, a modern roundabout should likewise receive serious consideration. Additionally, roundabouts should always be considered as an improvement strategy for existing 4-way stop or signal-controlled intersections with safety or operational problems.

The selection of the most appropriate traffic control at an intersection requires the completion of an Intersection Control Evaluation (ICE) study. This study replaces the Signal Justification Report (SJR) previously required for all new and revised traffic signal systems. The study should evaluate any reasonable intersection control alternative considering, safety and capacity impacts as well as political considerations.

Consideration of roundabouts is particularly encouraged if any of the following characteristics of the intersection exist:

- High left turn volumes,
- Documented right angle or left turning crash problem,
- Interchange ramp terminal,
- U turns occur with regular frequency,
- Greater than four legs of approach,
- Locations where right-of-way impacts on approach legs are a concern,
- Areas where traffic calming is desired,
- Roadway transitions from high to low speed operation, or
- In corridors being considered for access management.

Conditions where roundabouts may not be as effective as other intersection forms include:

- Where queuing may occur (e.g. a railroad crossing or traffic signal) which could back traffic into the roundabout,
- Within a coordinated system of traffic signals,
- Greatly unbalanced traffic volumes on approach legs when near capacity,
- Where right of way needed at the intersection node is unavailable, and
- At steep grades or vertical alignments where the geometry of the roundabout cannot be seen by the driver (e.g. beyond the crest of a vertical curve).

12-1.04 Analytical Tools

As with any facility or intersection type, analysis and quantification of travel delay is necessary to compute the level of service adequacy of a modern roundabout.

In the case of roundabouts, the effects of geometric features on traffic operation are more pronounced than with a conventional intersection. For this reason, where capacity considerations are expected to be a critical factor, selecting the optimal basic geometric design parameters will be key to ascertaining the adequacy of the overall concept. In these cases, an analytical modeling procedure combined with draft geometric design effort early in the project development process is encouraged.

Roundabout design and analysis models generally fall into two categories. Empirical models rely on historical field data to develop relationships between geometric design features and performance measures such as capacity and delay. Analytical models are based on the concept of gap acceptance theory as it applies to the driving task at a roundabout. Extensive research conducted in the United Kingdom (U.K.) supports the empirical formula method of roundabout analysis over the gap acceptance method of analysis. RODEL and ARCADY are computer software programs based on the U.K. empirical methods. At this time, MnDOT supports the use of either of these programs for geometric design-related capacity analysis and design element optimization.

It is important to be mindful that, regardless of the ability of these methods and models to accurately predict operational performance in real-world conditions, other components of the analyses, such as traffic forecasting, are far less precise. An awareness of this as well as system considerations and the application of engineering judgment will be crucial components in any analytical process of this type.

12-1.05 Roundabout Classification and Design Methodology

The methodology used and level of expertise required to develop a roundabout design will vary depending on the traffic demand, number of lanes (e.g. single lane versus multi-lane design) and general complexity of the situation.

Almost by definition, a roundabout design process should be expected to be an iterative one, particularly considering the design element optimization possible with the empirical methods and associated models. It is strongly encouraged to seek expert roundabout design consultation on any roundabout at an early stage of planning and design for safety and capacity purposes.

For the purposes of classification, roundabouts can be divided into three classes, each with their particular design approaches and demands.

12-1.05.01 Single-Lane Low-Demand Roundabouts

A single-lane roundabout where traffic capacity is not a critical item is typical of the design complexity of this level roundabout. This may occur in rural locations or in lower demand urban settings. A total entering design hourly volume (DHV) of less than 1500 (all legs) is a rule of thumb for classification purposes.
For this type of roundabout, traditional geometric design principles involving safety, comfort, drivability, and ease of use, and perception, in addition to the roundabout design component of fastest speed path, can usually be the overriding basis of design. Even though traffic operation is not necessarily critical, checking the draft design using a computer analytical model is encouraged.

12-1.05.02 Single-Lane High-Demand Roundabouts

The design complexity at this level involves single-lane roundabouts where traffic operations and capacity are critical design factors. A rule of thumb threshold for this roundabout class is where the total entering design hourly volume is greater than 1500. In these cases, use of preferred computer analytical models in an integral way during the planning and design process is required. The design team on a project of this sort should have prior roundabout design experience, and understand the function and output of the computer analytical model used.

12-1.05.03 Multi-Lane Roundabouts

The design complexity of this level involves roundabouts where one or more legs have a two (or more) lane entry and a portion of the circulating roadway needs to have at least a two-lane width in order to meet anticipated traffic demand. For these designs, roundabout expertise – either on the design team or in a consulting capacity – is required. Early and ongoing use of computer analytical models (i.e. RODEL, ARCADY) during the planning and design process to confirm adequacy of the concept and optimize geometric design attributes will be a compulsory item.

12-1.06 Design Review Process

Due to modern roundabouts' status as a relatively new and unique design form as well as the inherent complexity of their geometric and operational aspects, it is appropriate that a specialized design review process be established to ensure their success and effectiveness where constructed.

There are three critical junctures in the roundabout project development process where review and comment activities are appropriate. They are:

1. The Intersection Control Evaluation study (in the cases where the roundabout option is selected).
2. Completion of the Geometric Layout for staff approval.
3. The 30% milestone of construction plan development.

The review and approval requirements at each of the above junctures are as follows:

<u>Intersection Control Evaluation</u>

When roundabouts are determined to be a reasonable alternative during the ICE process, a capacity analysis is performed based on a preliminary layout. Overall capacity is highly dependent upon design features. Therefore, coordination with personnel who are experts in the design of roundabouts can be critical at this early stage. Comparisons with other traffic control devices should be based upon the maximum capacity that can be obtained in a given location. Additionally, an optimized design is valuable in determining other impacts, such as right of way and construction costs.

<u>Geometric Layout</u>

Based on the common facility types where modern roundabouts are typically proposed, it is expected that many if not most roundabout projects would fall under the category of Level 2 Layout preparation and approval. However, layout development guidance in the *Highway Project Development Process* Handbook (Part II, Section D, Subject Guidance: Geometric Layouts, Appendix 3) states, "Should the complexities of a layout or a partial layout be found to be beyond the scope of Level 2, then the C.O. Geometrics Engineer may request a Level 1 Layout approval." Based on the intent of this guidance and the inherent complexity of the roundabout design form, the State Geometrics Engineer has made a standing request that, until further notice, all roundabout layouts be designated as Level 1 Layout documents. It will be the responsibility of the Geometrics Engineer to maintain a standing review committee, which is sufficiently qualified and equipped to provide competent review services and make satisfactory recommendations to the approving parties.

All geometric layouts incorporating roundabouts will be reviewed during their development by MnDOT Office of Traffic, Safety and Technology (OTST) staff. This review will ensure that each roundabout design will accommodate signs at their appropriate locations. In the event a roundabout will incorporate a unique feature not addressed in MnDOT signing standards and guidelines, consult with OTST staff during geometric layout development.

30% Construction Plan

In addition to the customary review procedure that a MnDOT district office may have for construction plans at the 30% completion milestone, a review-and-comment submittal to the Central Office Geometric Design Support Unit will be required. This step is to ensure conformance of the detailed design to the intent of the Geometric Layout as well as identify any design issues that may not have been apparent during the preliminary design phase. Comments provided will be for the District Design Engineer's consideration and would not be binding unless specifically designated as so. Similar to the geometric layout review process, the Geometric Design Support Unit will be responsible for identifying the necessary expertise and support needed to competently and thoroughly evaluate the plans. This process may include a routing procedure, solicitation of direct input, or other potential means.

Construction plans incorporating roundabouts are to be reviewed by MnDOT Office of Traffic, Safety and Technology (OTST) staff. This review will ensure that the signing, pavement markings and lighting meet MnDOT standards and guidelines. In the event a roundabout will incorporate a unique feature that MnDOT signing, pavement marking or lighting standards or guidelines do not address, consult with OTST staff during plan development.

12-1.07 Design References

Roundabouts: An Informational Guide, Second Edition, published by the Transportation Research Board (NCHRP Report 672, 2010), represents the most widely accepted national guidance on the subject of modern roundabout planning and design. Its contents are based on established international and U.S. practices at the time of publication and are intended to present an approach most suitable for the United States. It is the most generally recognized guidebook for American design work and serves as a starting point for many states in their application of more specific design criteria.

There have been multiple studies on the use, effectiveness, and safety of roundabouts. A listing of guides, research papers, and other reports may be accessed on the MnDOT web site at http://www.dot.state.mn.us/roundabouts/resources.html.

12-2.0 PUBLIC INVOLVEMENT

12-2.01 Public Awareness

The success or failure of a project can often be attributed to how well the Department included the public in its development. This can be particularly true with introducing the modern roundabout because of lack of familiarity and confusion with past circular intersections. As mentioned, there are several excellent resources to assist the designer in explaining the concept to the public.

Concept acceptance and the project buy-in are best achieved when the local community has been involved from beginning of the project. Take as many opportunities as possible to explain the project. Public meetings are good places to start and continue to build project support.

Inform the public of advantages and disadvantages of a proposed roundabout. As with any new concept, the project team can anticipate a certain degree of skepticism about a proposed roundabout. It may be viewed as the traffic circle of the past; at best not seen as an improvement, at worst associated with poor operational characteristics. Early public education is essential to a successful project start up. Several educational tools and media are available to help designers inform the public about roundabouts, and to build support for the concept. Information brochures and videos can be very helpful. There is software available that demonstrates the characteristics of roundabout operations. At times, a local newspaper may be looking for general interest articles; this may be an opportunity to increase public awareness of roundabouts.

Politicians, maintenance personnel, emergency services personnel, school districts, and any special interests as may exist due to project location, should be included in the public awareness and information process.

Typically, in the project process, alternatives are considered. The alternatives generally include traffic signal or stop sign control, which are familiar to drivers and pedestrians. Presenting a comparison of traffic operation and safety is a good way to introduce roundabouts. It is also beneficial to inform the public of good nearby design examples.

Another important aspect of public information is to familiarize new drivers with how roundabouts operate. This can be accomplished with brochures, videos, and/or simulations.

12-2.02 Public Meetings

Public meetings provide an excellent opportunity to bring the public into the design process. Depending on the receptivity of the community, a less formal meeting where information can be exchanged, explained, and discussed can be very useful in developing a project. Holding open houses and public information “exchange” meetings, and attending city council and town board meetings or local service organizational meetings are all good formats for education and consensus building.

12-2.03 Information Brochures

Informational brochures are a very useful way to educate the public about roundabouts. Not only can they explain the roundabout concept, its advantages, and disadvantages, but they can also be used to compare roundabouts to older circular intersection concepts and traditional intersection types. They can also include graphics or photographic images to assist in demonstrating technical issues to non-technical audiences. Driver education is also provided in the Minnesota Drivers Manual published by the Minnesota Department of Public Safety.

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12-2.0 SCOPING AND FEASIBILITY

12-3.01 Scoping

Roundabouts may be considered for a wide range of intersection types including but not limited to freeway interchange ramp terminals, state route intersections, and state route/local route intersections. Roundabouts generally process high volume left turns more efficiently than all-way stop control or traffic signals, and will process a wide range of side road volumes. Roundabouts can improve safety by reducing conflicts, reducing vehicle speeds, and providing a clearer indication of the driver's right of way compared to other forms of intersection control. The required intersection sight distance is approximately half that required for a signalized intersection.

Coordinate early in the scoping stage with the District Planning and Traffic sections to determine whether a roundabout should further be considered as an alternate once an initial analysis is completed.

Critical to the acceptance of the roundabout intersection concept is overcoming the initial skepticism of its advantages and value over alternate intersection types. At a minimum, compare the capacity, delay and crash analysis for the roundabout and other alternatives to determine the relative advantages and disadvantages of each.

Roundabouts should be considered for any intersection improvement. A roundabout may also be considered for one or more stages of an intersection improvement strategy where the design year intersection treatment is not cost-effective or cannot be feasibly constructed. Examples of staged roundabouts include a roundabout designed to accommodate future additional entry or circulatory lanes or a roundabout designed to preserve right of way for a future interchange. Staged roundabouts should be designed to minimize the number of transitions to the ultimate design-year intersection treatment. Typically, the first stage has a similar inscribed circle diameter as the ultimate stage, but consists of fewer entry, circulating, and/or exit lanes.

Meet with local officials and adjoining property owners early in the process to address potential political or economic impacts. There are typically three phases to a roundabout project:

1. Feasibility
2. Alternatives analysis and preliminary design
3. Final design

Phases 2 and 3 will be addressed in subsequent procedures

12-3.02 Feasibility

The feasibility phase is conducted to estimate the general size of the roundabout (inscribed diameter, number of entry and exit lanes, and potential right-of-way conflicts). The feasibility phase is based on preliminary data and it is therefore not intended to provide detailed geometric dimensions.

Design year, design hour traffic volumes (DHV), and preliminary geometric values for the six geometric design parameters (half width, entry width, effective flare length, inscribed diameter, entry radius and entry angle) can be used to identify the general size of the roundabout and operating characteristics. Conduct a capacity analysis to estimate the general size of the roundabout to include the inscribed diameter, entry width, and number of entry lanes. Default software values should not be used in the capacity analyses.

There are two different methods to achieve the estimated general size of the roundabout. The first and preferred method is to use U.K. empirical software for determining the initial entry lane configuration in the capacity analyses. Table 12-3.04A provides typical geometric parameters for the design of urban and rural roundabouts. These values are a first estimate, preliminary and final design values will change.

The second method is the Highway Capacity Manual (HCM) methodology, for which an overview is presented in *Roundabouts: An Informational Guide*, Chapter 4, Section 4.5. This method essentially treats the roundabout as a series of independent "T" intersections and may provide valid results at low v/c ratios. This method does not account for interaction between the legs of the various roundabouts, whereas the empirical methodology does.

Do not assume that a roundabout will not work well when the side road traffic is a low percentage of the total traffic entering the intersection. One of the primary measures of effectiveness for a roundabout or other intersection treatments is vehicular delay. Queue length is a function of delay and is an important consideration as well. Other factors to consider are existing crash rates, severity of crashes, overall project cost and the ability to meet project objectives while minimizing negative impacts associated with the project such as business accesses, encroachments, etc.

Feasibility for roundabouts begins with specifying a preliminary configuration. The configuration is specified in terms of the minimum number of lanes required on each approach and thus which roundabout category is the most appropriate basis for design: urban or rural, single-lane, or multi-lane. Roundabouts are appropriate at high-speed intersections, especially those with a poor crash history. Roundabouts are a reasonable alternative at locations with poor visibility, as only short visibility left and right is needed. However, the stopping sight distance to the roundabout must be provided. There are many additional levels of detail required in the design and analysis of a high capacity, multi-lane roundabout that are beyond the scope of a planning level procedure. Therefore, this procedure focuses on the more common questions that can be answered using reasonable assumptions, a simple roadway alignment, and approximations.

A feasibility analysis requires an approximation of some of the design parameters and operational characteristics. Some changes in these approximations should be expected as the design evolves. A more detailed methodology for performing the geometric design and operational evaluation tasks is presented in the Geometric Design Section of this document. Also, refer to *Roundabouts: An Informational Guide*, Chapter 6 for general guidance.

12-3.03 Intersection Control Evaluation (ICE)

Engineers have an increasing number of options for intersection traffic control than they had in the past. Previously, the only solution to traffic delay and safety problems for at grade intersections was the installation of a traffic signal. Today, the engineer has a much wider number of options from which to choose. Depending on a number of factors, the optimal choice for intersection control may not be a traffic signal. Therefore, it is imperative that an *Intersection Control Evaluation* (ICE) study be conducted during the planning phase of any intersection improvement project. Previously, *Signal Justification Reports* (SJR's) had to be completed before a new signal or significant modification of a signal could proceed (*MN MUTCD* May, 2005 and MnDOT *Traffic Engineering Manual* updated July 1, 2003). An ICE will incorporate the SJR and expand the process. All intersection treatments must be considered in the planning phase. Contact the District Traffic Engineer for the required content of the ICE report.

12-3.04 Site Requirements

When a roundabout is being considered as an intersection alternative, the following sections give a list of site requirements to study for the ability to construct a roundabout.

<u>Inscribed Circle Diameter (ICD) and Capacity Limitation:</u>

The inscribed circle diameter needed for the roundabout is the most critical space requirement for installation. The following table 12-3.04A gives general inscribed circle diameters and daily service volumes for the different MnDOT categories of roundabouts. Diameters will vary from site to site and may fall outside these prescribed ranges in some situations. This table also provides a rough estimate of capacity for the roundabout categories. Since the actual capacity is based on turning movements and other factors, the RODEL or ARCADY design software must be used first to verify capacity prior to going forward with the roundabout alternative. Adjust all necessary RODEL values shown on the plans to U.S. Customary units (feet). Refer to *Roundabouts: An Informational Guide,* Exhibit 1-9, for information on additional categories.

More right of way is typically needed directly at the intersection. However, this may be more than offset by the right of way saved on approaches and exits compared with the requirements at alternatives like a signalized intersections.

Table 12-3.04A
TYPICAL INSCRIBED CIRCLE DIAMETERS AND DAILY SERVICE VOLUMES

Roundabout Type	Typical Inscribed Circle Diameter[1]	Typical Daily Service Volume[2] (vpd) 4-leg roundabouts
Urban Single-Lane	115 – 140 ft (35 – 43 m)	less than 25,000
Urban Multilane (2-lane entry)	150 - 200 ft (45 – 60 m)	25,000 to 55,000
Urban Multilane (3 or 4-lane entry)	200 – 280 ft (60 – 85 m)	55,000 to 80,000
Rural Single-Lane	120 – 150 ft (36 – 45 m)	less than 25,000
Rural Multilane (2-lane entry)	165 – 220 ft (55 – 67 m)	25,000 to 55,000
Rural Multilane (3-lane entry)	200 – 250 ft (60 – 76 m)	55,000 to 70,000

[1] The diameters provided are for general guidance (face to face of outside curb).
[2] Capacities vary substantially depending on entering traffic volumes and turning movements (circulating flow).

Terrain:

Roundabouts typically should be constructed on relatively level or rolling terrain with a maximum approach grade of 4% near the roundabout. Grades approaching 4% and steeper terrain may require greater transitions to provide an appropriate flat area or plateau for the intersection. Circulating roadway slopes of less than 2.5% is desired, whereas approaching and exit grades should not exceed 4% within the stopping sight distance of the roundabout (ICD).

For purposes of this text, the roundabout is broken into two main components, the 'Circulating Roadway' (diameter) and the 'Approaches and Departures' (intersection legs).

12-3.05 Pedestrian and Bicyclist Accommodations

Research conducted worldwide indicates fewer pedestrian crashes occur, and with less severity, at roundabout intersections when compared to signalized and unsignalized intersections with comparable volumes. Design principles need to be applied that provide for slow entries and exits for pedestrian safety. With proper design of a modern roundabout, the deflection in the design will create slow speeds at all entries and exits without producing radii that are too small or having negative effects on capacity.

Accommodating non-motorized users is a MnDOT priority. Therefore, give special design consideration to locations where:

1. Pedestrian and/or bicycle volumes are high, due to such land uses as; schools, playgrounds, residential/commercial areas, college or university settings.
2. The area is urban or suburban and has residential, shopping, employment centers, libraries, parks, or transit service nearby.
3. The area is mostly rural but a limited number of crossing opportunities exist or few alternative routes are available.
4. Pedestrians and bicyclist are experiencing particular difficulty in crossing and/or are being excessively delayed.

Land use is an important factor in determining the type of bicycle and pedestrian accommodation and some locations may warrant additional treatments. The designer is strongly encouraged to contact the State Bicycle Coordinator and the State Pedestrian Coordinator for guidance, in determining the types of bicycle and pedestrian accommodations needed.

12-3.05.01 Pedestrians

Due to relatively low operating speeds of 15-25 mph (25-40 km/h), the incidence and severity of crashes are lower at roundabouts than other types of intersections. Below is a list of roundabout advantages and disadvantages as related to pedestrians.

ROUNDABOUT ADVANTAGES AND DISADVANTAGES FOR PEDESTRIANS

Advantages

- Vehicle speed is reduced at all legs as compared to a two-way stop or signals.
- Pedestrians have fewer conflict points than at other intersections.
- Shorter lane crossing distance, resulting in less vehicle exposure to pedestrians.
- The splitter island refuge allows pedestrians to resolve conflicts with entering and exiting vehicles separately and simplifies the task of crossing the roadway.
- Crossing is often accomplished with less delay than at two-way stop or signalized intersections.

Disadvantages

- Vehicle traffic is yield controlled so vehicle traffic does not necessarily come to a full stop. Therefore, pedestrians may be hesitant to use the cross walk at first.
- May be unsettling to the pedestrian, depending on age, mobility, visual impairments, and ability to judge gaps in traffic.
- Pedestrians will have to adjust to the operation of a roundabout with its crosswalk location often placed behind the first stopped vehicle or approximately 25 ft (8 m) from the yield point.
- Pedestrian movements are more circuitous, and less intuitive than at traditional intersections.

General design elements for pedestrian crossings include:

1. Pedestrian crossing distance and location,
2. Crossing alignment,
3. Splitter island and pedestrian refuge design,
4. Providing for visually impaired pedestrians as well as other disabilities,
5. Discouraging pedestrian from crossing to the central island, and
6. Shared use path width and location.

Choosing the appropriate crossing location for pedestrians is a delicate balance between their safety and convenience, and operation of the roundabout. Pedestrians want crossing locations as close to the intersection as possible to minimize out-of-direction travel. The further the crossing is from the roundabout, the more likely those pedestrians will choose a shorter route that may put them in greater danger. Both crossing location and crossing distance are important. Minimize crossing distance to reduce exposure to pedestrian-vehicle conflicts. A pedestrian overpass or underpass may be needed to accommodate pedestrians in higher traffic volume locations.

In general, for single lane roundabouts, locate the pedestrian crossing approximately 25 ft (8 m) upstream from the yield point. This helps to reduce decision-making problems for drivers and to avoid creating a queue of vehicles waiting to enter the roundabout. However, for pedestrian safety the crossing should not be located too far back from the inscribed circle such that entering vehicle speeds are still high or exiting vehicles are accelerating. Locate the pedestrian crossing at two or three car lengths from the yield point for multi-lane entries. Make the crossing perpendicular to the direction of travel on entrances and exits to minimize pedestrian travel and exposure time as well as to assist visually impaired pedestrians. Detectable warnings need to be applied at curb ramps, splitter islands, and cut-throughs.

The greatest challenge lies with the continual movement of traffic and the difficulty for some pedestrians to judge gaps in an oncoming travel stream. This is especially true of children, the elderly, or the disabled who generally prefer larger gaps in the traffic stream and walk at slower speeds than those of other pedestrians. Pedestrians crossing at roundabouts should be given special consideration, to ensure that all crossings comply with the Americans with Disabilities Act (ADA) accessibility standards. See *Roundabouts: An Informational Guide*, Chapter 5, Section 5.3.3 Pedestrians, *MN MUTCD* for general guidance, and chapter 11 of this manual.

Roundabouts and other intersection types and channelized turn lanes present challenges to visually impaired pedestrians in both way finding and gap detection. Bypass lanes may complicate navigation for visually impaired pedestrians due to additional vehicle conflict points. Generally, right-turn bypass lanes should be carefully evaluated because they may increase conflicts with bicyclists and pedestrians. However, a bypass lane may prevent the need for a multilane roundabout. The pedestrian design factors discussed earlier help provide way finding cues for visually impaired pedestrians. For gap detection, the FHWA states that the revised draft accessibility guidelines for public rights-of-way are the recommended best practices for areas that are not fully addressed by the present ADA standards. According to those guidelines, for roundabouts with multi-lane crossings, a pedestrian activated signal at each segment of each crosswalk is consider a best practice. They should clearly identify which crosswalk segment the signal serves and the signals need to be accessible. Other options exist to provide accessibility including grade-separated crossings.

12-3.05.02 Bicyclists

The experience in other countries with bicyclists at roundabouts has been mixed with regard to safety. The Insurance Institute for Highway Safety reports that roundabouts provide a 10 percent reduction in bicycle crashes when 24 signalized intersections were converted to roundabouts in the U.S. Multi-lane entry roundabouts may be more problematic than single lane entries.

The operation of a bicycle through a roundabout presents challenges to the bicyclist similar to that of traditional signalized intersections especially for turning movements. As with pedestrians, one of the difficulties in accommodating bicyclists is their wide range of skills and comfort levels in mixed traffic. While experienced bicyclists may have no difficulty maneuvering through a roundabout, less experienced, or slower, bicyclists may have difficulty and discomfort mixing with vehicles, and are better accommodated as pedestrians on an adjacent shared use path. The complexity of vehicle interactions within a roundabout could leave a bicyclist vulnerable. Bike lane markings within the circulatory roadway shall not be used, see *MN MUTCD* for signing and striping. Effective designs that constrain motorized vehicles to speeds more compatible with bicycle speeds, around 15-20 mph (25-30 km/h), promote safety and comfort for bicyclist.

Design features such as proper deflection, entry curvature, and entry width help slow traffic entering the roundabout. Providing a ramp from the roadway to a shared-use path prior to the intersection allows a bicyclist to exit the roadway and proceed around the intersection safely with crosswalks.

Bicyclists are often less visible and therefore more vulnerable when merging into, and diverging from, multilane roundabouts. Therefore, it is recommended that a wider shared-use pedestrian-bicycle path, separate from the circulatory roadway, be built where bicycle use is expected. While this will likely be more comfortable for the some bicyclist, the experienced bicyclist, will be significantly slowed down by having to cross as a pedestrian at the cross walk and may choose to continue to traverse a multilane roundabout as a vehicle.

Providing bicyclists with an alternative route along another street or path allows bicyclists an option to avoid the roundabout. This should be considered as part of overall network planning. The provision of alternative routes should not be used to justify compromising the safety of bicycle traffic through the roundabout because some bicyclists and those with destinations near the roundabout may use the roadway.

Try to provide bicyclists the choice of proceeding through the roundabout as either a vehicle or as a pedestrian. In general, bicyclists are better served by being treated as vehicles. However, at high volume single lane or multi-lane roundabouts, provide shared use paths, which include a physical separation from vehicles around the periphery of the roundabout. The following guidance is intended for shared-use paths at roundabouts:

1. Construct a widened sidewalk or separate shared-use path around the outside of a roundabout to accommodate bicyclists who prefer not to travel through the roundabout.

2. Do not provide a bike lane within the circulatory roadway. Begin and end the shared-use path upstream of the yield point to allow the bicyclist an opportunity to transition onto the path away from the circulatory roadway itself. More upstream distance may be needed on multi-lane or rural approaches.
3. Provide a ramp or other suitable connection between the bike lane on the roadway and the shared use path on both entry and exit.
4. Make the detached shared-use path or sidewalk a minimum width of 8 ft (2.5 m). A 10 ft (3 m) wide path is preferred to allow for two-way travel. A 6 ft (2 m) wide path may be acceptable only if bicycle and pedestrian use is very low. In all cases, the path should be detached from the roundabout at a desired boulevard width of 6 ft (2 m) and minimum offset of 2 ft (0.6 m).
5. Provide a continuous and detectable landscape barrier (boulevard) along the street site of the path.
6. Grade separation (overpasses or underpasses) for bicyclist and pedestrians may be considered for high-capacity and multilane roundabouts.

Review the MnDOT Bikeway Facilities Design Manual and consult with the State Bicycle Coordinator and the State Pedestrian Coordinator for more information on the design requirements for bicycle and shared-use path design.

Grade Separation (overpasses or underpasses) for bicyclists may be considered for high-capacity roundabouts. For information on permanent public trails, crossing rural public roads, contact the State Bicycle Coordinator or the State Pedestrian Coordinator.

12-3.06 Transit, Large Oversized Vehicles, and Emergency Vehicles

12-3.06.01 Transit

Transit considerations at roundabouts are similar to those for any other intersection configuration. A properly designed roundabout will readily accommodate buses. If possible, locate bus stops downstream of the roundabout and far enough away to prevent traffic from backing up into the roundabout. Coordinate bus stop locations with the community. Provide bus pullouts, if possible, to get the buses out of the traffic stream.

12-3.06.02 Large Oversized Vehicles and Emergency Vehicle Considerations

Design roundabouts for the largest vehicles that can routinely be anticipated. All oversized/ overweight vehicles including building or house movers are required to obtain permit from the MnDOT Office of Freight and Commercial Vehicle Operations (OFCVO). When a roundabout is being considered, OFCVO and District Permits Office should be contacted to determine if the location sees significant oversized/overweight truck movements or is a designated truck route.

Modern roundabouts are designed with a truck apron to accommodate wheel tracking of larger vehicles. Designers should assume that the tractor of the standard design vehicle will not encroach onto the truck apron. The truck apron is used for the rear wheel swept path only (trailer). On some multilane roundabouts, large vehicles can use the entire width of the circulatory roadway to negotiate through the roundabout. In most cases, the standard design vehicle should stay in lane for all turning movements while using the truck apron when on the inside lane. In some extreme cases, roundabouts have been designed with a gated roadway through the center island to accommodate oversized or emergency vehicles.

A well-designed roundabout will address load-shifting problems with larger vehicles as well as allow for all turning movements without running over right curbs or sidewalks. Problems such as inadequate entry deflection leading to high entry speeds, long tangents leading into tight curves, sharp turns at exits, excessive cross slopes, and adverse cross slopes have been the principal causes of load shifting. These issues need to be remedied in a design before design approval. Right turns are problematic for trucks as they require large turning radii and tend to run over sidewalks and splitter islands to make the turn if the roundabout is not designed properly. It is not permitted or good design practice to have trucks run over outside curbs.

Typical emergency vehicles passing through a roundabout do not encounter the same problems as other large vehicles. However, they may require the use of a mountable apron to bypass traffic or if the emergency vehicle is as large as the design vehicle. On emergency response routes, compare the delay for the relevant movements with alternative intersection types and controls.

12-3.07 Social, Environmental, and Economic Considerations

Public acceptance of roundabouts can be one of the biggest challenges facing a jurisdiction that is planning to install its first roundabout. Without the benefit of explanation or first-hand experience, the public is likely to incorrectly associate roundabouts with older, nonconforming traffic circles that they have either experienced or heard about. Equally likely, without adequate information the public (and agencies alike) will often have a natural resistance to changes in their driving behavior and driving environment.

Public education and involvement is encouraged to not only provide information on a specific roundabout project, but also to educate people on the safety and capacity benefits, community benefits, how to drive a roundabouts esthetic features, and actions to take when emergency vehicles are present.

Construction of a roundabout has the potential to impact social, environmental, and economic attributes in the project area, similar to any highway construction project. Therefore, the designer should refer to the MnDOT *Highway Project Development Process* Handbook for assistance in assessing these possible impacts.

Impacts on visual resources can be a serious issue as well. However, the roundabout offers an excellent opportunity for enhancing the visual environment since the interior of the circle can be landscaped to become an attractive local feature. In addition, the potential adverse visual impact of signal poles is avoided with a roundabout solution. Public support can be encouraged if the local community can see the alternate as a visual enhancement. With regard to noise, energy consumption, and air pollution, the modern roundabout offers distinct advantages over other intersection types. Vehicles can create significant air and noise pollution while idling and accelerating through an intersection. On the other hand, vehicles are generally kept moving at lower speeds through a roundabout resulting in less fuel consumption and less air and noise pollution.

12-3.08 System Considerations

Roundabouts have been considered as isolated intersections throughout this section. However, roundabouts may need to fit into a network of intersections with the traffic control functions of a roundabout supporting the function of nearby intersections and vice versa.

12-3.08.01 Access Management

Management of access to arterial roads is vital to creating a safe and efficient transportation system for motorists, bicyclists, and pedestrians. Access guidance is provided through the MnDOT *Access Management Manual*. Some benefits include:

1. Increased capacity along arterial roads,
2. Decrease delay and blockages for nearby accesses,
3. Reduction of overall traffic congestion and delay,
4. Improved safety,
5. More efficient use of land, and
6. Savings on infrastructure investments.

The operational characteristics of roundabouts may offer advantages when compared to existing conventional approaches to access management. For example connecting two roundabout intersections with a raised median precluding lefts in/out of side streets or business accesses to preserve highway capacity is much less detrimental as U-Turns are not problematic at the roundabout. This provides the desired capacity preservation and safety along the mainline with much less impact to business accessibility.

Major private driveways may be permitted along the circulating roadway. The installation of a roundabout strictly for access to a private driveway is generally discouraged, unless the roundabout is installed at a private driveway where the private entrance is designed as a public intersection, the private driveway provides access to multiple parcels and the driveway location is consistent with the public intersection spacing guidance in the MnDOT *Access Management Manual*.

Minor commercial and residential driveways are not recommended along the circulating roadway unless it is designed as a leg of the roundabout. Some situations may dictate the need for a driveway and must be analyzed on a case-by-case basis. Driveways may be located along the entrance and exit legs, but need to be set back to not interfere with pedestrian movements in the crosswalks, and to minimize the number of conflict points with vehicles approaching or exiting the roundabout. Driveways located along the entrance and exit legs should be separated from the circulating roadway in accordance with the *Road Design Manual*, Section 5-3.04. The distance shown in Section 5-3.04.02 should be measured from the yield line of an entrance or the radius point of an exit leg and the circulating roadway. If a driveway is located within the minimum stopping sight distance (based on the posted speed of the entrance/exit leg of the radius point, the designer should consider either providing a left turn lane or extending the median and limiting the driveway to right-in/right-out only).

The preliminary planning phase for any intersection including roundabouts should include a comprehensive review of access management issues for the site. Consider the possible need to realign/relocate existing driveways, and include their associated costs in the project's preliminary estimate. Pedestrian accessibility and safety should be part of the comprehensive access management review.

12-3.08.02 Roundabouts in a Highway Network

In order to understand how roundabouts operate within a roadway system, it is important to understand their fundamental arrival and departure characteristics and how they may interact with other intersections and highway features.

Planned Network, Access Management:

Rather than thinking of roundabouts as an isolated intersection or replacement for signalization, identify likely network improvements early in the planning process. This is consistent with encouraging public and other stakeholder interaction to prepare or update local comprehensive or corridor plans with circulation elements. Project planning and design are likely to be more successful when they are part of a larger local planning process. Then, land-use and transportation relationships can be identified and future decisions related to both.

Roundabouts may be integral elements in town and city circulation plans with multiple objectives of improving circulation, safety, pedestrian and bicycle mobility, and access management. Roundabouts rely on the slowing of all vehicles to process traffic efficiently and safely which results in a secondary feature of "calming" traffic. It can be expected that local studies and plans will be a source of requests for roundabout studies, projects, and coordination on state trunk highways. A potential use of roundabouts is to function as gateways or entries to denser development, such as cities or towns, to indicate to drivers the need to reduce speed for upcoming conflicts including turning movements and pedestrian crossings.

Retrofitting an urbanizing corridor or commercial strip development to be consistent with the MnDOT *Access Management Manual* may be a particularly good application for roundabouts. Roundabouts can facilitate the construction of raised medians by providing safe locations for U-turns. Left-turn movements from driveways onto a highway that may currently experience long delays and require two-stage left-turn movements could be replaced with a simpler right turn, followed by a U-turn at the next roundabout.

Platooned Arrivals on Approaches:

Vehicles exiting a signalized intersection tend to be grouped into platoons. Platoons, however, tend to disperse as they move down-stream. Roundabout performance is affected by its proximity to signalized intersections and the resulting distribution of entering traffic. If a signalized intersection is very close to the roundabout, it may cause vehicles to arrive at the roundabout in closely spaced platoons. The volume of the arriving platoon and the capacity of the roundabout will dictate the ability of the roundabout to process the platoon. The spacing between a roundabout and a signalized intersection on a corridor with coordinated signals should be consistent with the spacing of signalized intersections as indicated in the MnDOT *Access Management Manual*. Analyze these situations carefully to achieve a proper design for the situation.

Roundabout Departure Pattern:

Traffic leaving a roundabout tends to be more random than for other types of intersection control. Downstream gaps are shorter but more frequent as compared to a signal. The slower approach and departing speeds along with the gaps allow for ingress/egress from nearby driveways or side streets. The slowing effects are diminished as vehicles proceed further downstream. However, the gaps created at the roundabout are carried downstream and vehicles tend to disperse again providing opportunities for side street traffic to enter the mainline roadway.

Sometimes traffic on a side street can find it difficult to enter a main street at an un-signalized intersection. This happens when traffic platoons from signalized intersections on either side of it arrive at the side street intersection at or about the same time. If a roundabout replaced one of these signalized intersections, then its traffic platoons would be dispersed and it would be easier for traffic on the side street to enter the main street.

If a roundabout is used in a network of closely spaced coordinated signalized intersections, then it may be difficult to maintain the closely packed platoons required for the signals to function optimally. If a tightly packed platoon approached a roundabout, it could proceed through the roundabout as long as there was no circulating traffic or traffic upstream from the left. Only one circulating vehicle would result in the platoon breaking down. Hence, this hybrid use of roundabouts in a coordinated signalized network needs to be evaluated carefully.

Another circumstance in which a roundabout may be advantageous is as an alternative to signal control at a critical signalized intersection within a coordinated network. Such intersections are the bottlenecks and usually determine the required cycle length, or are placed at a signal system boundary to operate in isolated actuated mode to minimize their effect on the rest of the surrounding system. If a roundabout can be designed to operate within its capacity, it may allow a shortening of the system cycle length with resultant benefits to delays and queues at other intersections.

12-3.08.03 Closely Spaced Roundabouts

It is sometimes desirable to consider the operation of two or more roundabouts in close proximity to each other. Generally, though, the spacing of roundabouts should be consistent with the spacing of primary full-movement intersections in accordance with the MnDOT *Access Management Manual*. In these cases, the expected queue length at each roundabout becomes important. Compute the expected queues for each approach to check that sufficient queuing space is provided for vehicles between the roundabouts. If there is insufficient space, then drivers may occasionally queue into the upstream roundabout and reduce the desired operations. However, the roundabout pair can be designed to minimize queuing between the roundabouts by limiting the capacity of the inbound approaches.

Closely spaced roundabouts may improve safety and accessibility to business or residential access or side streets by slowing the traffic on the major road. Drivers may be reluctant to accelerate to the expected speed on the arterial if they are also required to slow again for the next close roundabout. This may benefit nearby residents. Additional information including closely spaced offset T-intersections is contained in *Roundabouts: An Informational Guide*.

12-3.08.04 Roundabout Interchange Ramp Terminals

Freeway ramp junctions with intersecting crossroads are situations where a roundabout intersection treatment can be particularly advantageous. This is especially so if the interchange typically has a high proportion of left-turn flows combined with limited queue storage space on the bridge crossing, exit ramp or crossroad approaches. In such circumstances, roundabouts operating within their capacity are well suited to solving these problems when compared with other forms of intersection control. Furthermore, the headway between vehicles leaving the roundabout along the entrance ramp is more random than when signalized intersections are used. This type of traffic flow allows for smoother merging behavior and superior operational performance at the freeway entrance terminal, similar to the effects of ramp metering.

Traffic performance evaluation of the roundabout interchange is the same as for a single conventional roundabout. The maximum entry capacity depends on the circulatory flow and the geometry of the roundabouts.

The benefits and costs associated with this type of interchange follow those for a single roundabout. Additionally, depending on circumstances and site-specific demands, economical advantages unique to roundabout use at ramp intersections include:

1. Intersection sight distance requirements will generally be less than what would be needed for conventional intersections. As a result, grading needs and tie-in limits for a typical interchange will tend to be less.
2. Bridge cross sections between ramp intersections in a diamond interchange do not need to include left turn lane provision.
3. In some cases, frontage roads can be connected into the ramp roundabout intersections, forming multi-leg nodes. This approach can eliminate costs and right-of-way needs associated with obtaining adequate separation between ramp and frontage road intersections.

There are no special design parameters for roundabout interchanges. They are only constrained by the physical space available to the designer and the configuration selected. The teardrop form, which does not allow for full circulation around the center island, can be useful if grades are a design issue since they remove a potential cross-slope constraint on the missing circulatory road segments. However, teardrop roundabouts are not typically encouraged. If there are more roads intersecting with the interchange than the single cross road, then two independent circular roundabouts are likely to be the best solution.

Refer to *Roundabouts: An Informational Guide*, Chapter 6, Section 6.10 for additional information.

12-3.08.05 At-Grade Rail Crossings

Locating any intersection near an at-grade railroad crossing is generally discouraged. However, intersections are sometimes located near railroad-highway at-grade crossings. Contact the MnDOT Office of Freight, Rail, and Waterways and consider allowing the railroad crossing to pass through the circle center or across one of the legs. Additional information on roundabouts in the vicinity of At-Grade rail crossings is contained in *Roundabouts: An Informational Guide*, Chapter 7, Section 7.6, and *MN MUTCD*.

12-4.0 GEOMETRIC DESIGN

12-4.01 Introduction

The preface of the publication *Roundabouts: An Informational Guide* states that:

"Selection and design of a roundabout, as with any intersection treatment, requires the balancing of competing objectives. These range from transportation-oriented objectives like safety, operational performance, and accessibility for all users to other factors such as economics, land use, aesthetics, and environmental aspects. Sufficient flexibility is provided to encourage independent designs and techniques tailored to particular situations while emphasizing performance-based evaluations of those designs.

"Since there is no absolutely optimum design, this guide is not intended as an inflexible rule book but rather attempts to explain some principles of good design and indicate potential trade-offs that one may face in a variety of situations. In this respect, the principles and techniques in this document must be combined with the judgment and expertise of engineers, planners, and other professionals. Adherence to these principles still does not ensure good design, which remains the responsibility of the professionals in charge of the work."

More so than conventional intersections or practically any other design form, the geometric design of roundabout intersections directly dictates their capacity and operational performance. This is so much the case that the geometric and operational analyses, generally considered distinct disciplinary pieces of project design and often performed separately on typical projects, are inseparable in roundabout design. For that reason, much of the content in this section invokes traffic engineering terms and subject matter that centers on achieving operational goals while balancing them with safety and other considerations.

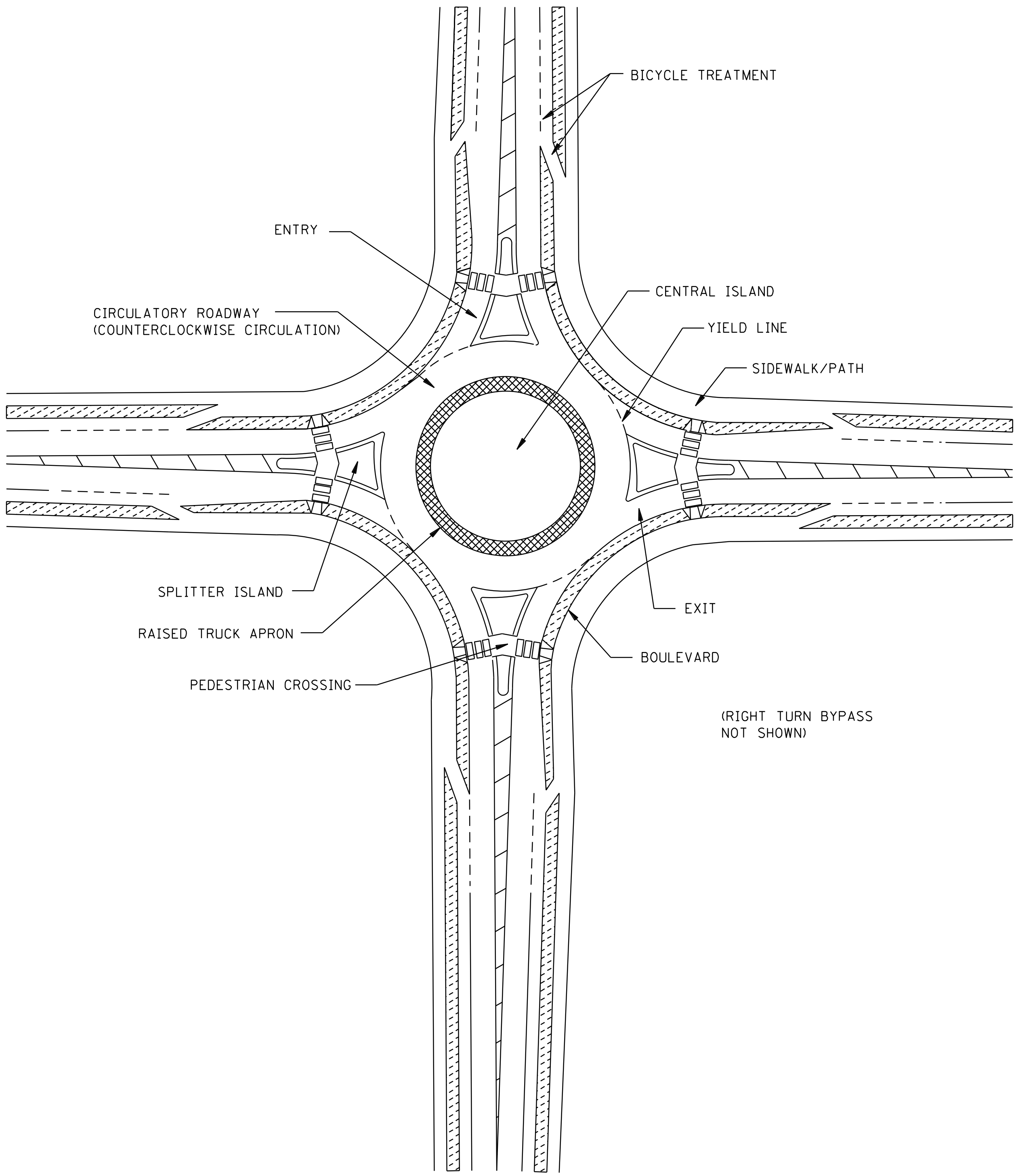
In a general sense, roadway engineering is often an iterative process. Roundabout design, due to the dynamic balancing of considerations and the often profound effect that manipulation of geometric elements can have on performance, tends to be iterative by its nature, sometimes requiring numerous iterations to achieve the desired balance between geometric, operational and safety factors. Similarly, even though a step-by-step design process is presented in this section, the designer must understand that adherence to design principles, awareness, and understanding of the inherent design tradeoffs are the central points of design regardless of whether any design procedure is followed.

In analysis of roundabout capacity and delay, MnDOT recognizes the United Kingdom (U.K.) Empirical Method as being successful in modeling real-world conditions for roundabout operation and prescribes its use in design of roundabouts forecast to be near or at capacity in the design year (refer to 12-1.0). Although low demand roundabouts or designs developed by other jurisdictions may not entail the use of this analytical tool, this section presents a process methodology based on the U.K. Empirical Method and the compatible computer software.

12-4.02 Features and Design Parameters

Roundabout features are shown and described in Figure 12-4.02A and Table 12-4.02A. Key roundabout design parameters based on the U.K. empirical method are shown and defined in Figure 12-4.02B, Figure 12-4.02C, and Table 12-4.02B. In the empirical methodology, these six parameters are the determining factors in a roundabout's capacity and associated delay under demand conditions. Figures 12-4.02B and 12-4.02C present two methods for determining the appropriate entry angle.

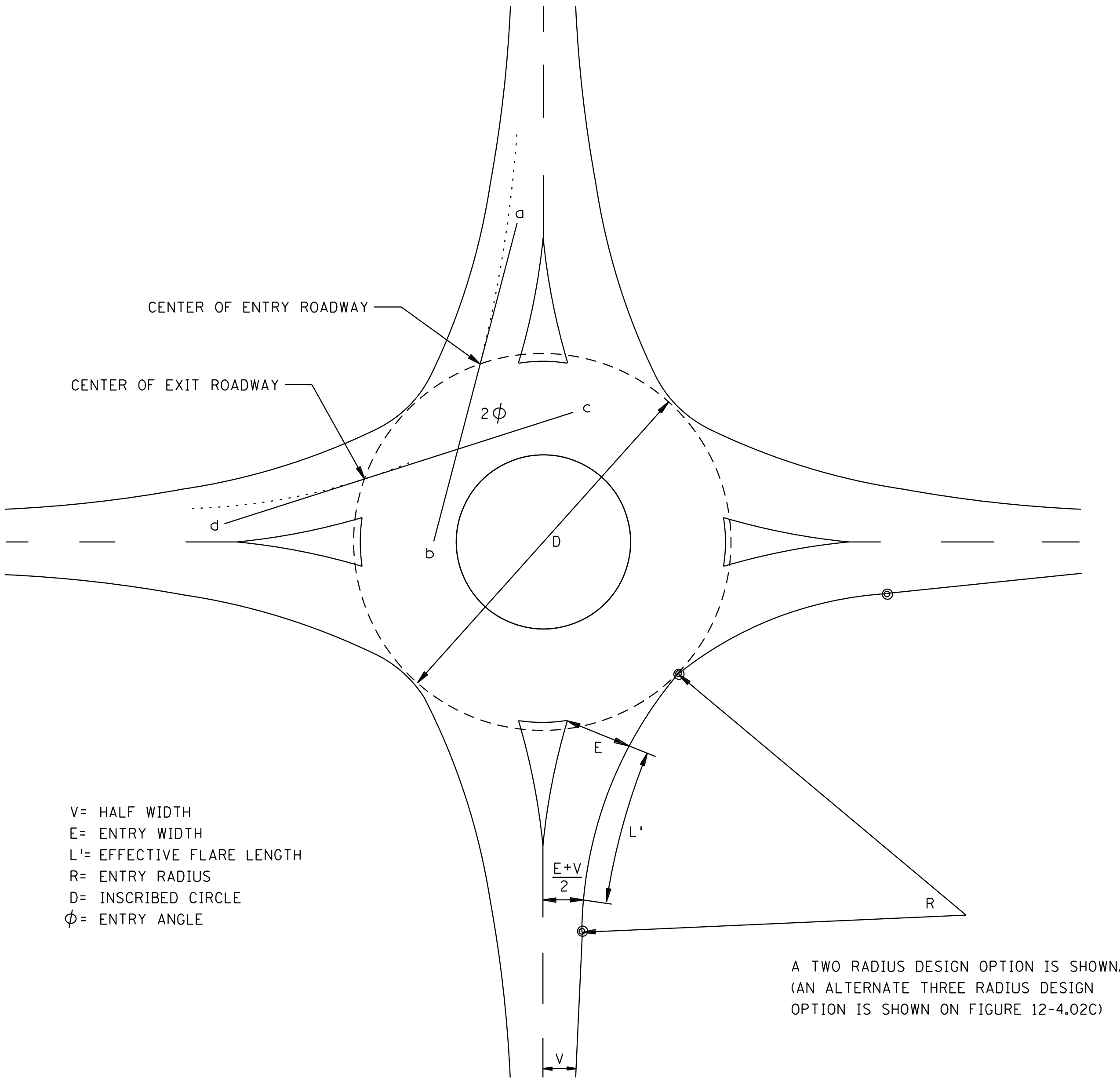
Table 12-4.02C shows typical design values for the key design parameters in the design of urban and rural roundabouts. It must be noted that these values are intended merely to give an idea of common dimensions or, at most, a possible starting point for design. They do not represent design criteria or recommended values. Table 12-4.02D lists other significant geometric attributes in roundabout designs.



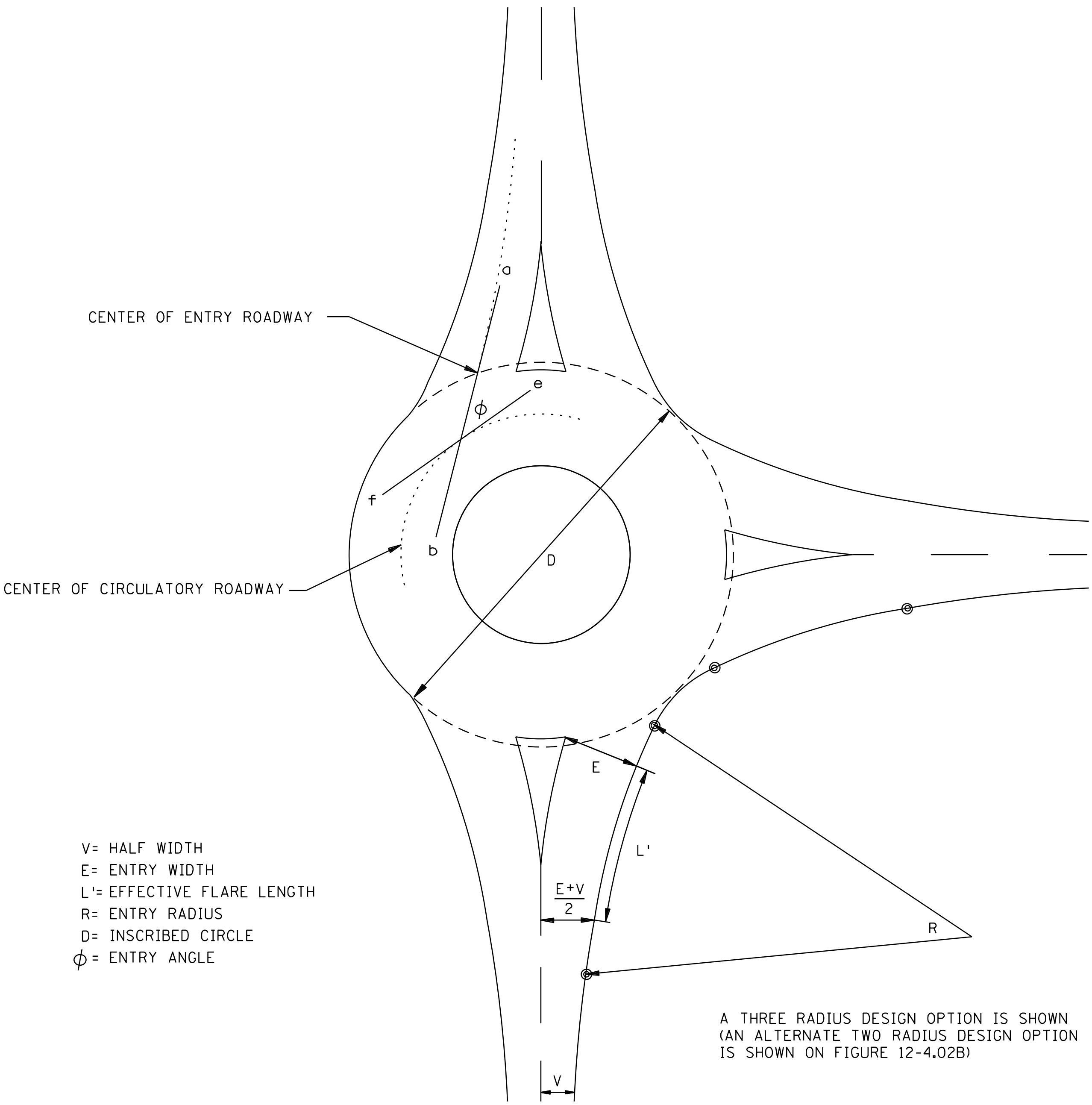
KEY ROUNDABOUT FEATURES
Figure 12-4.02A

Table 12-4.02A
KEY ROUNDABOUT FEATURES

Feature	Description
Entry	The approaching roadway prior to the circulating roadway and between the right curb face of the approach side of the splitter island. This key roundabout feature is the largest determinant of a roundabout's capacity and safety.
Exit	The exiting roadway after the circulating roadway and between the right curb face and the exit side of the splitter island.
Central island	The raised area in the center of a roundabout, around which traffic circulates.
Splitter island	A raised median on an approach used to separate entering from exiting traffic, deflect and slow entering traffic, and to provide refuge for pedestrians crossing the road in two stages.
Circulatory roadway	The curved one-way roadway used by vehicles to travel in a counterclockwise fashion around the central island.
Raised truck apron	The mountable portion of the central island adjacent to the circulatory roadway. It is required to accommodate the wheel tracking of long or oversized vehicles.
Bypass Lane	A right turn lane that bypasses the roundabout, physically separated from the circulatory roadway. Bypass lanes do not intersect the roundabout and have no conflicting streams of traffic.
Yield Line	A pavement marking line of demarcation separating traffic approaching the roundabout from the traffic already in the circulating roadway.
Pedestrian crossings	Pedestrian crossings provided at roundabouts must be accessible. The crossing accommodates all pedestrians (including the visually impaired), wheelchairs, strollers, and bicycles to cross the path, street, etc. in a two-staged crossing with a refuge cut into the splitter island to allow pass through movements.
Bicycle treatments	Bicycle treatments at roundabouts provide bicyclists the option of traveling through the roundabout either by riding in the travel lane as a vehicle, or by exiting the roadway and using the crosswalk as a pedestrian, or as a cyclist using the shared-use path, depending on the bicyclist's level of comfort.
Boulevards	Boulevards are provided at most roundabouts to separate vehicular and pedestrian traffic and to encourage pedestrians to cross only at the designated crossing locations.
Sidewalk / path	A pathway for pedestrians to walk. It is common to provide a shared use path at the perimeter of the roundabout to accommodate both pedestrians and bicyclists.



KEY ROUNDABOUT DESIGN PARAMETERS EXAMPLE 1
FIGURE 12-4.02B



KEY ROUNDABOUT DESIGN PARAMETERS EXAMPLE 2
FIGURE 12-4.02C

Table 12-4.02B
KEY ROUNDABOUT DESIGN PARAMETERS

Parameter	Description
Half Width = V	The half width is the width of the roadway used by approaching traffic upstream of any changes in width associated with the roundabout. The half width is typically no more than half of the total width of the roadway. If the facility has a marked bike lane, the half width is to the white line. If there is no marked bike lane then the width is measured from the curb face on the right side to the curb face of the splitter island, or marked centerline, on the left side.
Entry width = E	The entry width defines the width of the entry where it meets the inscribed circle. It is measured perpendicularly from the outside curb face to the inside curb face at the splitter island's nearest point to the inscribed circle within the entry. The effective entry width may be less due to design factors and land use distribution.
Effective Flare Length = L′	Typically, half the total distance between V and E. At this distance, the approach roadway width equals the average of V and E. The flare must be developed uniformly and avoid a sharp break where the flare starts. Full flare length is twice the effective flare length.
Entry radius = R	The entry radius is the minimum radius of curvature of the outside curb within an entry approach.
Entry Angle = ∅, degrees	**Ø (Phi) represents the conflicting angle between entering and circulating streams of traffic.** In general, 2Ø (as shown in Figure 12-4.02B) is the acute angle formed by the junction of the tangent line (a-b) projected from the midpoint of E and the tangent line (c-d) projected from the midpoint of the adjacent exit width. Alternatively, where the adjacent exist is further away from the entry, Ø is the acute angle formed by the junction of the tangent line (a-b) and the tangent line (e-f) to the midpoint of the circulating width, as shown in Figure 12-4.02C. See RDM section 12-4.05.10 for further explanation.
Inscribed Circle Diameter = D	The inscribed circle diameter is the basic parameter used to define the largest circle size of a roundabout. It is the largest diameter measured to the outside edge of the circulating roadway.

Table 12-4.02C
TYPICAL DESIGN VALUES FOR KEY GEOMETRIC PARAMETERS[A]

Geometric Parameter	Single-Lane Entry	Dual-Lane Entry	Triple-Lane Entry
1 Half width[B]	Travel lane width approaching the roundabout prior to any flared section.		
2 Entry width[B]	Face of curb to face of curb shortest distance at yield point.		
3 Effective Flare length[B]	15-330 ft (5-100 m) if needed		
4 Inscribed circle diameter	130 ft (40 m)	160 ft (50 m)	250 ft (75 m)
5 Entry Radius	65 ft (20 m)	80 ft (25 m)	100 ft (30 m)
6 Entry angle	30 Degrees		
7 Circulating roadway width	20-25 ft (6-7 m) (truck apron may be needed)	30 ft (10 m) (truck apron not needed)	45 ft (14 m) (truck apron not needed)
8 Exit radius	50-65 ft (15-20 m)	65-100 ft (20-30 m)	100-130 ft (30-40 m)

[A] At this time, RODEL works only with metric values.
[B] High influence on capacity.

Table 12-4.02D
OTHER IMPORTANT FACTORS IN ROUNDABOUT DESIGN

Fastest speed path	The fastest travel path possible for a single vehicle through a roundabout, in the absence of other traffic and disregarding lane markings.
Circulatory roadway width	The width between the outer edge of the inscribed circular diameter (ICD) at the curb face of the roadway and the central island diameter (CID) or the outer edge of the truck apron curb face. It does not include the width of any mountable apron, which is defined to be part of the central island. The circulatory roadway width defines the roadway width, curb face to curb face, for vehicle circulation around the central island.
Exit radius	The effective radius of curvature of the outside curb within an exit roadway nearest the ICD.
Exit width	The exit width defines the width of the exit roadway nearest the inscribed circle. It is measured perpendicularly from the right curb face edge of the exit to the intersection point of the left curb face edge of the splitter island.
Approaches/departures (intersection legs):	The most critical vertical design area of the roundabout is the portion of roadway from the approach end of the splitter island to the circulatory roadway. This area requires special attention by the designer to ensure that the user is able to safely enter and exit the circulatory roadway. This area usually requires pavement cross slope transitions to provide an appropriate super-elevation rate through the entire transition area and within the circulatory roadway. Entry grades are not to exceed 4%. It is desirable to match the exit grades and the entry grades; however, the exit grade may be steeper but should not exceed 4%. Adjustments to the circulatory roadway cross slope may be required to meet these criteria, but should be balanced with the effects on the circulatory roadway. Circulating roadway profile grades should be relatively gentler with a desirable maximum of 2.5%. For a drawing of the preliminary cross section and layout, refer to *Roundabouts: An Informational Guide*, Chapter 6.

12-4.03 Roundabout Design Process

As discussed in 12-4.01, the general nature of the roundabout design process is an iterative one. It is also a process in which minor adjustments in geometric attributes can have significant effects on the performance of the design. In the execution of this process, there must be an awareness of this iterative nature as well as an understanding that any of the steps may need to be looped back to an earlier step for adjustment.

Because of this iterative process as well as the fact that the optimal position of the roundabout may not be finally determined until geometrics can be roughly investigated for various location options, it is typically advisable to prepare initial layout drawings with a hand-sketch methodology and level of detail. This method allows rough investigation of feasibility and compatibility of individual components before significant effort is invested in detailing design elements. Furthermore, it is often a benefit to the public involvement process to initially exhibit hand sketches rather than finished-looking engineering drawings; this can avoid the appearance that the design has already been determined.

There are no easy ten-steps to roundabout design. Much of the knowledge in roundabout design is counter-intuitive to the technically minded engineer. Designing roundabouts can range from easy (single lane roundabouts) to very complex (multi-lane roundabouts). Essentially, roundabout design is as far away from a "cookie cutter" design as intersection design can get.

Although it may appear inherently otherwise and extensively attempted, roundabouts are not homogeneous and cannot be standardized. There are many different types of roundabouts, such as single lanes, two-lanes, three-lanes, circles, ellipses, bypass lanes, "snagged" bypass lanes, double roundabouts, mini-roundabouts, etc, in which a number of combinations or multiple combinations of the above can be in one roundabout. Each roundabout is unique where each potential "type" of roundabout is applied in different situations in which site-specific problems require special and distinctive solutions. The major differences in design techniques and skill levels fall between single lane roundabouts and multi-lane roundabouts where different principles apply.

Roundabout design is fundamentally holistic. The whole is more important than the parts. In other words, how the intersection functions as a single traffic control device is more important than the actual values of the specific design components (e.g. a radius). However, how the parts interact with each other is crucially important. Likewise, although individual geometric values are not as important as the intersection operation as a whole, the values must be within ranges that generally succeed.

The following list and explanation of design steps is a sample design process that typically applies to most roundabout design practices. However, each roundabout design also typically requires a different design and thinking process depending on the unique design constraints, traffic volumes, roadway speeds, existing topography, and geometric alignments of the roadways. Not all aspects of design or the design process are included herein, however, the provided general design steps should be sufficient to get most designers started in an initial conceptual roundabout design.

12-4.03.01 General Design Steps & Explanation:

1. **Review of Existing Conditions:** Review the most recent site plans and roadway alignment information. Review existing roadways with respect to surrounding topography, centerlines, curb faces, edge of pavement, roadway lane markings, existing or proposed bike lanes, nearby crosswalks, environmental constraints, buildings, drainage structures, adjacent access points, horse or rail crossings, school zones, and right of way constraints. This should include any special design constraints such as specific properties that cannot be encroached or specific desired lane widths. Review any traffic study, which should include final future design year traffic volumes and assumptions of the proposed intersection or corridor project.

   These items should provide adequate background traffic conditions, existing traffic conditions within and outside the project area, as well as the level of detail, design parameters, right of way constraints, and location for the proposed roundabout.

2. **Review Future Conditions:** Review the future AM and PM peak hour turning movement volumes at the intersection developed from the future projected traffic volume data. Sketch a simple schematic diagram consisting of the final future peak hour turning movement volumes at the intersection(s). In order to accurately identify the roundabout geometric and capacity needs, the following should be provided and required prior to starting the capacity (RODEL, ARCADY) analyses or roundabout design:

    - Future AM Peak Hour Turning Movement Volumes,
    - Future PM Peak Hour Turning Movement Volumes,
    - Future *Percent* Heavy Vehicles (by Approach) for Each Peak Hour,
    - Design Vehicle Type by Turning Movement (i.e. WB-50, WB-62, etc.),
    - Vertical Constraints,
    - Right of Way (ROW) Constraints,
    - Existing and Proposed Roadway Alignment Base Map (with travel lanes, proposed face of curb tie-in, striping, bike lanes, ROW, etc.),
    - Pedestrian Volumes (if significantly high), and
    - Identify if Bike Lanes and Sidewalks will be needed or proposed.

    The future traffic conditions with respect to the operations and flows of the existing roadways should be reviewed and possibly discussed with the lead jurisdiction for project understanding and operational issues. These operational issues including the potential excessive delays should be used in the design process and geometry criteria. In addition, any relevant adjacent site plans, access points, utility infrastructure needs, and roadway cross-sections that may affect the roundabout design should be provided, reviewed, and incorporated.

3. **Understand the Specific Design Problem(s):** Prior to commencing a design, the designer must first understand the design problem(s) to be solved (ROW issues, acute angles, grades, approach legs, roadway alignment, etc.) with the specific site location. After evaluating the traffic volumes, the designer should have a good “feel” of how many lanes may be initially required (such as a heavy north south through movement may require two-lane entries and exits northbound and southbound).

    A general roundabout diameter can then be chosen based on the traffic needs, proximity to constraints, design vehicle, and the relative speeds of the roadways (i.e. if high speed approaches are present). The designer must be conscious of the design vehicle when choosing a diameter.

4. **Perform Capacity Analyses:** After obtaining all of the pertinent information regarding the roadways, site, and traffic volumes, and after a general roundabout diameter has been initially identified the designer should perform a geometric analysis of the proposed roundabout using RODEL or ARCADY. The output will provide the initial lane geometry and capacity requirements for the roundabout based on the future design volumes.

    This will set the design requirements for the conceptual roundabout design. The AM and PM traffic volumes will need to be analyzed at the intersection at both the standard and peak percentile confidence levels for a minimum of four computer model calculations. This will ensure the roundabout will operate appropriately under all peak-hour traffic conditions during typical design and critical design operations. The final results of this analysis will produce key information to include in the roundabout design, some of which are the following initial information:

    - Initial roundabout diameter (estimated size),
    - Entry lane configurations at each approach,
    - Future traffic volume capacity by approach,
    - Minimum approach widths and entry radii of the roundabout,
    - Delay of each approach and the overall delay of the intersection,
    - Queue lengths for each approach, and
    - Future level of service.

5. **Lane Configuration and Roundabout Placement:** Once the minimum design requirements have been established, a modern roundabout design can be sketched by initially identifying the flow of traffic and lane configuration requirements for the circulatory roadway and the exits of the roundabout. This task includes the placement of the roundabout's circle to roughly determine the lane configuration and location of the proposed roundabout. Special consideration should be taken for any skewed intersection angles and ROW constraints.

6. **Plan Initial Layout:** Once the capacity requirements have been identified, the hand sketch or initial conceptual layout should be refined (prior to CAD). A preliminary geometric layout should be developed only to further identify the site's specific design issues. Once the designer has a grasp of these issues, the concept should be refined iteratively to develop a solid sketch (without the use of exact values such as radii). Visual inspection of the sketch concept can then further identify fastest path, ROW, deflection, leg angles, and other issues.

   The purpose of this process is simply because designers, who first design in CAD, find it difficult to completely move or change a roundabout design with the level of effort already completed. Their minds become narrow and focused on the details of the exact geometry opposed to a holistic roundabout design.

7. **Formalize Design Digitally (CAD):** Once the general location and roundabout configuration have been preliminary developed and all of the design issues have been resolved, a full conceptual modern roundabout design can be initiated in CAD. Assuming all of the above information has been completed and thoroughly reviewed, the designer can develop a horizontal roundabout design for the intersection with respect to the required geometric parameters as well as safety in an electronic CAD file format. The designer should complete a roundabout design with respect to the face of curb for the intersection. In multi-lane designs, the lane striping is just as critical as the face of curb to minimize entry and exit path overlap, provide proper lane widths and widening, as well as communicate to the driver lane designations and possible spiral lane movements.

   It is critically important that the horizontal geometry of the roundabout adhere to the required safety and capacity parameters in the roundabout design. The design must use the RODEL / ARCADY output (within capacity ranges) with appropriate design use and application of the six basic geometric roundabout parameters (E, L′, V, Ø (Phi), R, and D). The entry width (E), average effective flare length (L′), entry angle (Ø), the entry radius (R1), and the inscribed circular diameter (ICD) all directly relate to the capacity and safety of modern roundabouts. All of these values should not be understated or overemphasized as they all directly relate to each other. The proper balance and design use of these six geometric parameters can result in an efficient and safe design.

8. **Design Vehicle Check & Modifications:** The specific design vehicle for each turning movement should be verified as adequate within the roundabout design. A CAD-based software program such as AutoTURN should be used for the turning movements of the intersection roadways to verify proper truck turning radii through the roundabout for every approach and movement. In addition, the truck apron size (width) should be identified for the roundabout. All truck movements should have proper buffer space between the swept path of trucks and the face of curb.

9. **Safety and Fastest Path Review:** Fastest path design speeds as well as a number of other safety factors and design features such as the Ø (Phi) angle must be performed and checked. The specific fastest design paths should be developed and verified as adequate and reasonable (speeds and deflection). If deficiencies or deviations in any of the design features and safety factors are found, the roundabout must be reanalyzed and redesigned either with many small changes or by completely shifting alignments and geometry or the placement of the circle with an entire redesign effort (iterative process).

10. **Complete the Design:** When a solid design with respect to the face of curb (and striping for multi-lane roundabouts) has been completed, and functions for the design vehicle(s), the design should then incorporate needed crosswalks, detached sidewalks, shared use paths and ramps, truck aprons, Americans with Disabilities Act (ADA) ramps, and the like. All efforts should be made to avoid any ROW issues. The design must be based upon acceptable thresholds to maintain adequate speeds and safety design elements.

    At this stage of the design process, a qualified roundabout design expert may perform some form of approval or review consultation. Once a roundabout design has been properly reviewed, approved, and designed with respect to horizontal geometry, many other geometric and non-geometric design components must now be completed in order for a roundabout to function as it was designed. These design components are key to the public driving the roundabout as it was intended without further safety or operational issues. Some of these items are:

    - Signing,
    - Striping,
    - Lighting,
    - Landscaping,
    - Construction Materials,
    - Vertical Design / Profiles / Grading,
    - Superelevation, Transitions, Gutter Slopes, and Drainage Inlet Locations,
    - Roadway Surface Types and Construction Methods,
    - Curb and Gutter Details (including mountable curbs), and
    - Construction Staging and Traffic Control.

All aspects of roundabout design including horizontal geometry, vertical profiles, signing, striping, landscaping, lighting, and construction materials should either be designed by or reviewed by an experienced roundabout designer. Nothing can replace real-world design and field experience.

Continual practice, mentoring from roundabout experts, roundabout training and education, and quality roundabout review greatly assists the capacity and safety of the design of modern roundabouts. However, all designers must spend time in the field reviewing roundabout construction and completed roundabouts in order to understand roundabouts and roundabout design completely. After years of daily practice, one can still learn. Small changes in roundabout design (in the order of inches) can make or break the actual proper operation and safety of a modern roundabout as a whole.

12-4.04 Design Principles

The overall guiding principle in the design of a roundabout is provision of an operationally adequate facility that also provides good safety performance. In roundabout geometric design, these are often competing goals, as geometric elements that promote higher traffic flows often allow higher speeds into and through the roundabout. Issues relating to overall speed and speed consistency – consistency between different traffic streams and between successive elements within a traffic stream – are the most prevalent cause of safety problems where they have been experienced with roundabouts. The balancing of the speed/capacity/safety relationship is the overarching design principle in roundabout engineering.

The process of designing roundabouts may require a considerable amount of iteration among geometric design, operational analysis, and safety evaluation. Minor adjustments in geometry can result in significant changes in safety and/or operational performance. Thus, the designer often needs to revise and refine the initial design to enhance the roundabouts capacity and safety. It is not typically possible to produce an optimal geometric design on the first attempt.

Because roundabout design is an iterative process, it may be advisable to prepare the initial concept drawings at a sketch level detail. It is important that the individual components are compatible with each other so that the roundabout will meet its overall performance objectives. Before the details of the geometry are finalized, three fundamental elements must be determined in the preliminary design stage:

1. The optimal position;
2. The optimal alignment and arrangement of the approach legs; and
3. The optimal roundabout size.

12-4.04.01 Vehicle Paths

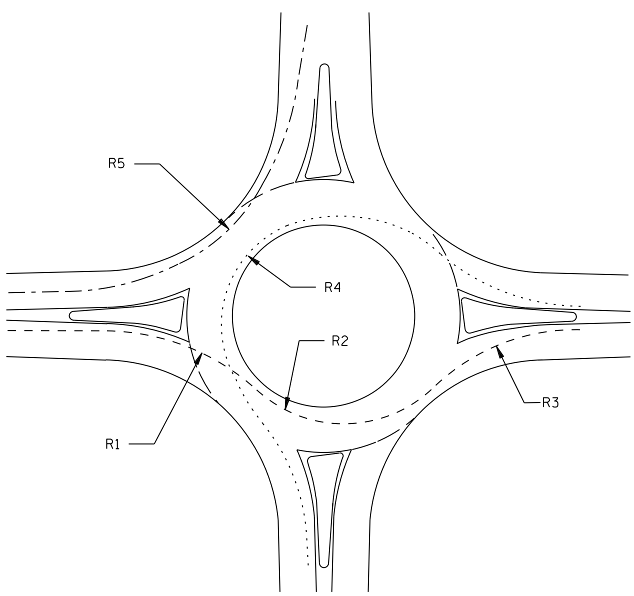
Roundabouts: An Informational Guide, Exhibits 6-48 through 6-50 and accompanying text in the corresponding section illustrate and describe the concept of the fastest vehicle path allowed by the roundabout geometry to determine the speeds through the roundabout. To quote text from *Roundabouts: An Informational Guide*: "This [the fastest path] is the smoothest, flattest path possible for a single vehicle, in the absence of other traffic and ignoring all lane markings, traversing through the entry, around the central island, and out the exit."

12-4.04.02 Speed Consistency

A complementary aspect to the design principles of entry speed and deflection is the concept of speed consistency within the design. The elements of the roundabout should be designed so that the relative speeds between consecutive geometric elements as well as between conflicting traffic streams be kept within certain design values. The benefit of achieving these speed consistencies is primarily safety-related, particularly reducing the likelihood of loss-of-control crashes, although entry capacity can benefit by reducing speed differential between entering and circulating traffic.

The geometric basis for the speeds used for consistency checks is the fastest vehicular path concept (refer to 12-4.04.01). Figure 12-4.04A and Table 12-4.04A illustrate the critical path radii that may be considered in this analysis. Typically, the speed relationships between R1, R2, and R3 as well as between R1 and R4 are of primary interest. Along the through path, the desired relationship is R1>R2<R3, where R3 should not be less than R1. Similarly, the relationship along the left-turning path is R1>R4. The difference in achieved design speed from R1 to R2 or R4 should be 6-8 mph (10-15 km/h) desirable and 12 mph (20 km/h) absolute maximum.

For most designs, the R1/R4 relationship will be the most restrictive for speed differential at each entry. However, the R1/R2/R3 relationship should also be checked, particularly to ensure the exit design speed is not restrictive. (Whereas design criteria in past years advocated relatively tight exit radii to minimize exit speeds, recent best practice suggests a more relaxed exit radius for improved drivability. It has been found that speeds at roundabout exits are still low due to R2 speeds and the short distance between R2 and the exit leg, rendering R3 practically irrelevant as a speed control.)



VEHICLE PATH RADII
Figure 12-4.04A (FHWA Exhibit 6-12)
Table 12-4.04A

RADII USED TO DEFINE THE FASTEST PATH THROUGH A ROUNDABOUT

Entry Path Radius, R1	The minimum radius on the fastest through path prior to the yield line. This is not the same as Entry Radius.
Circulating Path Radius, R2	The minimum radius on the fastest through path around the central island.
Exit Path Radius, R3	The minimum radius on the fastest through path into the exit.
Left Turn Path Radius, R4	The minimum radius on the path of the conflicting left-turn movement.
Right Turn Path Radius, R5	The minimum radius on the fastest path of a right-turning vehicle.

12-4.04.03 Design Vehicle

Per Chapter 5 of the *Road Design Manual*, the four primary design vehicles for general use in design on MnDOT facilities are the passenger car (P), single-unit truck (SU), city bus (BUS) and the WB-62 tandem tractor trailer. Although selection of the appropriate vehicle is dictated by site-specific circumstance, the restrictive nature of roundabout geometry makes this judgment a critical one. For this reason, a consideration of the consequences of usage, of any roundabout approach by WB-62 vehicles – even where they are not the designated design vehicle – is strongly recommended. Additionally, usage or possible usage of the facility by unconventional vehicles (e.g. farm vehicles, oversized loads) must be researched and the design tailored to accommodate them accordingly.

12-4.04.04 Alignment of Approaches and Entries (Deflection)

Roundabouts: An Informational Guide, Exhibit 6-10 and accompanying text generally represents valid policy for single-lane roundabouts. Centerlines of roadways do not need to pass through the center of the inscribed circle. It is acceptable design practice (especially in multi-lane roundabouts) to offset the entries to the left of the center of the roundabout to achieve proper deflection and appropriate fastest path R1 speeds. The key factor in roundabout design is deflection at entry, which has nothing to do with centerlines of roadways. Adherence to the principles of deflection is crucial to the operation and safety of roundabouts. MnDOT considers this design element to be of the utmost importance.

12-4.04.05 Geometric Design Criteria

12-4.05.01 Length of Conflicting Leg of Sight Triangle

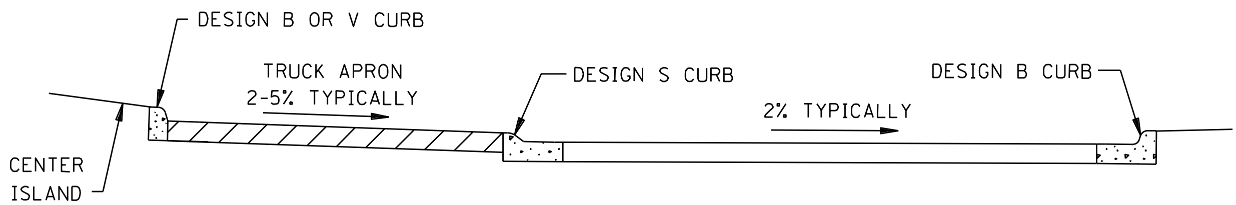
The critical gap for entering the major road, t_c, equals 3.5 - 4.5 seconds. This modifies the computed distance in *Roundabouts: An Informational Guide* Exhibit 6-59 to those provided in Table 12-4.05A, which are based on a t_c value of 4.5 seconds.

Table 12-4.05A
ROUNDABOUT INTERSECTION SIGHT DISTANCE

Conflicting Approach Speed mph (km/h)	Computed Distance ft (m)
10 (15)	66 (20)
15 (25)	99 (30)
20 (30)	132 (40)
25 (40)	165 (50)
30 (50)	198 (60)

12-4.05.02 Superelevation

For multi-lane roundabouts, the designer may alternatively elect to crown the circulatory roadway – for example, 2 percent in each direction from a lane line – in order to control snowmelt and equalize circulating speeds. Operating speed, drainage provision, pavement grades, and other factors should be considered in this determination. The cross slope of the truck apron may range from 2 to 5 percent.



TYPICAL CIRCULATORY ROADWAY SECTION
Figure 12-4.05A

12-4.05.03 Bicycle Provisions

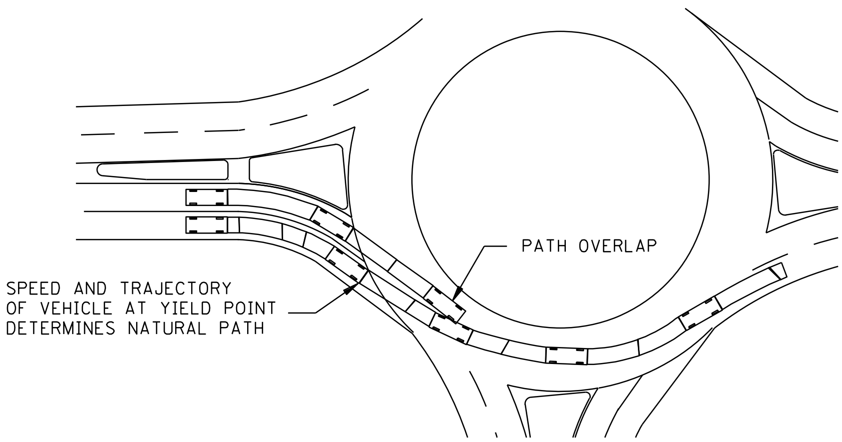
Design the bike ramps between the roadway and the shared path such that they angle up to the path where the bicycles exit and angle down toward the roadway where the bicycles re-enter the roadway. Do not provide a perpendicular ramp between the two surfaces causing bicyclists to stop, or nearly stop the forward motion to enter one facility or the other. All urban and suburban roundabout locations with a shared use path must include bicycle ramps between the roadway and a shared use path. On an approach the bike ramp should be approximately 6 ft (2 m) wide (4 ft (1.2 m) minimum) with a 35-45 degree angle from the travel way or taper. On exits the bike ramp should be approximately 5 ft (1.5 m) wide (4 ft (1.2 m) minimum) with a 20-30 degree angle to the roadway.

12-4.05.04 Vehicle Path Overlap

Vehicle path overlap and methods to avoid path overlap: Designing multi-lane roundabouts is significantly more complex than single-lane roundabouts. Factors include the additional conflicts present with multiple traffic streams entering, circulating, and exiting the roundabout in adjacent lanes. The natural path of a vehicle is the path it will take based on the speed and orientation imposed by the roundabout geometry. While the fastest path assumes a vehicle will intentionally cut across the lane markings to maximize speed, the natural path assumes there are other vehicles present and all vehicles will attempt to stay within the proper lane.

Designers should determine the natural path by assuming the vehicles stay within their lane prior to the tightest entry curve in the approach. Beyond this point, the vehicle will maintain its natural trajectory into the entry and circulatory roadway. The vehicle will then continue into the circulatory roadway and exit with no sudden changes in lane. If the roundabout geometry tends to lead vehicles into the wrong lane, this can result in operational or safety deficiencies.

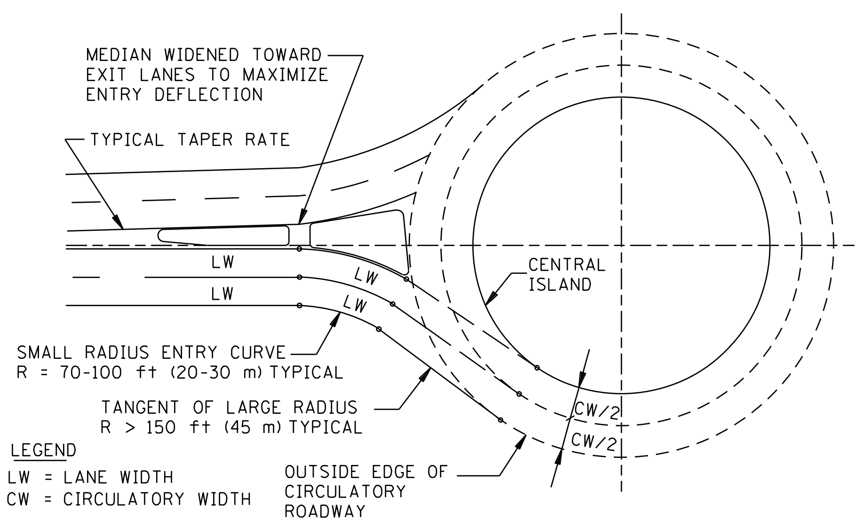
Path overlap occurs when the natural paths of vehicles in adjacent lanes overlap or cross one condition to another. It occurs most commonly at entries, where the geometry of the right-hand entry lane tends to lead vehicles into the left-hand circulatory lane. However, vehicle path overlap can also occur at exits, where the exit geometry or striping of exit tends to lead vehicles from the left-hand lane into the right-hand exit lane. Figure12-4.05B illustrates an example of entry path overlap at a multi-lane roundabout. Here the left lane geometry directs the approach vehicle into the central island or a sudden change in its direction to stay in lane while the right lane geometry directs the approach vehicle toward the adjacent inside or left lane, thus creating a condition which could cause a crash with two vehicles tying to occupy the same space (the inside lane).



VEHICLE PATH OVERLAP
Figure 12-4.05B

12-4.05.05 Design Method to Avoid Path Overlap

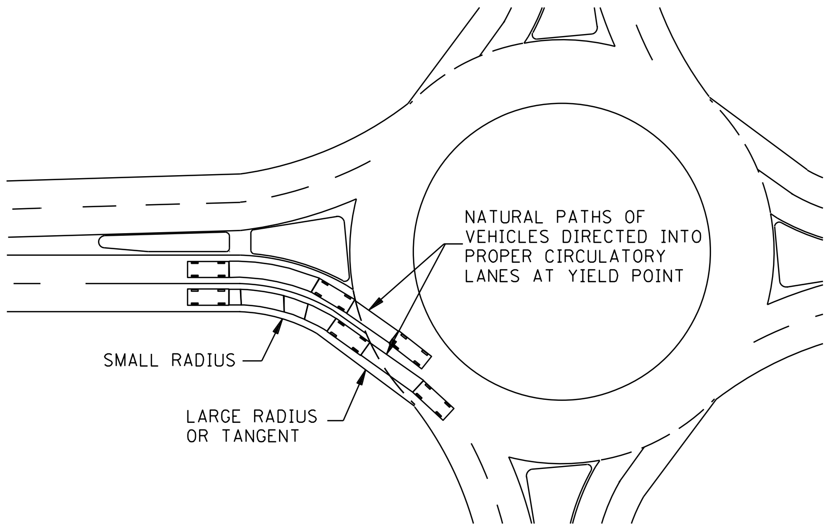
Figure 12-4.05C shows the preferred method to avoid path overlap. This is more consistent with *Roundabouts: An Informational Guide* Exhibit 6-30 and is the preferred design for multi-lane entries. Start with an inner entry curve designed so when the edge of the splitter island curve is extended across the circulatory roadway the line is tangent to the central island as shown. Once the lane geometry is determined to avoid path overlap then design the adjacent lane(s). The radius entry curve will vary depending on the approach geometry and the fastest speed path but will typically range from 70-100 ft (20-30 m). A tangent or large-radius curve greater than 150 ft (45 m) is then fit between the entry curve and the outside edge of the circulatory roadway.



DESIGN TECHNIQUES TO AVOID PATH OVERLAP
Figure 12-4.05C

A second method is to start with a larger sweeping inner curve and provide a smaller radius curve near the approach that is tangent to the central island. This method is also described in *Roundabouts: An Informational Guide,* Section 6.5.4.

The primary objective of this design technique is to locate the entry curve at the optimal placement so that the projection of the inside entry lane at the yield point forms a line tangent to the central island. This inner curve design concept is essential for multi-lane design and is recommended for single lane entries as well. Figure 12-4.05D illustrates the result of proper entry design.



MULTI-LANE ENTRY DESIGN
Figure 12-4.05D

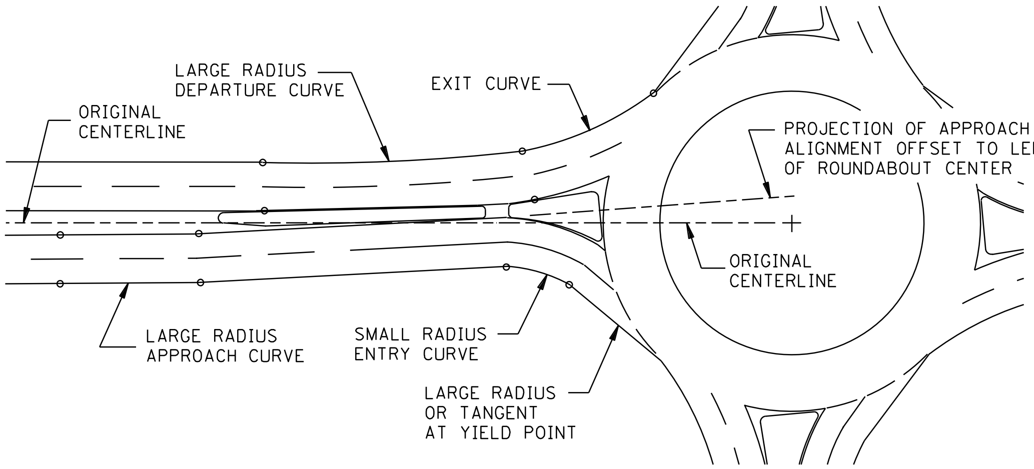
The location of the entry curve directly affects path overlap. If it is located too close to the circulatory roadway, it can result in path overlap. However, if it is located too far away from the circulatory roadway, it can result in inadequate deflection (i.e. entry speeds too fast).

12-4.05.06 Design Techniques to Increase Entry Deflection

Designing multi-lane roundabouts without path overlap while achieving adequate deflection to control entry speeds can be difficult. The same measures that improve path overlap issues generally result in increased fastest path speeds. One technique for reducing the entry speed without creating path overlap is to increase the inscribed circle diameter of the roundabout. Often the inscribed circle of a double lane roundabout must be 165-200 ft (50 m-60 m) in diameter, or more, to achieve a satisfactory entry design. However, increasing the diameter will result in slightly faster circulatory speeds. Therefore, the designer is challenged to balance the entry speeds and circulatory speeds. This often requires much iteration of design, speed checks, and path overlap checks.

12-4.05.07 Approach Offset to Increase Entry Deflection

The technique of offsetting the approach alignment left of the roundabout center is effective at increasing entry deflection (see Figure 12-4.05E). However, this also decreases the entry angle Ø (Phi), which if decreased too far can create reduced capacity, unsafe entry conditions, line of sight issues, unbalanced lane use, etcetera. It also reduces the deflection of the exit on the same leg, which will increase the fast path speed at the entry. Therefore, the distance of the approach offset from the roundabout center should generally be kept to a minimum to maximize its effectiveness in design. Always remember that the fastest speed paths are a critical element of design. Another effective method may be to increase the inscribed diameter slightly.



APPROACH OFFSET
Figure 12-4.05E

12-4.05.08 Curbing

Curbs are required at rural roundabouts also. It is important to modify the rural cross section by introducing a curb/gutter as the highway approaches the roundabout. Curbs are used in the rural roundabout area to define the roundabout entry, calm approach speeds, and indicate a change in roadway environment. Reduce the shoulder width by tapering a Design B curb and gutter toward the travel lane.

12-4.05.09 Entry Flare Length = L′

The average effective flare length is the length of a curve from E away from the right curb to (E+V)/2 that provide effective flare to vehicles. The average effective flare length is NOT the total length of flare between V and E and is not always half the distance between V and E. Sharpness of Flare (S) can assist in the "effectiveness" of a flare [S=1.6(E-V)/L′]. Large values of S correspond to short, severe flares, and small values of S correspond to long, gradual flares that may have less effect on the average effective flare length.

12-4.05.10 Entry Angle, Ø (Phi)

Ø (Phi) is not discussed in *Roundabouts: An Informational Guide*. This is one of the six key roundabout design parameters when using the British Empirical Method. The three methods, or design conditions, of defining Ø (Phi) are described below. The desirable range for the Ø (Phi) angle is between 20 and 40 degrees with 30 degrees being the optimal. This angle should not be the controlling design measure but it is important for both capacity and safety.

There are three methods or design conditions in which Ø (Phi) can be measured. They are:

Condition 1: Ø = 2 Ø /2 where the distance between the left sides of an entry and the next exit are NOT more than 98 ft (30 m). In Condition 1, the acute angle is denoted as 2 Ø in which the actual value must be divided by two to obtain Ø.

Condition 2: Ø = Ø if the distance between the left sides of an entry and the next exit are more than 98 ft (30 m).

Condition 3: Applicable when an adjacent exit does not exist or an exit located at such a distance or obtuse angle to render the circulatory roadway a dominating factor of an entry (such as in a "3-leg" intersection). Ø (Phi) is now the angle formed by the intersection of the tangent line (a-b) projected from the midpoint of the entry width with a tangent line (e-f) drawn along the middle of the circulatory roadway. Used at "T" intersections or where the adjacent entrance and exit lane(s) are far apart.

12-4.05.11 Circulatory Roadway Width

The circulating width is based on the size of the roundabout and the design vehicle required for the design. It is typically 1.0 to 1.2 times the width of the widest entry width. Nearly all roundabouts should be accompanied by an appropriately sized truck apron.

12-4.05.12 Approaches/Departures

Entry grades at a minimum of 50 ft (15 m) are not to exceed 4%.

12-4.06 Capacity and Operation

An operational analysis produces two kinds of estimates: (1) the capacity of a facility, i.e., the ability of the facility to accommodate various streams of users, and (2) the level of performance, often measured in terms of one or more measures of effectiveness, such as delay and queues.

The *Highway Capacity Manual* (HCM) defines the capacity of a facility as "the maximum hourly rate at which persons or vehicles can reasonably be expected to traverse a point or uniform section of a lane or roadway during a given time period under prevailing roadway, traffic, and control conditions." While capacity is a specific measure that can be defined and estimated, level of service (LOS) is a qualitative measure that "characterizes operational conditions within a traffic stream and their perception by motorists and passengers." Delay is the measure of effectiveness that is used to define level of service at intersections, while an operational analysis can be used to evaluate the performance of an existing roundabout during a base or future year, its more common function may be to evaluate new roundabout designs. *Roundabouts: An Informational Guide* covers the HCM method of roundabout analysis.

The U.K. Empirical Method and the RODEL and ARCADY software are based on the premise that certain geometric features contribute to roundabout performance beyond what an elementary gap acceptance model would predict. These performance characteristics, expressed as empirical formulae, are based on research done under the auspices of the British government in real-world driving conditions. They are considered most accurate and applicable when a roundabout is at or near capacity. Further information can be found in *RODEL I Interactive Roundabout Design*.

Both HCM and U.K. Empirical methodologies are considered valid analytical tools depending on the traffic demand. Refer to 12-1.0 for MnDOT-specific guidelines regarding project application. The entirety of the content in this subsection is based on the U.K. Empirical Method and RODEL / ARCADY input, as higher design volume circumstances will tend to demand this level of analysis.

12-4.06.01 Roundabout Capacity

The capacity of each entry to a roundabout is the maximum rate at which vehicles can reasonably be expected to enter the roundabout from an approach during a given time period under prevailing traffic and roadway (geometric) conditions. An operational analysis considers a precise set of geometric conditions and traffic flow rates defined for the design hour volume (DHV) for each roundabout entry. Analysis of the peak hour time period is critical to assess the level of performance of the roundabout and its individual components. The capacity of the entire roundabout is not considered, as it depends on many factors. The focus in this section is on the roundabout entry.
It is similar to the operational analysis methods used for other forms of intersections. In each case, the capacity of the entry or approach is computed as a function of traffic on the other (conflicting) approaches, the interaction of these traffic streams, and the intersection geometry.

For a properly designed roundabout, the yield point is the relevant point for capacity analysis.
The approach capacity is the capacity provided at the yield point. This is determined by a number of geometric parameters in addition to the entry width. On multilane roundabouts, it is important to balance the traffic use of each lane, otherwise some lanes may be overloaded while others are under used. In addition, poorly designed exits may influence driver behavior and cause lane imbalance and congestion at the opposite leg.

12-4.06.02 Factors Affecting Capacity

The maximum flow rate that can be accommodated at a roundabout entry depends on two factors: the circulating flow on the roundabout that conflicts with the entry flow, and the geometric elements of the roundabout.

When the circulating flow is low, drivers at the entry are able to enter the roundabout without significant delay. The larger gaps in the circulating flow are more useful to the entering drivers and more than one vehicle may enter each gap. As the circulating flow increases, the size of the gaps in the circulating flow decreases, and the rate at which vehicles can enter also decreases.

The geometric elements of the roundabout also affect the rate of entry flow. The most important geometric element is the width of the entry and circulatory roadways, or the number of lanes at the entry and on the roundabout. Two entry lanes permit nearly twice the rate of entry flow as does one lane. Wider circulatory roadways allow vehicles to travel alongside, or follow, each other in tighter bunches and so provide longer gaps between bunches of vehicles. The effective flare length can also substantially affect capacity. The inscribed circle diameter and the entry angle have minor effects on capacity.

12-4.06.02.1 Entry Lanes and Volume Balance

A roundabout can typically accommodate the same volume of traffic as a signalized intersection with fewer entry lanes. Roundabouts can be designed for a wide range of traffic flow conditions. There is no formula of minimum side road traffic where a roundabout will not function properly. If all-way stop control or a traffic signal will function properly then analyze the intersection to determine if a roundabout will also function properly. Utilize the RODEL software to determine the number of entry lanes needed and capacity.

12-4.06.02.2 Approach Alignment

Roundabouts can accommodate a wide range of approach alignments and skews. However, they work best when the approach alignments intersect the roundabout at roughly 90 degrees. As with most intersection designs, roadway re-alignment work is often necessary to “square-up” the intersection and improve operations and performance.

12-4.06.02.3 Single Lane Roundabout Capacity

Roundabout capacity is site specific since it is related to the geometric features of each site. For planning purposes, single-lane roundabouts can be expected to handle an AADT of approximately 25,000 veh/day and peak-hour flows between 2,000 vph and 2,500 vph. This rate exceeds 1,900 vph, which is the typical single-lane capacity of a signalized intersection (reported in passenger car equivalents per hour of green time per lane; *Highway Capacity Manual,* Chapter 16). This rate can be achieved for several reasons. First, this is the total of all the approaches, not a single approach. Second, because of separated approaches and right turns, much of the traffic does not conflict. Exit flows exceeding 1,200 vph may indicate the need for a double-lane exit. Sites with AADTs or DHV approaching these limits must be evaluated carefully to ensure desired and optimal performance.

12-4.06.02.4 Multi-Lane Roundabout Capacity

For planning purposes, multilane roundabouts can be expected to handle AADT between 40,000 and 55,000 vpd and peak-hour flows between 4,000 vph and 5,500 vph. The expected capacity can be even higher with the use of by-pass lanes.

12-4.06.02.5 Pedestrian Effects on Entry Capacity

Pedestrians crossing at a marked crosswalk that have priority over entering motor vehicles can have a significant effect on the entry capacity. In such cases, if the pedestrian crossing volume and circulating volume are known, multiply the vehicular capacity by a factor M according to the relationship shown in Exhibit 4-7 or 4-8 of *Roundabouts: An Informational Guide* for single-lane and double-lane roundabouts, respectively. Note that the effects of conflicting pedestrians on the approach capacity decrease as conflicting vehicular volumes increase, as entering vehicles become more likely to have to stop regardless of whether pedestrians are present. Consult the Highway Capacity Manual for additional guidance on the capacity of pedestrian crossings if the capacity of the crosswalk itself is an issue. The capacity reduction factor, M, can be entered in RODEL under the Capacity Factor [CAPF] field.

12-4.06.02.6 Exit Capacity Considerations

It is difficult to achieve an exit flow on a single lane of more than 1,400 vph, even under good operating conditions for vehicles (i.e., tangential alignment, and no pedestrians and bicyclists). Under normal urban conditions and LOS, the exit lane capacity is in the range of 1,200 vph to 1,300 vph. Therefore, exit flows exceeding 1,200 vph may indicate a lower LOS or the need for a multilane exit.

12-4.06.03 Operational Analysis

Two measures are typically used to estimate the performance of a given roundabout design: delay, and queue length. Each measure provides a unique perspective on the quality of service of a roundabout under a given set of traffic and geometric conditions.

12-4.06.03.1 Data Requirements

The analysis method described in this section requires the specification of traffic volumes for each approach to the roundabout, including the flow rate for each directional movement. Volumes are typically expressed in passenger cars per hour (pcph), for the specified peak-hour analysis period. To account for trucks, set the empirically based software to Vehicle (VEH) for FLOWTYPE and the input under the Passenger Car Equivalent (PCE) heading to (1+ % trucks). Example: A 12% truck condition would have 1.12 entered for the PCU value.

Traffic volume data for roundabouts is needed for each directional movement for at least the morning and evening peak periods, because the various movements, and thus approach and circulating volumes, may peak at different times. Typically, intersection volume counts are made at the intersection stop bar, with an observer noting the number of cars that pass that point over a specified time period. However, when demand exceeds capacity (i.e., when queues do not dissipate within the analysis period), the stop bar counts reflect only the volume that is served, not the demand volume. In this case, collect data upstream of the end of a queue so that true demand volumes are available for analysis.

The relationship between the standard origin-to-destination turning movements at an intersection and the circulating and entry flows at a roundabout is important, yet is often complicated to compute, particularly if an intersection has more than four approaches. RODEL and ARCADY take the standard origin-to-destination turning movements and convert them to entering and circulating flows. For existing roundabouts, data collection can be troublesome. It is recommended that the site be videotaped during peak-hour operations and typical directional turning movements be carefully observed and recorded based on the video recording.

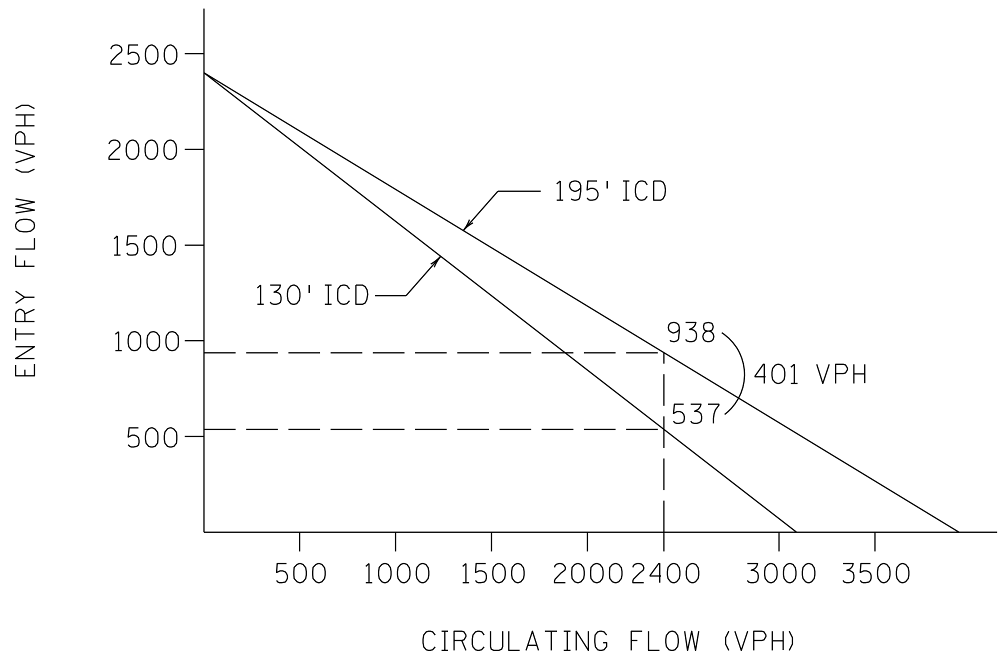
12-4.06.03.2 Driver Behavior and Geometric Elements

A roundabout brings together conflicting traffic streams, allows the streams to safely merge and traverse the roundabout and diverge to their desired directions. The geometric elements of the roundabout provide guidance to drivers approaching, entering, and traveling through a roundabout.

Drivers approaching a roundabout must slow to a speed that will allow them to safely interact with other users of the roundabout and to negotiate the roundabout. The width of the approach roadway, the curvature of the roadway, and the volume of traffic present on the approach govern this speed. As drivers approach the yield point, they must check for conflicting vehicles already on the circulatory roadway and determine when it is safe and prudent to enter the circulating stream. The widths of the approach roadway and entry determine the number of vehicle streams that may form side-by-side at the yield point and govern the rate at which vehicles may enter the circulating roadway. The size of the inscribed circle affects the radius of the driver's path, which in turn determines the speed at which drivers travel on the roundabout. The width of the circulatory roadway determines the number of vehicles that may travel side-by-side on the roundabout.

The U.K. methodology is based on empirical relationships that directly relate capacity to both traffic characteristics and roundabout geometry. The empirical relationships reveal that small changes in the geometric parameters produce significant changes in capacity. For instance, if the approach is flared to enough roadway width, additional short lanes may be provided. The use of a flare from one lane to two lanes can nearly double the approach capacity, without requiring a two-lane roadway prior to the roundabout. A flared entrance is designed to have equal width and taper and there is no long or short lane. Wider entries require wider circulatory roadway widths to accommodate multiple lanes. This provides for more opportunities for the circulatory traffic to bunch together, thus increasing the number of acceptable opportunities for vehicles to enter the roundabout. The number of vehicles entering into an acceptable gap in the circulating traffic is quite small. Because drivers frequently use short lanes to reduce the queue length, short lanes can be very effective in increasing vehicle group sizes and the resultant increase in roundabout capacity.

British research indicates that approach width, entry width, effective flare length, entry angle, and other critical design parameters listed in table 12-4.06A, have the most significant effect on entry capacity. When circulating flows are high, increasing the inscribed circle diameter (ICD) will also substantially increase capacity. Essentially, an additional lane is added to the approach and circulatory roadway. Figure 12-4.06A shows an example where the capacity on one leg of the roundabout is increased by 401 vehicles per hour when the ICD is increased from 130 ft (40 m) to 195 ft (60 m) (SLR to MLR). This increased capacity can happen on more than one leg.



CAPACITY VS. INSCRIBED CIRCLE DIAMETER
Figure 12-4.06A

The entry radius has little effect on capacity provided that it is 65 ft (20 m) or more. Use of an entry radius significantly lower than 45 ft (14 m) reduces capacity with increasing crash severity. A small entry radius tends to produce large entry angles, and the converse is also true. The use of perpendicular entries (70 degrees or more) and small entry radii (less than 50 ft (15 m)) will reduce capacity. The empirical model allows designers to perform sensitivity analyses by manipulating geometric design elements to determine both the operational and safety effects of these elements on their designs. Thus, the geometric elements of a roundabout, together with the volume of traffic desiring to use a roundabout at a given time, determine the efficiency of roundabout operation.

Table 12-4.06A
CRITICAL DESIGN PARAMETERS

Intersection	**Leg 1**	**Leg 2**	**Leg 3**	**Leg 4**	**Leg 5**	**Leg 6**
Half width, ft, (V=)						
Entry width, ft, (E=)						
Effective Flare, ft, (L′ =)						
Entry Radius, ft, (R=)						
Entry Angle (∅=)						
R1, Radius/speed						
R2, Radius/speed						
R3, Radius/speed						
R4, Radius/speed						
R5, Radius/speed						
Inscribed Circle Dia., ft, =						

Design Vehicle:_______________________________________
Circulating Roadway Width:______________________________
Truck Apron Width and cross slope:________________________
Circulating Roadway Cross Slope or Typical section:_____________
Control of Access & Parking near the roundabout:______________
Pedestrian/Bicyclist Accommodations:______________________________

12-4.06.03.3 Delay

Delay is a standard parameter used to measure the performance of an intersection. The Highway Capacity Manual identifies delay as the primary measure of effectiveness for both signalized and un-signalized intersections, with level of service determined from the delay estimate. Empirically based software determines the average and maximum delay in seconds for each approach at a roundabout, as well as the roundabout's overall average delay in seconds. This overall average delay is used in determining the roundabout's level of service.

12-4.06.03.4 Queue Length

Queue length is important when assessing the adequacy of the geometric design of the roundabout approaches. Empirically based software calculates an average and maximum queue for each approach, in vehicles. The approach roadway should have adequate storage capacity so that the queue does not obstruct driveway access or another intersection. Depending on location, a queue of 10 vehicles may be unacceptable at one site while a queue of 50 vehicles at another site may not present a problem. The empirically based software queue length is the mean of the random queue length distribution. The random 95% queue is about two times the empirically based software queues. If the roundabout is operating well with empirically based software set at the 85% capacity confidence level, then the 50% queue lengths will be small.

12-4.06.03.5 Capacity Analysis

The two performance measures – delay and queue length – need to be checked at two different confidence levels with empirically based software. Conduct an empirically based software analysis at both the 50% and 85% confidence levels (CL). The 50% CL analysis represents real expectations of the modern roundabout's performance and provides for an equal comparison to other intersection types because a 50% CL is built into other software programs used to evaluate other types of intersections. The 85% confidence level analysis is a sensitivity check for excessive delay on any of the approaches when there are minor changes in traffic flow and capacity. A sharp rise in delay on any approach leg indicates that design of that entry is approaching a high v/c ratio. This provides information to the designer to check if a modest geometric layout refinement will provide a lower v/c ratio and consequently prolong the life of the intersection by avoiding failure of that leg.

In short, a design with an acceptable level of service at 85% confidence level is desired, but not required. Use engineering judgment to determine if a design resulting in an unacceptable level of service at the 85% confidence level is still the best alternative at the specific location. Regardless of the level of service reported using an 85% confidence level, use the results from empirically based software at the 50% CL when doing a comparison with other intersection alternatives.

12-5.0 MAINTENANCE CONSIDERATIONS IN DESIGN

This section is intended to identify design opportunities that may facilitate effective operations for maintenance personnel. As with any new roadway configuration, highway maintenance staff will need to learn how to apply traditional maintenance applications as well as learn new techniques for effectively maintaining the roadway. Snow and ice operations are a particular concern and will be the primary emphasis of this section; a secondary emphasis will be on routine or ordinary maintenance.

12-5.01 Snow and Ice Operations

A goal of snow and ice operations is to effectively mitigate the visual impact that snow may have on the recognition of the roadway surface. When the visual perception of the roadway is lost, it is important for snowplow operators to have landmarks available to successfully navigate the roundabout approach and intersection. Without this guidance, unnecessary damage from the plow (or the snow it is moving) may occur to curbs, medians, light poles, and signage. Listed below are some considerations that may be easily incorporated into the roundabout design that will facilitate positive guidance to snowplow operators.

1. Snowmelt should be considered when placing a drainage structure. It is unlikely that 100% of the snow will be removed from truck apron.
2. Multiple passes will be required to clear the intersection area of the roundabout. The focus of initial snow removal efforts is to clear the driving lanes. The roundabout design should accommodate snow storage space on the outer perimeter or away from the roundabout, which should be free from obstructions whenever possible. A majority of the plows in the MnDOT fleet can only push snow to the right – this restriction should be factored into the placement of roadside objects. Snow storage space around the perimeter of the roundabout is limited.
3. The roundabout design should not have a ditch or swale behind the truck apron.

12-5.02 Routine or Ordinary Maintenance

The routine maintenance required for roundabouts is similar to other intersection types. Two unique characteristics that deserve special considerations are landscaping and pavement markings.

1. A realistic maintenance program should be considered in the design of the landscape features of a roundabout. It is unrealistic to expect MnDOT to maintain a complex landscaping design associated with a roundabout. A local jurisdiction may pursue an agreement with MnDOT to provide maintenance to the landscaping details. However, when there is no interest from the local agency in maintaining the appurtenances, the design should consist of "hardscape" items and/or landscape plantings that require little or no maintenance. In all cases, the minimum sight distance clear zones and blockage zones should be adhered too. All roundabouts must provide some form of visual conspicuity in the central island to promote safety.
2. The landscaping plan should examine the possibility of creating a living snow fence into the design of modern roundabouts, especially in locations where drifting is likely. Locating trees, bushes, or shrubs to the northwest of the intersection may minimize drifting and facilitate effective snow removal.
3. Pavement markings provide positive guidance for the vehicles as they approach a roundabout; they also require inspection and replacement on a regular basis. The striping equipment is big, bulky, and has a large turning radius. Maintaining the striping within the roundabout may require a lot of handwork or must be contracted to companies that have smaller and more mobile equipment. To minimize the maintenance efforts associated with pavement marking within the roundabout a variety of design techniques can eliminate the need for pavement markings without eliminating the positive guidance needed to successfully navigate through the intersection. Different pavement types, colors, surfacing and transitional curbing can provide visual feedback to the drivers and facilitate movement through the roundabout in lieu of pavement markings.

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12-6.0 TRAFFIC CONTROL DEVICES

Signing of modern roundabouts is a critical component of design that is just as important as the geometric layout. Roundabout signs must work together in order to accurately communicate to the driver. Signing and striping are two important tools roundabout designers can use for driver comprehension, especially with multi-lane roundabouts. Proper advanced warning signs, regulatory control signs, lane guidance signs (multi-lane roundabouts), and directional guidance signs are required. The modern roundabout must be signed effectively with reduced sign clutter in order to be effective. The key to roundabout safety with respect to signing is consistency.

The process of approaching and navigating a roundabout involves acquiring and processing information, either from the geometry of the road and roundabout approach, or from pavement markings and signs. Signs should be designed and installed to minimize detection, reading, processing time, all to maximize comprehension. A motorist must be able to detect a sign, read and comprehend the signs content, make related decisions concerning vehicle speed, exit leg choice, and approach lane choice.

The selection, location, and placement of traffic control devices for roundabouts are determined by the use of manuals (*MN MUTCD, Traffic Engineering Manual*). Contact the MnDOT Office of Traffic, Safety and Technology (OTST) for the latest traffic control requirements, guidelines, and current best practices: http://www.dot.state.mn.us/trafficeng/.

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12-7.0 LANDSCAPING

12-7.01 Advantages

Landscaping the central island, splitter islands (where appropriate), and the approaches can benefit both public safety and enhance the visual quality of the intersection and the community. The landscaping of the roundabout and approaches should:

1. Make the central island more conspicuous.
2. Improve the aesthetics of the area while complementing surrounding streetscapes as much as possible.
3. Visually reinforce the geometry, intended circulation paths of all modes and necessary decision-making.
4. Avoid obscuring the form of the roundabout, the signing to the driver, or pedestrian crossings.
5. Maintain adequate sight distances as well as required sight blockage zones.
6. Clearly indicate to drivers that they cannot pass straight through the intersection.
7. Discourage pedestrian traffic through the central island.
8. Help blind and visually impaired pedestrians locate sidewalks and crosswalks.

12-7.02 Central Island Landscaping

The central island landscaping enhances the safety of the intersection by making it more conspicuous and by lowering speeds. Select plantings to ensure adequate sight distance for the life of the project by considering future maintenance as well as current design requirements. Avoid landscaping designs in the central island that may encourage pedestrians to cross the central island. Consider the salt tolerance of any plant material, as well as snow storage and removal practices. In addition, prevent unnecessary runoff and creation of wet and potentially slippery pavement conditions by avoiding landscaping treatments that require provision of irrigation systems or extensive supplemental watering.

The desired slope of the central island should approximate but not exceed 1:4. As an absolute minimum, keep the outside 6 ft (2 m) of the central island free from specific landscape features to provide a minimum level of roadside safety, and site distance as discussed in 12-4.

Where truck aprons are used in conjunction with a streetscape project, construct a roadway pavement that is consistent with other streetscape elements. However, the material used for the apron should be a different color or texture than the material used for the sidewalks to discourage pedestrians from crossing the circulatory roadway. Avoid street furniture that may attract pedestrian traffic to the central island, such as benches, decorative statues, community welcome signs, or monuments with small text. If fountains or monuments are being considered for the central island, they must be designed in a way that will enable proper viewing from the perimeter of the roundabout. In addition, they must be located and designed to minimize the possibility and severity of impact from an errant vehicle.

Reference *Roundabouts: An Informational Guide* for the different sight distance criteria for permissible landscaping areas/zones and height requirements.

12-7.03 Splitter Island and Approach Landscaping

In general, unless the splitter islands are very large, they must not contain trees, planters, or light poles. Avoid landscaping which will obstruct sight distance, as the splitter islands are usually located within the critical sight triangles.

12-7.04 Perimeter Landscaping

Landscaping on the approaches to the roundabout can enhance safety by making the intersection more conspicuous and by countering the perception of a high-speed through traffic movement. Avoid landscaping over 24 inches (600 mm) in height, within 75 ft (25 m) in advance of the yield point. Plantings in the splitter islands (where appropriate) and on the right and left side of the approaches (except within 50 ft (15 m) of the yield point) can help to create a funneling effect and induce a decrease in speeds approaching the roundabout. Low profile landscaping in the corner radii can help to channelize pedestrians to the crosswalk areas and discourage pedestrian crossings to the central island.

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12-8.0 REFERENCES

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http:www.dot.state.mn.us/atoz.html

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