

**Roundabout Warrants:
A Proposed Framework for Future Development**

Jeremy R. Chapman
Research Assistant
Department of Civil and Environmental Engineering
University of Illinois @ Urbana-Champaign
3216 Newmark Civil Engineering Lab
205 N. Mathews Ave.
Urbana, IL 61801
217-333-6975
jrchapman@home.com

Rahim F. Benekohal
Professor
Department of Civil and Environmental Engineering
University of Illinois @ Urbana-Champaign
205 N. Mathews Ave.
Urbana, IL 61801
217-244-6288
217-333-1924 FAX
rbenekoh@uiuc.edu

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Abstract

This paper looked at the available research done in the area of roundabout intersections, and focused primarily on specific areas of concern regarding their installation. The Federal Highway Administration's 2000 publication *Roundabouts: An Informational Guide* looks at what should be done after the decision to install a roundabout has already been made. This guide, while a good reference, does not provide specific decision-making criteria, which provided the main focus of this proposed framework. The areas of focus suggested in this paper are not to be considered exhaustive nor complete, but merely suggested criteria, as the use of warrants seeks to imply. The areas covered in depth by these criteria are pedestrian volume, horizontal alignment, vertical alignment, and unbalanced flow volumes. Additionally, safety and relevant local concerns should be focused on in the overall decision-making process.

Introduction

Considering that very few intersections have identical characteristics, the idea of warrants was developed for the installation of traffic signals. The conversion from a stop-controlled intersection to a signal-controlled intersection is not without major costs, and the same can be said for the roundabout. Today, traffic engineers routinely consult Section 4C of the Manual on Uniform Traffic Control Devices (1988 Edition) when making decisions regarding the installation of traffic signals and other traffic-control devices.

The first step in making a decision regarding any intersection is to consider the criteria and applicable factors therein. Until very recently, there was not a single federal reference manual on the roundabout, and even now it is, by title, only an informational guide. The perceived lack of guidelines forces local communities to question whether or not they can afford to proceed without federal direction. This study looks at current research, and outlines a possible framework to guide engineers in the installation of roundabouts.

First, what defines a roundabout intersection? Bared, Prosser, and Tan Esse (1997) stated: Modern roundabouts are distinguished from traffic circles by their uniform characteristics in operation and design. All roundabouts use the yield-on-entry rule requiring the entering vehicle to yield to vehicles in the circle. The design incorporates a number of geometric elements to assist and direct traffic through the intersection. This does not mean that roundabouts have "cookie cutter" designs, but it does mean that the same elements are included in each design. Each roundabout provides for the deflection of the vehicle's path to slow traffic and promote yielding, and the roadway entry usually flares to increase capacity.

Currently, the installation of roundabout intersections is occurring in a seemingly random manner. The need for a roundabout typically does not become established, just the desire for such an intersection. The general public in many cases gains a favorable impression

regarding the roundabout, but only after installation. The biggest concern is when a roundabout is installed incorrectly, and the application subsequently has to be removed.

The expense of reconstruction to either a 4-way stop-controlled intersection, or a signal-controlled intersection is prohibitive, especially if the roundabout is not at the end of its life expectancy (in terms of capacity or facilities maintenance). The costs faced, therefore, are harmful economically, and also to the reputation of this “new” style of intersection. This can damage, if not completely destroy any future use in that area. The public will always focus on that failure when discussion comes around to the possible installation of another roundabout in a different area of the city or state.

The need for roundabout warrants is clear, and the basic outline for these warrants is not without justification in existing data. The information that is routinely gathered to satisfy the signal warrants should be suitable for the roundabout warrants as well. The roundabout does have strengths in application that cannot be met by a 4-way-stop or by a traffic signal, and these need to be brought out through the justification for installation.

Proposed Warrants and Necessary Data Collection

The preliminary engineering data required is very much the same as for the traffic control signal warrants. To this end (utilizing the proposed updated guidance of Section 4C.1 of the MUTCD Millennium Edition) engineering study data may include the following:

- a. The number of vehicles entering the intersection in each hour from each approach during 12 consecutive hours of an average day. The 12 hours selected should contain the greatest percentage of the 24-hour volume.
- b. Vehicular volumes for each traffic movement from each approach, classified by vehicle type (heavy trucks, passenger cars and light trucks, public-transit vehicles, and, in some locations, bicycles), during each 15-minute period of the two hours in the morning and two hours in the afternoon during which total traffic entering the intersection is greatest.
- c. Pedestrian volume counts on each crosswalk during the same periods as the vehicular counts in paragraph b above and during hours of highest pedestrian volume. Where young or elderly persons need special consideration, the pedestrians may be classified by general observation.
- d. The posted or statutory speed limit or the 85th-percentile speed on the uncontrolled approaches to the location.
- e. A condition diagram showing details of the physical layout, including such features as intersectional geometrics, channelization, grades, sight-distance restrictions, bus stops and routings, parking conditions, pavement markings, roadway lighting, driveways, nearby railroad crossings, distance to nearest highway traffic signals, utility poles and fixtures, and adjacent land use.
- f. A collision diagram showing accident experience by type, location, direction of movement, severity, time of day, date, and day of week for at least one year.

This data collection is basically standard for any intersection study, and should represent the foundation for evaluation of any decision made. Besides the basic criteria set forth in each of the suggested warrants, the following items should be considered before any changes should be made.

- a. Safety – besides the general concern for pedestrians, the overall safety of the location needs to be looked at to determine the best course of action. This should be quantifiable.
- b. Costs – any change from a stop-controlled intersection will cost a significant amount. There should be a quantifiable reason to justify the expenditure.
- c. Traffic Calming – a typical intersection (stop-controlled or signalized) tends not to offer much towards traffic calming, but the geometry of a roundabout can have just that effect. To some extent this can be quantified, but it also has some non-quantifiable aspects.
- d. Neighborhood Character & Location Impact – While quantifiable variables are important in decision-making, looking at aesthetics is also critical. Residential neighborhoods usually have lower traffic volumes, but may face very high peak hour volumes as people leave for or arrive home from work. For those two peak hours each day a traffic signal may be necessary, but for the rest of the time, it is only an eyesore and an inconvenience to the area.

Therefore, the suggested warrants that are presented in this paper are:

- Warrant 1 – Pedestrian Volume
- Warrant 2 – Horizontal Alignment
- Warrant 3 – Vertical Alignment
- Warrant 4 – Unbalanced Flow Volumes

Warrant 1 – Pedestrian Volume

A roundabout installation provides for continuous traffic flow with little if any stopping. This decreases the ability for pedestrian crossing if the intersection is in a high-traffic area, especially if there are more than 2 lanes of traffic. The concern for the safety of pedestrians should be the top priority when renovating an intersection.

It is suggested, then, that through a utilization of the suggestions in the proposed updated signal warrant 4 from section 4C of the MUTCD Millennium Edition, the installation of a roundabout should not be considered if both of the following criteria are met:

- a. The pedestrian volume crossing the major roadway at an intersection during an average day is 100 or more for each of any 4 hours or 190 or more during any 1 hour.
- b. There are fewer than 60 gaps per hour in the traffic stream of adequate length to allow pedestrians to cross during the same period when the pedestrian volume criterion is satisfied. Where there is a divided roadway having a median of sufficient width for pedestrians to wait, the requirement applies to each direction of vehicular traffic.

Keeping safety at the forefront, if it is determined that the pedestrian volumes are below the maximums set within this warrant, then in conjunction with reasonable projections (both pedestrian and traffic), a roundabout may be installed. However, if it is determined that the pedestrian or traffic volumes are likely to increase beyond the maximums set forth in this warrant, then a roundabout is not recommended.

This suggestion is based on the research of Oh and Sisiopiku (2000), who wrote that: roundabouts provide more pedestrian capacities under the vehicular volume up to 1100 veh/hr/direction at 2-lane, 2-way intersections. Compared to a signalized intersection with cycle length of 60 seconds, a roundabout outperforms the signalized alternative for vehicular volumes up to 1400 veh/hr/direction.

At 4-lane, 2-way facilities, roundabouts are superior to signalized intersections in terms of pedestrian capacity for the light vehicular volumes only up to 600 veh/hr/direction.

It can logically be assumed that the existence of dividing islands should have a positive effect on pedestrian delay. Taking into account that pedestrians could cross to the dividing island, they could and then proceed to spend time identifying another acceptable gap while on the dividing island. As a direct result the overall delay could thereby decrease since the minimum acceptable gap for a two-staged pedestrian crossing would be approximately half the gap required for a full-staged pedestrian crossing.

Oh and Sisiopiku (2000) proposed the following to calculate the maximum pedestrian crossing rate (MPCR) for roundabouts, with the following assumptions:

- A pedestrian waits for at least the minimum gap before crossing a one-way flow;
- There are enough pedestrians to ensure continuous flow; and
- Vehicle arrival intervals follow the exponential distribution without bunched flow.
- Dividing islands are present in the roundabout design.

$$\mu_R = 3600\lambda \left[-e^{-\lambda t} (1-e^{-\lambda t'}) \frac{e^{-\lambda t'}}{(1-e^{-\lambda t'})^2} + \lambda e^{-\lambda t} \frac{e^{-t'}}{(1-e^{-t'})} \right] \quad (1)$$

where: μ_R = MPCR at roundabouts (ped/hr/m)
 λ = vehicle arrival rate (veh/sec)
 t = time needed by a pedestrian to cross a roadway (sec)
 t' = headway between pedestrians (sec)

As a result of this equation, Oh and Sisiopiku (2000) found that in the case of a 2-lane, 2-way roadway, assuming the ideal saturation flow of 1900 passenger cars per hour per lane (pcphpl), there is still room for pedestrian crossings during the oversaturation state. Figure 1, a graph comparing MPCR (ped/hr/m) to Vehicle volume (veh/hr/dir), indicates that the MPCR value is 360 ped/hr/m at the threshold of the aforementioned oversaturation state.

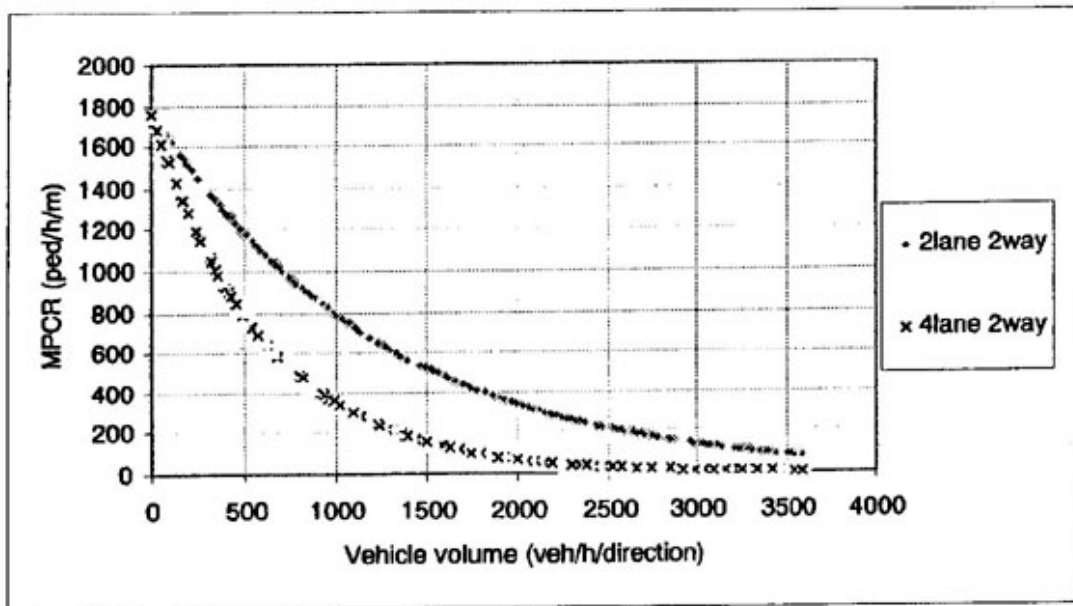


Figure 1 – MPCR at roundabouts (Oh and Sisiopiku (2000))

The results of the graph in Figure 1 are summarized below in Table 1, which compares vehicle volume levels with the MPCR for roundabouts and signalized intersections for both 2-lane, 2-way and 4-lane, 2-way intersections.

Vehicle Volume (veh/hr/ direction)	MPCR (ped/hr/meter)					
	2-Lane 2-Way			4-Lane 2-Way		
	Roundabout	Signalized Intersection		Roundabout	Signalized Intersection	
		C=60 sec	C=120 sec		C=60 sec	C=120 sec
500-600	1094	552	716	671	363	622
601-700	1009	552	716	570	363	622
701-800	931	552	716	485	363	622
801-900	858	552	716	412	363	622
901-1000	790	552	716	349	363	622
1001-1100	727	552	716	296	363	622
1101-1200	669	552	716	251	363	622
1201-1300	615	552	716	213	363	622
1301-1400	566	552	716	180	363	622
1401-1500	520	552	716	153	363	622

Table 1 – Pedestrian Capacity and Vehicle Volume Comparison

(Oh and Sisiopiku (2000))

The concern for pedestrians then becomes the delay factor, or simply, the length of time the average pedestrian have to wait to cross any of the legs of the roundabout. Using MPCR and queuing theory concepts, Oh and Sisiopiku (2000) derived an equation to calculate total waiting time.

$$W_t = \rho_k^2 / (v_k (1 - \rho_k)) + \rho_s^2 / (v_s (1 - \rho_s)) \quad (2)$$

where: W_t = total waiting time (sec)
 ρ_k = pedestrian arrival rate at the curbside/ μ_k
 ρ_s = pedestrian arrival rate at the dividing island/ μ_s
 v_k = pedestrian arrival rate at the curbside (ped/hr/m)
 v_s = pedestrian arrival rate at the dividing island (ped/hr/m)
 μ_k = MPCR during a given green time at the curbside (ped/hr/m)
 μ_s = MPCR during a given green time at the dividing island (ped/hr/m)

This equation produces the overall delay for pedestrians at a roundabout, and was used to develop Figure 2.

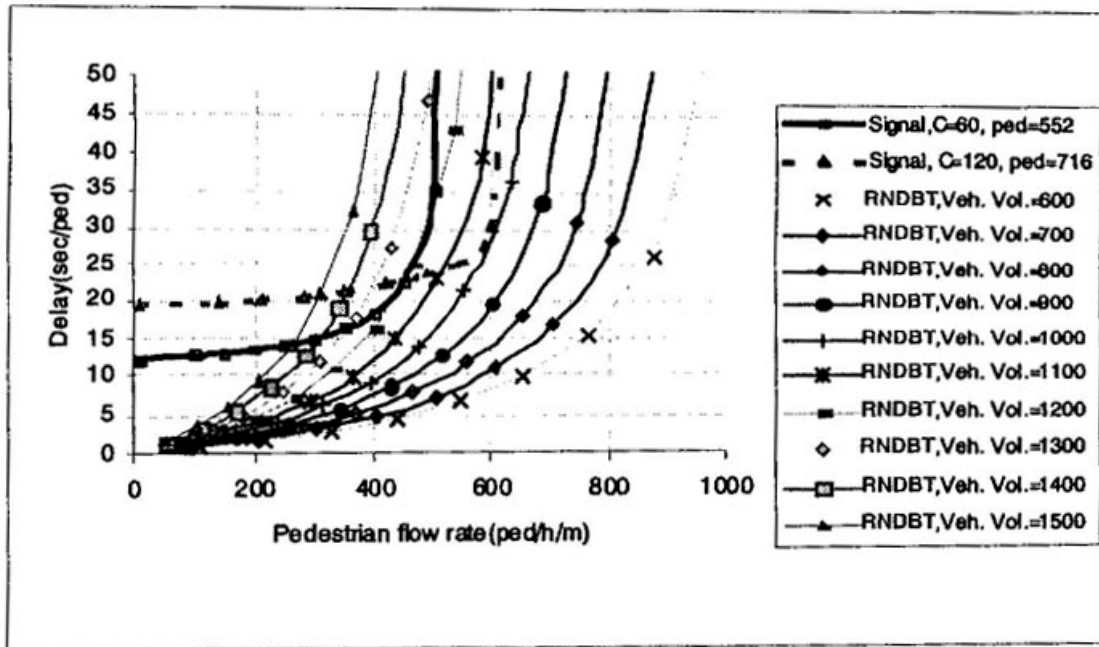


Figure 2 – Average Pedestrian Delay comparison at 2-lane, 2-way roadways.
(Oh and Sisiopiku (2000))

The equations derived by Oh and Sisiopiku (2000) provide an excellent means for determining the pedestrian capacity of a particular roundabout intersection. The only remaining area of concern then is the vehicle entry speed, which is controllable by the geometry (specifically the entry deflection angle), so it becomes a matter of concern in the design process, and not covered here.

Existing Geometric Conditions (Warrants 2 & 3)

There are no comparable warrants for the installation of a traffic signal system in the case of an unusual or intricate street arrangement pattern. These warrants, therefore, seek to address problems that only the roundabout may be able to provide a solution for.

The roundabout is usually modeled as a series of T-intersections (3-legged). This arrangement, considering the circular orientation, allows for approaches that do not intersect at 90-degree angles. It also allows for the inclusion of more than 4 approaches without a complex signal arrangement. The nature of a roundabout provides for a somewhat simple, and safe (considering there is no risk of a head-on or right angle collision in the design) accommodation of these unusual arrangements.

In most cases, the improvement to an intersection requires the acquisition of right-of-way (ROW). A single-lane roundabout can fit within the existing intersection footprint, with only minor ROW acquisitions for sidewalks, etc. In the case of a multi-lane roundabout, the ROW acquisition will probably increase.

There are two separate areas of geometric concern regarding roundabouts, so horizontal and vertical alignments will be treated separately as follows.

Warrant 2 – Horizontal Alignment

Skewed intersections have always represented a design challenge, and pose a safety risk for those motorists who have to negotiate them. Figure 3 illustrates the nomenclature of skewed intersections.

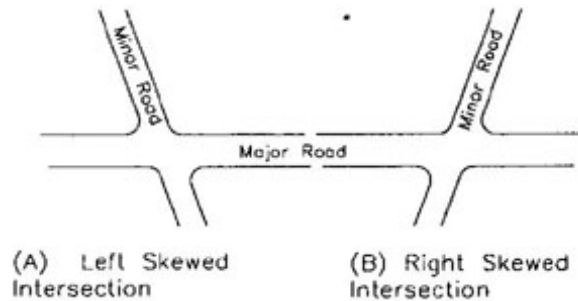


Figure 3 – Skewed intersection nomenclature (Gattis and Low (1998))

Gattis and Low (1998) suggested eight potential problems that could occur at skewed intersections.

1. Vehicles passing through a skewed-angle intersection may have a longer distance to traverse while crossing the intersecting roadway. The longer distance will result in an increased time of exposure to the cross-street traffic. This in turn may call for an increased amount of intersection sight distance. This exposure is more significant for some longer combination vehicles (or other non-passenger car designs) because of their lower acceleration rates and longer lengths.
2. Drivers with certain physical limitations may find it more difficult to turn their head, neck, or upper body for an adequate line of sight down an acute-angle approach.
3. Drivers making right or left turns at skewed-angle intersections in general may have more difficulty aligning their vehicles as they enter the cross street.
4. Unless adequate attention was given to the geometric design of the intersection radii, drivers making right turns around an acute-angle radius may encroach on lanes intended for oncoming traffic from the right.
5. Properly designed skewed intersections often require a larger intersection area to accommodate the turning paths of larger design vehicles through the acute angles. This larger intersection area may confuse drivers and also may cause them to deviate from the intended path.
6. When intersection angles are skewed, valley gutters parallel to one roadway will not be perpendicular to the crossing roadway. For vehicles crossing a skewed valley gutter, the tires on each end of the axle will not cross the gutter simultaneously as they would have with a perpendicular valley gutter; instead, they will cross at different times. For each axle that crosses the valley gutter, two bumps instead of a single bump will result.

7. Through-roadway drivers making left turns across an obtuse angle may attempt to maintain a higher than normal turning speed and cut across the oncoming traffic lane on the intersecting street.
8. The line of sight of drivers with an acute-angle approach to their right may be obstructed by the body of certain vehicles. Vehicle body parts that can obstruct the driver's line of sight include the door frame, a panel aft of the door, or the cargo box of a single-unit truck. Some of these problems as described may exist only when the driver is located on the left side of the vehicle. When the driver is positioned on the right side of the vehicle, the operational problem resulting from a skewed-angle intersection may take place to the left instead of to the right.

Of these problems, the roundabout can provide relief for most of them.

Problem 1 no longer exists simply because all vehicles follow the same path around the roundabout, and traverse approximately the same distance to cover 180 degrees of the circle.

Problem 2 is not solved, but some relief is offered in that drivers will rarely have a severely acute-angle to negotiate because their individual approach will meet the circle at an approximately right angle. Also, the roundabout installation could allow for some alteration of the approach angle, and this should be explored during the design process.

Problems 3, 4, 5 & 7 are all related to alignment and intended path concerns, and are eliminated because all drivers follow a fixed path as they revolve around the circle.

- A driver originally making a right-turn would follow the circular path 90 degrees around the circle and exit.
- A driver originally making a left-turn would follow the circular path 270 degrees around the circle and exit.

Problem 6 is answered only in that the gutter system of a roundabout would preclude any instance of valley gutters. If a municipality utilizes valley gutters on its streets, it would have to modify its storm drainage with the addition of inlets to eliminate the crossing gutters from the roundabout area. This is a concern that engineers should take into account when siting a roundabout, but should not be considered a reason to reject a roundabout installation.

Problem 8 is a differing type of geometric concern, considering that vehicles approaching from the right are obscured by the driver's own vehicle. The roundabout, by design, solves this problem. There are no vehicles approaching from the driver's right side in the circular flow of a roundabout, so regardless of the approach angle the driver will not have an obscured area.

Using the methodology provided by the current *A Policy on Geometric Design of Highways and Streets* (the "Green Book") by AASHTO, Gattis and Low calculated the available sight distance for 5.4-m and 4.4-m setbacks. These values are provided in Tables 2 and 3 (both from Gattis and Low (1998)), and were developed using the sight distance triangle in Figure 4.

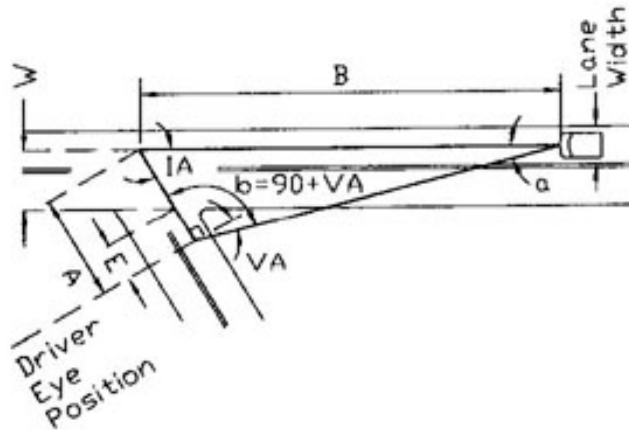


Figure 4 – Sight distance triangle geometry (Gattis and Low (1998))

	Desirable Vision Angle (VA_{SB}) 4.5°		Minimum Vision Angle (VA_{LF}) 13.5°	
Intersection Angle (IA) (degrees)	ASD (m)	Design Speed (km/hr)	ASD (m)	Design Speed (km/hr)
55	23.6	<30	31.8	31
60	26.9	<30	39.8	37
65	32.3	32	55.4	46
70	41.6	38	95.7	65
75	60.1	49	408.2	>120

Note: Based on a distance from driver's eye to edge of cross road of 5.4 m (per NCHRP 383), and a distance from the near road edge to the center of the path of the oncoming vehicle from the right $(3.6 + 3.6/2) = 5.4$.

Table 2 – Resulting Available Sight Distance for a 5.4-m Setback

	Desirable Vision Angle (VA_{SB}) 4.5°		Minimum Vision Angle (VA_{LF}) 13.5°	
Intersection Angle (IA) (degrees)	ASD (m)	Design Speed (km/hr)	ASD (m)	Design Speed (km/hr)
60	24.6	<30	36.4	35
65	29.5	30	50.5	43
70	37.8	36	87.1	61
75	54.6	46	371.1	>120

Note: Based on a distance from driver's eye to edge of cross road of 4.4 m (per NCHRP 383), and a distance from the near road edge to the center of the path of the oncoming vehicle from the right $(3.6 + 3.6/2) = 5.4$.

Table 3 – Resulting Available Sight Distance for a 4.4-m Setback

Tables 2 & 3 indicate the maximum design speeds that a given roundabout entrance can accommodate based on the sight distance triangle geometry from figure 4. These tables can be used in one of two ways then: either to determine the new approach angle to maintain a specific design speed; or to determine the maximum design speed for a fixed approach angle.

In that there is no warrant for the installation of a traffic signal system for these skewed intersections, it is suggested that the installation of a roundabout could be considered a superior alternative when:

- a. The geometric realignment of the approaches is cost prohibitive, or
- b. The current alignment is not conducive to the installation of a traffic signal system without geometric improvements, or
- c. There are more than four approaches intersecting at a single unsignalized location.

If there is a traffic signal system already in place, it is suggested that the conversion to a roundabout should only be considered if the intersection volumes are below the minimum levels set forth in the proposed updated signal warrant 3, category a, from section 4C of the MUTCD Millennium Edition. If all three of the following conditions exist for the same 1 hour (any four consecutive 15-minute periods) of an average day:

- (1) The total delay experienced by the traffic on one minor-roadway approach (one direction only) controlled by a STOP sign equals or exceeds: 4 vehicle-hours for a one-lane approach; or 5 vehicle-hours for a two-lane approach, and
- (2) The volume on the same minor-roadway approach (one direction only) equals or exceeds 100 vph for one moving lane of traffic or 150 vph for two moving lanes.
- (3) The total entering volume serviced during the hour equals or exceeds 650 vph for intersections with three approaches or 800 vph for intersections with four or more approaches.

Warrant 3 – Vertical Alignment

In *Roundabouts: An Informational Guide* (FHWA 2000), Section 6.3.11.3 makes recommendations regarding the installation of roundabouts on grades.

It is generally not desirable to locate roundabouts in locations where grades through the intersection are greater than four percent. Installing roundabouts on roadways with grades lower than three percent are generally not problematic. At locations where a constant grade must be maintained through the intersection, the circulatory roadway may be constructed on a constant-slope plane. This means, for instance, that the cross-slope may vary from +3 percent on the high side of the roundabout (sloped toward the central island) to –3 percent on the low side (sloped outward). Note that central island cross slopes will pass through level at a minimum of two locations for roundabouts constructed on a constant grade.

It is suggested that this guidance be utilized, and that a roundabout should not be installed at a location if all the following criteria are met.

- (1) The grades through the intersection are greater than four percent;
- (2) Crest vertical curves with steep approaches are present;
- (3) The vertical profile cannot be adjusted without great expense;
- (4) The intersection cannot be relocated; and
- (5) There is another design alternative that could be used that would not be inferior to the roundabout.

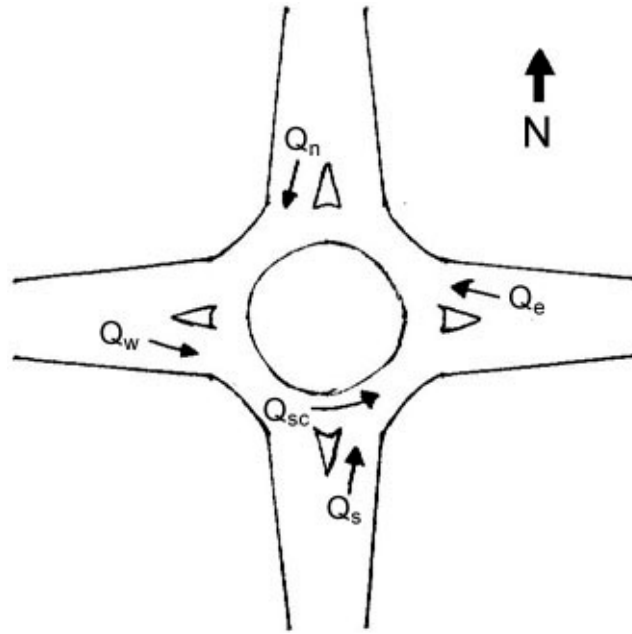
Warrant 4 – Unbalanced Flow Volumes

A roundabout intersection is usually considered superior to unsignalized intersections because it does not require drivers to stop at entry if there are no other vehicles in the intersection. The concern that can be raised then is what happens if one (or both) of the major street approaches has such a disproportionate amount of the overall traffic volume that it would prevent any vehicles from the minor approaches from entering (or would permit such entry only after a significant queue has formed).

A typical and obviously inappropriate set of conditions is where the traffic volume on one approach is so high that it effectively precludes vehicles from entering at any other approach. Under these conditions the total volume of traffic trying to use the roundabout may be quite moderate but inordinate delays would result on some approaches due to this large imbalance in the approach volumes. An obvious question arising here is at what level of an imbalance in flows are unacceptable delays likely to occur? Many analysis methods cannot answer this question since they effectively treat each approach as an isolated T-intersection. (Krogscheepers and Roebuck (2000)).

Krogscheepers and Roebuck defined unbalanced flow (or the ratio-of-imbalance for the northern approach ρ_n – see Figure 5 for layout) as:

$$\rho_n = \frac{Q_{wn}}{Q_{wn} + Q_{sn} + Q_{cn}} = \frac{Q_{wn}}{Q_{nc}} \quad (3)$$



Where: Q_{sc} = $Q_{ws} + Q_{ns} + Q_{es}$
 Q_{ws} = Traffic from west passing south
 Q_{ns} = Traffic from north passing south
 Q_{es} = Traffic from east passing south

Figure 5 – Definition of unbalanced flows

Utilizing equation 3 to calculate the ratio of imbalance, it is possible then to utilize curves that Krogscheepers and Roebuck produced through both observation and two different types of modeling software (SIDRA and TRACSIM – see Figure 6). The curves produced are not robust however, and therefore cannot provide an authoritative basis for a warrant.

It would be suggested then, that a warrant (pending further research) would recommend that a roundabout should not be installed at a location in the following cases:

- When the ρ value calculated is less than 35%, or
- When the ρ value calculated is greater than 55%.

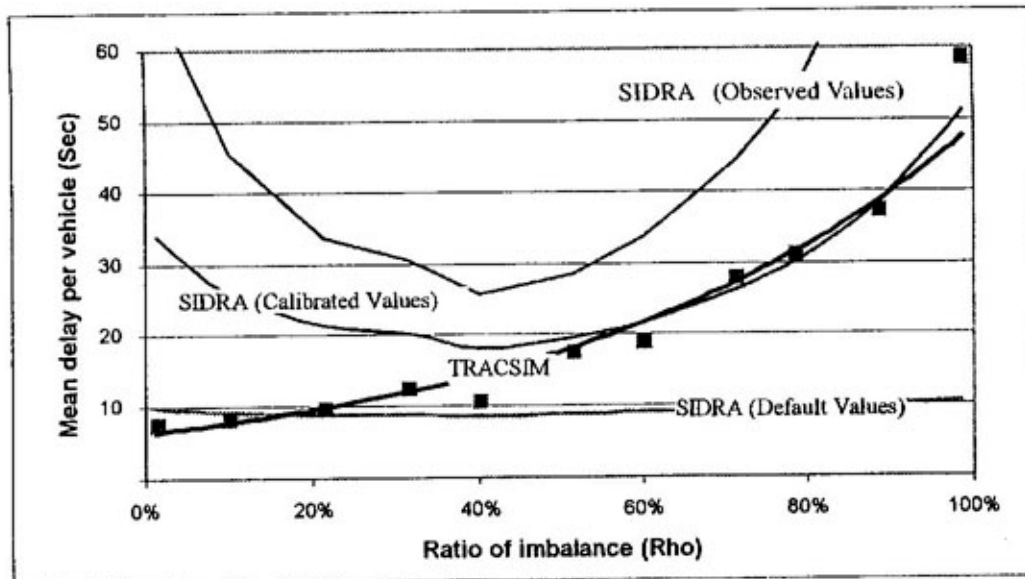


Figure 6 – Effects of Unbalanced Flows (data set 1 – Krogscheepers and Roebuck 2000)

Conclusions

The FHWA publication: *Roundabouts: An Informational Guide*, has provided federal recognition to the popularity of the roundabout. This guide does not go far enough, however, in that it only provides information through the synthesis of a wide variety of design manuals from states and other countries. The informational guide makes some recommendations, but does not set forth any requirements.

The roundabout intersection is quickly gaining popularity in the United States. Unfortunately, the rapid expansion of the use of roundabouts is currently not controlled by any real guidance or authority. The roundabout needs to have its own set of guidelines to dictate the proper (or more importantly improper) usage, and warrants have already been proven successful for traffic signals.

The application of warrants for roundabouts seems to be the next logical step for providing guidance and control of their usage. As research continues to expand knowledge about the roundabout, changes and adjustments can be made, but warrants now should provide a good foundation to build from.

The framework in this paper should help engineers determine what items are important when they are making the decision as to what type of intersection improvement to go with. The focus on pedestrian volumes, horizontal and vertical alignments, and unbalanced flow volumes are all areas that need to be looked at in an intersection study.

These areas are only a suggested starting point however, and it is clear from doing this study that there is a need for further research in each of the suggested warrant areas. The work done by Oh and Sisiopiku (2000) should be expanded and the equations should be tested in multiple locations. The research performed by Gattis and Low (1998) was done with skewed intersections and not roundabouts, and this should be explored further. The information provided in the FHWA roundabout guide, Section 6.3.11.3 regarding vertical alignments is logical, but also should be studied in the field. The work done by Krogscheepers and Roebuck (2000) needs to be expanded through field research as well. Upon completion, this additional research should confirm more fully the initial findings of these researchers, and also provide a further basis for the framework presented in this paper.

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Background Information

The research involved in compiling this paper constituted reading many articles related to the roundabout intersection. Of these papers, many were excellent, but not related to the topic at hand. These papers are as follows:

Al-Masaeid, Hashem R., and Faddah, Mohammad Z., “Capacity of Roundabouts in Jordan,” Transportation Research Record No. 1572, 1997.

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Two texts were read for background as well, these are:

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