CONE-OF-VISION IMPACTS IN ROUNDABOUTS FINAL REPORT

Prepared for: Centre of Transportation Engineering & Planning

Prepared by:	Bunt & Associates Engineering (Alberta) Ltd.
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bunt & associates
TRANSPORTATION PLANNERS AND ENGINEERS

May 27th, 2010 Refer to File: 1122-03

Centre of Transportation Engineering & Planning
c/o Alberta Transportation – Technical Standards Branch
2nd Floor Twin Atria Building, 4999 – 98 Avenue
Edmonton, Alberta T6B 2X3

Attention: Mr. Neil Little, Executive Director

Dear Neil

Re: Cone of Vision Impacts in Roundabouts – Final Report

Please find attached the final report for the above-noted CTEP research project. This report includes the results of the analysis, key findings/conclusions, and corresponding recommendations.

Thank you for the opportunity to be involved with this interesting research project, and please call if you have any questions and/or wish to discuss any issue in further detail.

Sincerely,

BUNT & ASSOCIATES

Per:

Mike Furuya, M.Eng., P.Eng.,
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1.0 INTRODUCTION

1.1 BACKGROUND

Prior to the automobile, traffic circles were designed for aesthetic and military purposes[1]. Civic features such as fountains and other architectural features were commonly placed in the central island[2]. With the introduction of the automobile and its increasing popularity, the need to manage traffic congestion encouraged the use of traffic circles (later the large rotaries) as a traffic control device. By the 1930's, the traffic circle was a common intersection for managing traffic congestion. However, with the growth of traffic, the early traffic circles were exceeding the available capacity and were being replaced with other forms of traffic control (e.g., traffic lights).

Unlike the practice in North America, the British did not abandon the use of the traffic circle. In the 1950s, the British altered the rules of the road (i.e., yield on entry), which lead to the evolution of the modern roundabout. By the mid-70s, many countries including Australia were building yield on entry roundabouts. It would take an additional 20 years before the first modern roundabouts would be constructed in the North America. Since then, the modern roundabout is considered to be one of the designer's most effective tools to manage traffic congestion.

As the popularity of roundabouts increases as an effective means of controlling traffic and improving traffic safety, both public and private organizations are considering roundabouts as the preferred choice when compared to other types of traffic control (e.g., traffic signal). With this increasing popularity, urban planners and/or designers continue to use roundabouts as means to enhance the urban form within a particular development (both in the residential and commercial environments). Specifically, there is an increasing desire to place large urban features within the central island. However, with the presence of moving vehicles, the placement of urban features can obstruct the sightlines within the roundabout and therefore impact the overall safety within the roundabout (e.g., the placement of major obstacles such as large trees, concrete features, walls, etc… have caused fatalities and/or serious injuries). Although the placement of objects in the central island enhances the driver's awareness of the upcoming roundabout (or traffic control), the placement of large fixed objects within the central island is generally discouraged for safety reasons.

1.2 PROBLEM STATEMENT

As roundabouts become more attractive to city planners, there is a growing tendency to add features within the central island of urban roundabouts, which may or may not have safety implications. Based on the current practice, fixed urban features are not encouraged within the central island from a sight distance point of view. At present, the anticipated traffic volumes and design speed of the roundabouts primarily drive the design process. Discussions regarding stopping sight distance are related to the requirements for entering and exiting vehicles

[1] Evolution of Roundabout Technology: A History-based Literature Review, Edmund Waddell
[2] Synthesis of North American Roundabout Practice, TAC, 2008

and for vehicles traveling within the circulating roadway. As such, the area that does not impact the sight lines is highly dependent on the design speed and overall inscribe diameter of the roundabout. With this in mind, the current approach for verifying whether-or-not an urban feature would obstruct sight lines (or cone-of-vision) is an iterative (or trial and error) process.

Considering the current state of the industry, the development of a geometric model that aids in the establishment of setting boundaries for urban features (i.e., does not obstruct sight lines and outside clear zone) would be useful for guiding engineers and planners. With this in mind, Bunt & Associates hopes that this potential research project would add value to the industry and encourage a more critical review of the current practices associated with the application of sight distance requirements within roundabouts. To the best of our knowledge, this geometric model has not been developed by anyone.

1.3 STUDY OBJECTIVES

The objective of this research project is to assess the sight distance impacts and/or effects of placing urban features in the central island and to determine acceptable tolerances from a sight distance perspective. Specifically, Bunt & Associates' goal is to develop a geometric model that establishes a relationship between the placement of urban features within the central island and the inscribe diameter. This would formalize and may eliminate the current trial and error approach.

The corresponding study objectives are as follows:

1.3.1 Literature and Geometric Review

- Undertake a relevant but comprehensive research exercise aimed at understanding the state of the art if any, for developing a geometric model that establishes the relationship between the placement of fixed urban features and the inscribe diameter.

- Assess the impacts related to Human Factors, specifically the cone-of-vision while travelling through the roundabout.

- Review the collision performance/experience at roundabouts. Typically, failure to yield at entry, run off circulating road, and run into the central island are the three primary collision types normally observed at roundabouts. With this in mind, the objective of this review would be to determine if the lack of sight distance due to large urban features influences the collision types predominately observed at roundabouts.

- Review and assess the different types of sight distance requirements normally applied to roundabouts. (e.g., stopping sight requirements at the entry and exit points and within the circulating roadway). The intent of the review would be to verify the basis for assumptions (e.g., speed, critical gaps, etc…).

1.3.2 Development of Geometric Model

- Based on the data generated for the above task, develop a geometric model that establishes the relationship between the diameter of urban feature and sight distance, inscribe diameter (design speed), and clear zone requirements.

- Undertake a comprehensive review of the sight distance requirements for different sizes of roundabouts. The exercise would follow the typical requirements as outlined in the FHWA Roundabout Information Guide and consider the requirements associated with the critical gap (i.e., time and space requirements needed for vehicles to entry the roundabout from a stop and varying rolling speeds).

1.3.3 Model Validation

- Review existing roundabouts of different sizes. The intent of this will be to supplement the theoretical sight line analysis based on acceptable cones of vision (sight line) analysis. Bunt & Associates will specifically study four locally based roundabouts in Calgary as follows: 1) McKenzie Towne, 2) Garrison Woods, 3) Discovery Ridge, and 4) Lansdowne and 42nd Avenue.

- As part of this assessment, Bunt & Associates will obtain from the City any and all germane site plans (as built or block profiles) to establish the geometric features, description of central island features and its relationship to the inscribe diameter.

- Compare, calibrate and test the newly developed model against the four noted study roundabouts and assess the variances between the theoretical requirements and the in-situ conditions.

The analysis undertaken to complete these tasks is summarized in the remainder of this report.

2.0 LITERATURE AND GEOMETRIC REVIEW

2.1 OBJECTIVE

The intent of the literature/geometric review was to: 1) Gain an understanding of the geometric relationships between the placement of fixed urban features and the inscribe diameter, 2) understanding the risk associated with the operations of roundabouts, and 3) review the different types of sight distance requirements normally applied to roundabouts. This review of literature associated with this aspect of the project was extensive, including the suggested sources as well as design manuals, industry guidelines, and other sources as identified through this exercise. The specific sources included the following:

Guides

- Transportation Association of Canada (TAC)
- Quebec Ministere des Transports (MTQ)
- British Columbia Ministry of Transportation (BC MoT)
- Federal Highway Administration (FHWA)
- American Association of State Highway and Transportation Officials (AASHTO)
- Kansas Department of Transportation
- Washington State Department of Transportation

Industry Standards

- Institute of Transportation Engineers
- Transportation Research Board
- PIARC

The review of available literature outlined the basic principles/fundamentals and identified the geometric tools used to validate the required sight lines within a roundabout.

2.2 CENTRAL ISLAND AND LANDSCAPE CONSIDERATIONS

Roundabouts are defined as circulatory at-grade intersections. The modern roundabouts exhibit yield-at-entry and deflection of entering traffic concepts. One of the primary features of a roundabout is the raised central island, which encourages entering traffic to deflect to the right and enter the traffic stream at lower speeds. The size of the central island is function of optimizing capacity, safety, and the accommodation of the selected design vehicle. Typically, the central island is raised and may include a truck apron for larger vehicles (e.g., fire truck, transit bus, WB-20, etc…).

In some cases, landscaping is used to improve the conspicuity of the roundabout and/or used for aesthetic purposes (e.g., entrance features to/from a community). However, the placement of urban features can obstruct the sightlines within the roundabout and therefore impact the overall safety within the roundabout. Although the placement of objects in the central island enhances the driver's awareness of the upcoming roundabout (or traffic control), the placement of large fixed objects within the central island is generally discouraged for safety reasons. With this in mind, size and type of the landscaping features will be influenced by the sight distance requirements. The following sections describe the typical sight distance requirements for roundabouts.

2.3 SIGHT DISTANCE

To understand sight distance requirements within roundabouts, Bunt & Associates reviewed the different types of sight distance requirements and basic principles that are used to establish the minimum design requirements. Sight distance is defined as follows:

> *Sight distance is the distance along a roadway throughout which an object of specified height is continually visible to the driver. The distance is dependent on the height of the driver's eye above the road surface, specific object height above the road surface, and the height and lateral position of sight obstructions within the driver line of sight*[3]

In roundabouts, there are a number critical components that are required to ensure that adequate sight distance is provided within the roundabout, specifically: 1) approaching sight distance to the crosswalk locations, 2) the stopping sight distance within the circulatory roadway, 3) stopping sight distance to the crosswalk on the exit, and 4) the intersection sight distance to vehicles traveling in the roundabout.

[3] A Policy on Geometric Design of Highways and Streets (Green Book), AASHTO, 2004

2.3.1 *Stopping Sight Distance*

Sufficient stopping sight distance (SSD) should be provided to ensure that a vehicle (driver) travelling at design speed has adequate distance to stop the vehicle prior to an upcoming hazard. For the purpose of the research project, the specific SSD requirements for a given design speed are based on the methodology outlined the industry standards.

The basic fundamentals[4] are summarized here:

$$SSD = 0.278(t)(V) + 0.039\,(V^2/a)$$

Where: t = perception-reaction time (2.5s)

V = Speed (km/h)

A = deceleration (3.4 m/s^2)

In the case with roundabouts, stopping sight distance to the crosswalks (both at the entry and exit locations) and within the circulatory roadway is considered to be critical. It is important to note that the stopping sight distance on the circulatory road is the distance along the arc of the roundabout.

The critical SSD requirements are illustrated in Figure 2.1.

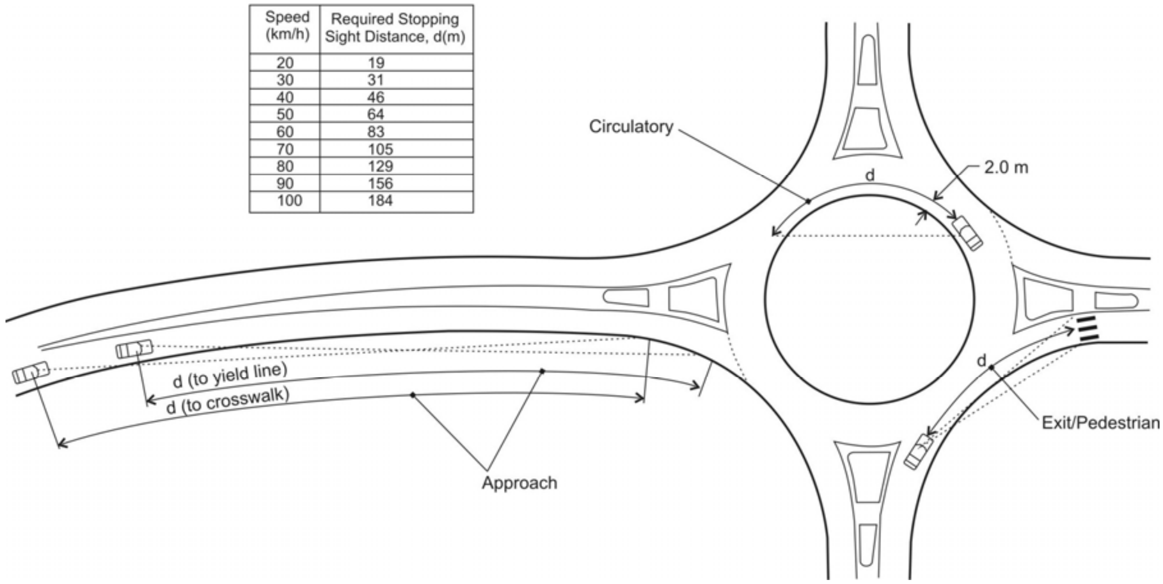
2.3.2 *Intersection Sight Distance*

Based on the operations at roundabouts (or rules of the road), motorists yield to vehicles within the circulatory roadway and enter the roundabout when there is a sufficient gap within the traffic stream. Past research has indicated that the driver will enter the traffic stream if the gap between vehicles is approximately 4.5 to 6.5 seconds, which translates to a sight distance requirement based on a given design speed.

Traditionally, departure and approach sight triangles are developed to ensure that adequate intersection distance is provided. In roundabouts, adequately intersection sight distance should be provided for approaching vehicles, as stopping sight distance to the crosswalks and within circulatory roadway adequately addresses the intersection sight distance for vehicles exiting the roundabout.

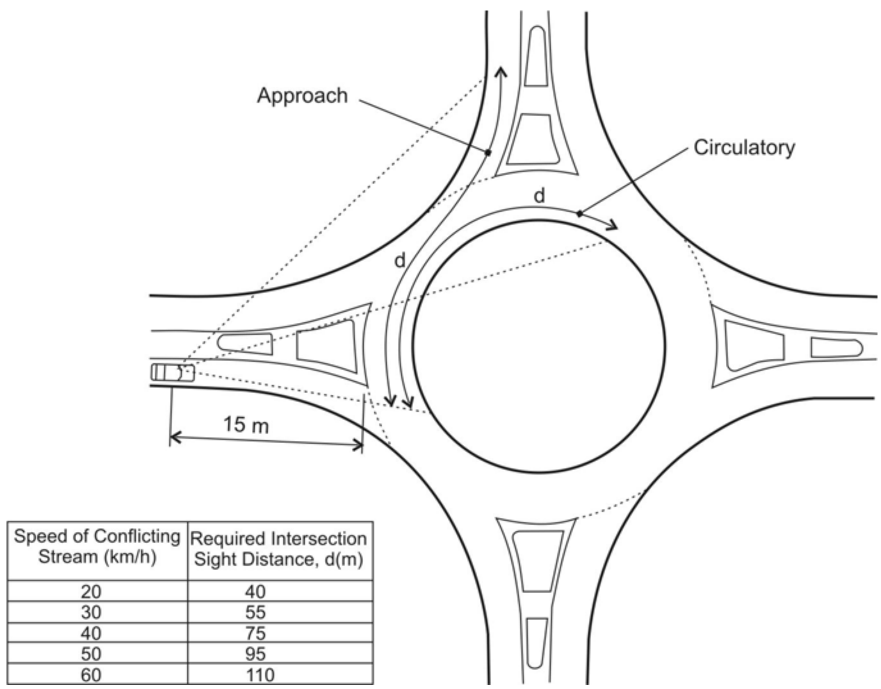
The typical intersection sight distance requirements at roundabouts are illustrated in Figure 2.2.

[4] Roundabouts: An Information Guide, FHWA, 2000



Speed (km/h)	Required Stopping Sight Distance, d(m)
20	19
30	31
40	46
50	64
60	83
70	105
80	129
90	156
100	184

Figure 2.1: Critical Stopping Sight Distance



Speed of Conflicting Stream (km/h)	Required Intersection Sight Distance, d(m)
20	40
30	55
40	75
50	95
60	110

Figure 2.2: Intersection Sight Distance Requirements at Roundabouts

2.4 DRIVER FIELD OF VISION

Given that the driving task is 90 percent visual[5], it is therefore critical that the motorists are provided with sufficient unobstructed sight distance to be able to react to upcoming road hazard. As outlined in TAC[6], if the driver field of vision (or cone-of-vision) is within 40 degrees (or 20 degrees on either side), the lateral vision it is considered to be adequate. Vision within a 10 degree cone-of-vision is considered to be excellent and therefore ideal for seeing objects or reading and understanding signage at optimum visual acuity.

As well, the results of the literature review also indicated that the driver's cone-of-vision is approximately 150 degree at 50 km/h[7]; however, the ability to see approaching objects clearly is significantly reduced beyond the 40 degree cone-of-vision[8]. That said, motorists traveling in roundabouts are negotiating a left hand curve, and based on the results of the human factors literature review[9], drivers tend to spend approximately 30 percent of their time looking at the inside edge line to obtain critical visual cues. The typical cone-of-vision limits are illustrated in Figure 2.3.

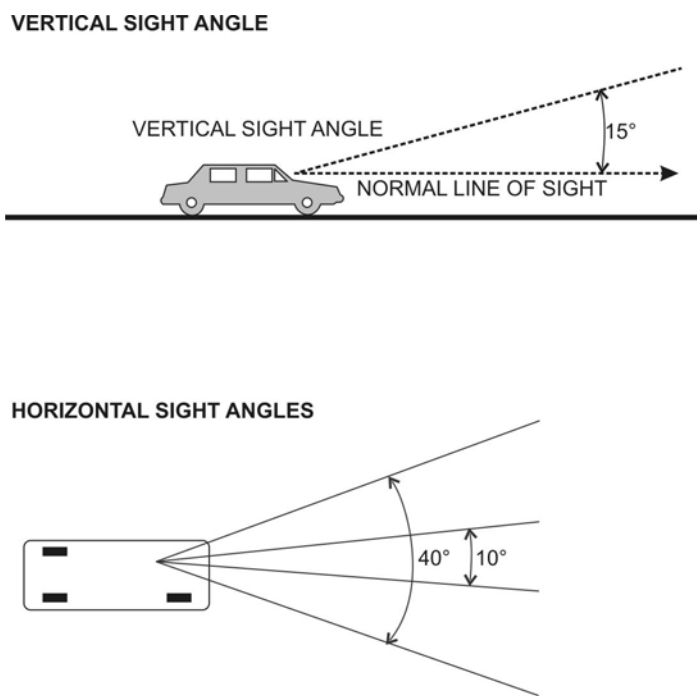


Figure 2.3: Driver Field of Vision

[5] The information the driver uses, Sivak, 1996
[6] Manual of Uniform Traffic Control Devices for Canada, TAC, 1998
[7] Human Factors in Traffic Safety, Robert Dewar and Paul Olson, 2002
[8] Transportation Engineering Handbook, ITE, 2003
[9] Driver Eye Fixations under Different Operating Conditions, Olson, Battle & Aoki, 1989

2.5 CLEAR ZONE REQUIREMENTS

In addition to the sight distance requirements, sufficient clear zone should be provided for the motorists to recover in the event they leave the circulatory roadway. Typically, clear zone requirements or widths are a function of speed, traffic volumes, and slope. In the case with roundabouts, the control speeds will be based on the fastest path through the roundabout.

Considering the typical operating speeds within a roundabout, the minimum clear zone requirement would be in the order of three (3) metres[10]. However, in the urban environment it may not be practical to provide the minimum clear zone requirements. Typically, streets in the urban environment that exhibit curbs and no shoulders, a minimum of 0.5 metres[11] should be provided for horizontal clearance (or clear zone). Ideally, large fixed objects such as statues and monuments should be placed outside the clear zone requirements. As well, trees within the clear zone should not exceed a mature diameter of 100 mm (4 inches)[12].

2.6 DESIGN GUIDELINE REVIEW

A review of selected design guidelines, specifically from municipalities throughout Canada and the United States, was undertaken as part of this research project. The intent of the review was to establish the types of tools and/or level of guidance that are provided to designers, specifically in the areas of sight distance and the placement of objects within the central island. Below is a list design manuals that were reviewed for this research project:

- Transportation Association of Canada (TAC)
- Quebec Ministere des Transports (MTQ)
- British Columbia Ministry of Transportation (BC MoT)
- Federal Highway Administration (FHWA)
- American Association of State Highway and Transportation Officials (AASHTO)
- Kansas Department of Transportation
- Washington State Department of Transportation

[10] A Policy on Geometric Design of Highways and Streets (Green Book), AASHTO, 2004
[11] Ibid
[12] Ibid

It is noted that the design principles applied in the international community (e.g., United Kingdom, France, Germany, Australia, etc…) were not included in this review. As the basis for the North America approach was sourced/built on the past experience of the European and Australian methodologies. With this in mind, Bunt & Associates considers the above-noted selected design manuals to be representative and therefore would reflect the current state of the industry.

This review focused on the overall design approach, design components associated with the Central Island and Sight Distance, and recommended tools. The results of the comparison review are summarized in Table 2.1.

2.7 SAFETY CONSIDERATIONS

Based on the basic design features (e.g., deflection, etc…) and traffic operations (yield on entry), roundabouts are considered to be one of the more effective traffic controls devices from traffic safety perspective. The reduced number of conflict points and lower operating speeds are the primary drivers for the popularity and desire to incorporate the roundabouts into the road network. Past research has indicated that with the introduction of roundabouts the crash experience at high risk locations (as compared to conventional intersections) could experience a crash reduction of 40 to 45 percent[13], with a significant reduction to the injury related crashes.

Although roundabouts are considered to be one of the safer traffic control devices, it however does not preclude that roundabouts are immune to traffic related crashes. With this in mind, Bunt & Associates undertook a review of the basic safety consideration that should be considered with the design of roundabouts. The primary objective for this review was to gain an understanding of the typical collision performance/experience at roundabouts, specifically collisions related to failure to yield at entry, run off circulating road, and run into the central island, and to determine if the lack of sight distance due to large urban features influences the collision types predominately observed at roundabouts.

The results of the review are summarized in Table 2.2.

[13] Traffic Safety Toolbox, ITE, 1999

Table 2.1: Design Element Comparison

Design Element	TAC	FHWA	AASHTO	Quebec	BCMoT	WSDOT	Kansas
Sight Distance	• No specific discussion	• Stopping sight distance should be provided at every entry point within, and on each entry and exit point. • SSD is define as d=0.278(2.5)(km/h)+ (0.039)(Km/h)^2/(3.4) • Eye height 1.08 m • Object height 0.6m • SSD along circulatory roadway is measured 2m from central island • Traditional sight triangle application to define ISD • ISD based on d=0.278(km/h)(6.5) • Measured 50 feet (15m) from yield line	• SSD is define as d=0.278(2.5)(km/h)+ (0.039)(Km/h)^2/(3.4) • ISD based on d=0.278(km/h)(t_c) • Eye height 1.08 m • Object height 0.6m	• Must be provided to the crosswalk and yield line and along the circular path, and is measured 2 m from the central island. • Minimum sight triangles are preferred – as larger sight lines promote higher speeds • Measured 15 m from yield line • ISD based on d=0.278(km/h)(6.5) • SSD refer to Tome I – conception routiere, Chapter 7 distances des visiblite	• No specific requirements – BCMoT has selected the 2003 Kansas Roundabout Guide as the primary resource	• Stopping sight distance and intersection sight distance must be provided • Momentary obstructions (such as poles and signposts) that do not hide the vehicles or VRUs is considered to be acceptable. • Equation for determining SSD and ISD based on FHWA and AASHTO • Traditional sight triangle application to define ISD • Critical gap 4.6 to 6.5 seconds • Measured 50 feet (15m) from yield line • SSD along circulatory roadway is measured 2m from central island	• Sight distance should be checked at a minimum of 3 locations: approach, within the circulatory road, and to the crosswalks • Design speed and fastest path are used to calculate sight distance requirements • Eye height 1.08 m • Object height 0.6m • SSD along circulatory roadway is measured 1.8m from central island • Equation for determining SSD and ISD based on FHWA and AASHTO • Traditional sight triangle application to define ISD • Critical gap 4.6 to 6.5 seconds • Measured 50 feet (15m) from yield line
Central Island/Landscaping/Clear Zone	• No specific discussion	• Landscaping will make the central island more conspicuous • Minimize hazards such as trees, poles, walls, guide rail, statues, or large rocks • Maintain adequate sight distances • Discourage pedestrian traffic through the central island • Perimeter of the central island should not be landscaped – width will vary – though a minimum of 2 m of clearance is recommended • Side slopes should not exceed 6:1	• Roundabouts provide an opportunity to provided attractive centerpieces. • Rigid objects should be avoided • Placement of the landscaping features should consider sight distance requirements	• Function of outside radius and width of circulating roadway • Key role in determining path deflection • Should contribute to visual recognition • Avoid fixed objects, discourages pedestrian crossing circulating roadway, and provides clear sight lines	• Refer to Kansas Roundabout Guide	• Landscaping of central island should improve visual impacts – sight distance requirements should be considered • Clear Zone requirements are based on fastest path through the roundabout • Sight distance checks should be overlaid onto a single drawing to determine clear vision areas • Landscaping should discourage pedestrian traffic through the central island	• Sight distance checks should be overlaid onto a single drawing to determine clear vision areas • Landscaping within the clear vision area should be limited to 2ft or 0.6 m • Fixed objects should be avoided. • Side slopes should not exceed 6:1 • Perimeter of the central island should not be landscaped – width will vary – though a minimum of 2 m of clearance is recommended

Table 2.2: Typical Safety Considerations

Safety Issues	Discussion	Type of mitigation measures
Failure to yield at entry to circulating vehicles	• This is the most common collision type. Some studies have shown that up to 37 % of the total crashes are related to this particular safety issue. • The combination of high entry geometry and sight distance greater than the minimum can increase the risk potential	• Increased defection before the yield line
Single vehicle runs off the circulating road	• Can be up to 20 to 40 % of total crashes • High entry path curvature (or little deflection) and entry speeds usually result in higher single vehicle crashes	• Attention to improving sight distance or visibility. • Increase deflection before the yield line
Single vehicle runs into central island	• Can be up to 20 to 40 % of total crashes • The intent of the central island is to encourage vehicles to deflect and reduce the overall operating speed. • To inform drivers of the upcoming traffic control, adequately visual cues, such as landscaping, should be provided. That said, the provided landscaping should not block the sight lines required for stopping sight distance.	• Slope should not exceed 6:1 and ideally the clear zone should be 2 to 5 m. Given that ideal clear zone requirements are typically restricted in the urban environment, all landscaping features should be frangible • Enhance the conspicuity of the central island • Remove hard obstacles from the central island • Increase deflection before the yield line • Ensure adequate stopping sight distance is provided
Shape of central island	• The shape of the roundabout can cause significant changes to the vehicles path and may encourage higher operating speeds through the roundabout, which increases the crash potential • Ideally the central island should exhibit a circular shape to promote a constant speed	• Should be circular in shape with a ratio of minor to major axis not less than ¾
Size of roundabout	• Central island diameter greater than 60 metres should be avoided. • The size of the central island is one of the key design elements in establishing the desired design speed. • Larger roundabouts tend to encourage higher operating speeds and tend to produce a roundabout that is less safe. • Past research suggest that capacity does increase beyond 20 m	• Develop smaller roundabouts to lower the operating speeds
Pedestrian-vehicle related collisions	• In most cases (specifically in North America), pedestrian safety in roundabouts is a perceived issue. • Roundabouts have poor accommodation for visually impaired. • Avoid the placement of fountains as they tend to mask the necessary auditory cues for visually impaired pedestrians and entice pedestrians to cross the circulatory road	• Ensure adequate sight lines are provided to all crossing locations • Provided splitter islands to provide refuge between the directional traffic
Bicyclist-vehicle related collisions	• Overlapping paths with motor vehicles are a typical cause • Most collision occur when cyclists is travelling through or exiting the roundabout • Cyclist are the most vulnerable road user • The placement of separate bicycle lanes should be avoided as the increase width increases vehicular speeds and place the cyclists on the critical conflict point at the exit.	• Provide option of traveling through or dismounting

2.8 DISCUSSION

- Intersections that have a higher safety performance (i.e., considered to be a low risk intersections) typically exhibit excellent visibility between all road users, provides sufficient information to make a decision and react accordingly, and accommodates the appropriate design vehicles. In order to achieve these types of characteristics, the roundabout should be sized to adequately accommodate build-out traffic levels, prompts lower operating speeds, and ensures that the both lateral and forward sight distance is provided to the critical visual cues.

- From a traffic safety perspective, a central island that has low visibility can induce unfamiliar drivers to make driver errors that may lead to a collision (e.g., run into central island features). As such, adequate visual simulation is required for motorist to understand the upcoming traffic control. It is noted that this particular observation applies to all types of traffic control devices.

- Based on the results of the literature review, excessive sight distance (or more then the required minimum) promotes higher entry and/or exit speeds. As such, features that restrict the sight distance to the minimum requirements are considered to the preferred approach.

- A review of the various guides confirmed that the development of the sight distance diagrams is essential to the design process. These diagrams are considered to be the primary (only) tool to verify the sight distance impacts associated with central island features. Both the Kansas and Washington State roundabout guides provide a schematic representation of how the minimum sight distance requirements may influence the type of urban and/or types of landscaping features that could be placed in the central island; however, no further detail was provided. In all cases, all of the guides lacked detailed discussion regarding the recommended areas (whereby anything could be placed in the central island) and/or tools/guidance that would aid in the process.

3.0 DEVELOPMENT OF GEOMETRIC MODEL

3.1 MODEL CONSIDERATIONS

The existing method of determining the availability of sightlines that meet sight distance requirements is trial and error in nature. While this method has produced the desired result, that is, allows the designer to pictorially evaluate the sufficiency of sightlines, it is considered to be time consuming. The ability to determine the size (diameter) of an urban feature through a mathematical formula is expected to reduce design time by providing the necessary initial size of an ornament, which can later be complemented by engineering judgment.

The roundabout is modeled as a continuous horizontal curve and urban features placed in the central island can obstruct driver's sightline. As with all horizontal curves, the integrity of sightlines has to be preserved so that adequate sight distance is available for seeing an obstruction that is either directly on the pavement surface or that is protruding onto the drive lanes. This is in addition to allowing for time to make a decision on how to react to the obstruction.

The single major consideration in this model is therefore the adequacy of sightlines within the peripheral view, which is also described as field of view or field of vision[14,15] of a driver. It is approximately 180 degrees in humans and represents the extent of the environment from which the eyes receive light. The peripheral view is known to include the binocular view, which extends about 140 degrees and is necessary for depth perception[16]. The remaining 40 degrees helps to detect objects outside the direct line of vision. Peripheral view is considered to be dynamic[17] because of the usual scanning of the environment by the driver. This allows an object outside of the 140 degrees to be brought into the binocular view. For the purpose of this analysis, the peripheral view with a limiting value of 180 degrees was used.

3.2 MODEL DEVELOPMENT

A number of elements were considered and were used as a basis for the model development, specifically: the size of obstruction to be removed from line of sight, the size of the inscribed diameter of the roundabout, the width of the driving lanes, the expected speed and the corresponding stopping sight distance. Of importance is the assumption that it is only the driver in the inner lane (in case of two lanes roundabout) that requires clearance from obstruction caused by an urban feature. These elements are summarized here:

- Size of Inscribed Circle: The minimum size of a roundabout's inscribed circle is partly dependent on whether the circulating roadway is single or double-lane. The general guidance is that the diameter of a single-lane roundabout be between 13.7-39.6 metres (45 and 130 feet) and 45.7- 61 metres (150 to 200 feet) for a double-lane roundabout.

[14] David Whyte, http://www.sciencebuddies.org.
[15] Douma, M. (2008). Peripheral Vision. Vision Science and the Emergence of Modern Art. http://wwww.webexhibits.org.
[16] http://en.wikipedia.org.
[17] Discussions with Dr Mike Boyer, Department of Psychology, University of Calgary.

- Lane width: Most road widths are designed as 3.5 to 3.7 metres with some modification for right lanes and ramps. In roundabouts, road width varies from jurisdiction to jurisdiction but they are generally between 4.2-5.8 metres (14-19 feet) for single-lane circulating roads. Double-lane circulating roads are generally between 8.8-9.8 metres (29-32 feet). The entry lane widths are somewhat narrower than the circulating roadway width.

- Circulating Roadway Design Speed: For a single lane roundabout, the design speeds typically ranges between 24 kilometres per hour (15 miles per hour) and 43.5 kilometres per hour (27 miles per hour). The minimum design speed for a double-lane roundabout is typically 35 kilometres per hour (22 miles per hour) and the maximum is in the order of 48 kilometres per hour (30 miles per hour). These are design speeds and are often different from the operating speed.

- Sight distance: When a driver is within the circulating road (inner if double), the minimum sight distance is the stopping sight distance. For this study, analysis is based on 4.5 seconds gap between circulating vehicles[18]. This is adequate for the 2.5 perception-reaction time minimum two seconds gap between vehicles. As discussed in the previous sections, this is the minimum time gap for determining stopping sight distance. When a vehicle is moving at a steady speed, the stopping sight distance is the product of the operating speed and the time required for the vehicle to come to a complete stop.

- Size of Obstruction to be Removed: Sight-distance restrictions on horizontal curves occur when obstructions are present that limit the available sight distance[19]. The size of obstruction on horizontal curve is estimated by determining the value of M_s (the mid ordinate of a curve that has an arc length equal to the stopping distance). This is illustrated in Figure 3.1.

M_s is theoretically given as:

$$M_s = R_v\left(1-\cos\left(\frac{90\ SSD}{\pi\ R_v}\right)\right) \quad \textit{Equation } 3.1$$

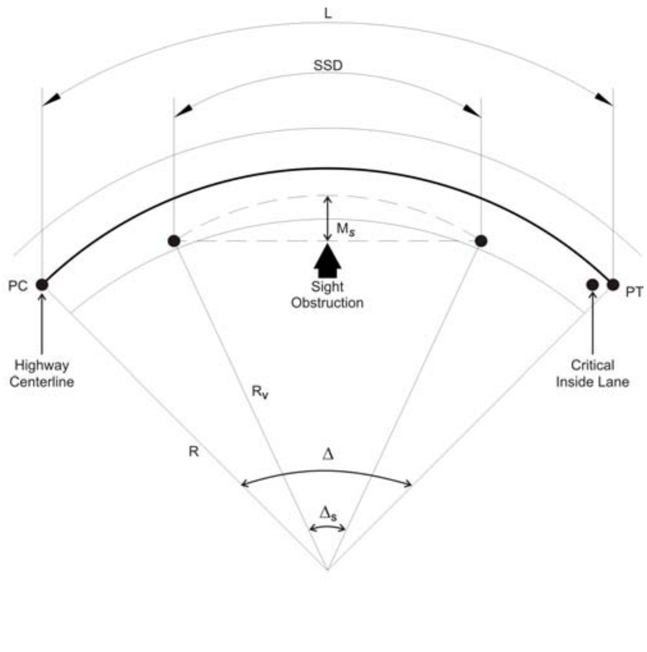
Where:

M_s = mid-ordinate necessary to provide adequate stopping sight distance (m)

SSD = stopping sight distance (m)

R_v = the radius of the vehicle's travel path, assumed to be the location of the driver's eyes for sight distance. It is generally taken as the middle of the innermost lane.

[18] It is noted that FHWA recommends 6.5 seconds gap, but this is only appropriate for vehicles from entry roads and not for those in circulation.
[19] Mannering, F.L and W. P. Kilareski. Principles of Highway Engineering and Traffic Analysis, Second Edition. New York: John Wiley and Sons, New York, 1998.



Source: Principles of Highway Engineering by Mannering, F.L., Washburn, S.S. and Kilareski, W.D.

Figure 3.1: Stopping Sight Distance for Horizontal Curves

3.2.1: Derivation of Diameter for an Urban Feature:

Equation 3.1 was used as a basis for establishing the value of the diameter of an urban feature within a roundabout. The various dimensions used in this derivation are illustrated in Figure 3.2.

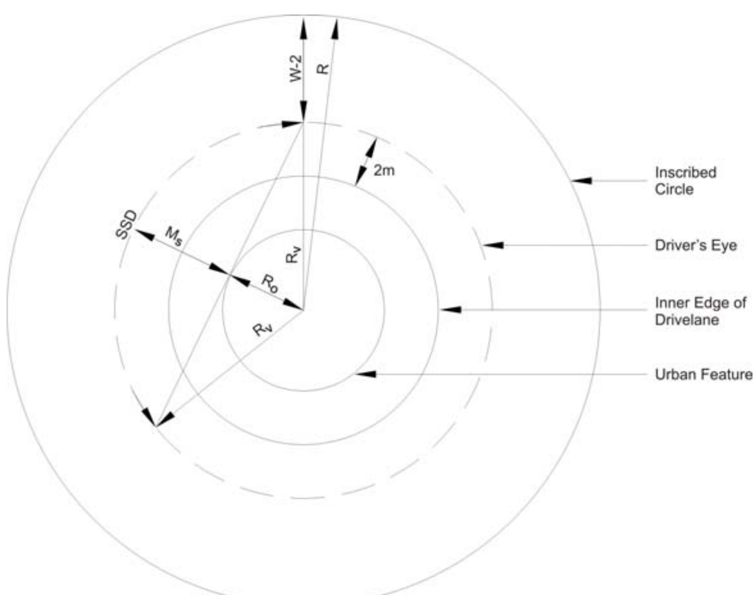


Figure 3.2:Roundabout Dimensions

From Figure 3.2,

$M_s = R_v - R_o$ *Equation 3.2*

Where,

R_o = radius of the urban feature (m).

Substituting Equation 3.2 in 3.1 gives,

$$R_o = R_v \cos\left(\frac{90\ SSD}{\pi\ R_v}\right) \quad \mathit{Equation}\ 3.3$$

In this derivation, the driver's eyes are assumed to be 2 metres away from the inner edge of the drive lane. It is noted that literature suggests half of the width of the drive lane for a simple horizontal curve, which would be approximately 1.8 metres.

If R_v is written as,

$R_v = R - w + 2$, and substituted in *Equation 3.3*, then

$$R_o = (R - w + 2)\cos\left(\frac{630\ SSD}{22(R - w + 2)}\right) \quad \mathit{Equation}\ 3.4$$

Where,

R = Radius of the inscribed circle (m).

W = width of circulating roadway (m).

By writing R as $D/2$, and D_o as $2R_o$

Equation 3.4 becomes,

$$D_o = (D - 2w + 4)\cos\left(\frac{630\ SSD}{11(D - 2w + 4)}\right) \quad \mathit{Equation}\ 3.5$$

Where,

D_o = diameter of the urban feature (m)

D = diameter of the inscribed circle (m)

Conditions: In order to obtain a practical solution to *Equation 3.5*, the following conditions are necessary.

(1) If D_o is negative, $D_o = 0$

(2) If $D_o < D-2w$, $D_o = D_o$

(3) If $D_o > D-2w$, $D_o = D-2w$

Condition (1) ensures that the angle subtended by the stopping sight distance from the driver's eyes is less than 180 degrees, that is, the stopping sight distance is within the peripheral view. Conditions (2) and (3) ensure that the diameter of the urban feature is not greater than the diameter of the central island. Figures 3.3 and 3.4 were developed using Equation 3.5 with conditions 1, 2 and 3 for single and double lanes roundabouts respectively. A set of tables was developed using the derived equation. The tables are included in Appendix A.

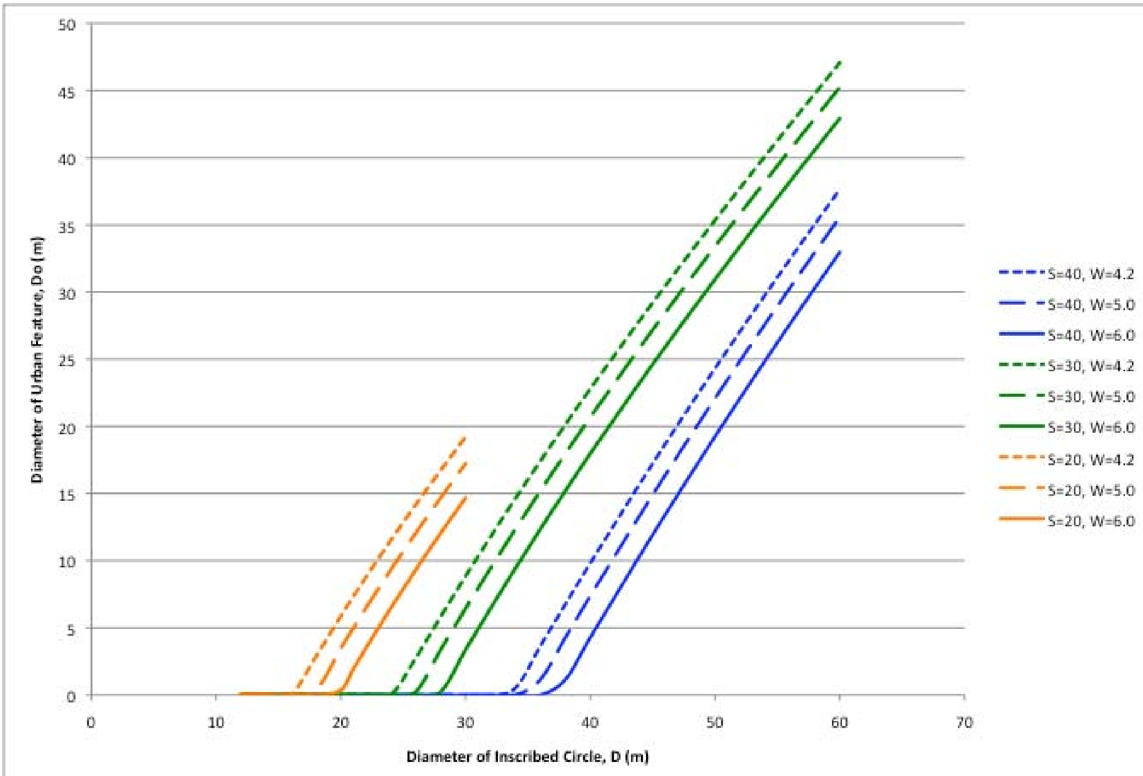


Figure 3.3: Single Lane Roundabout

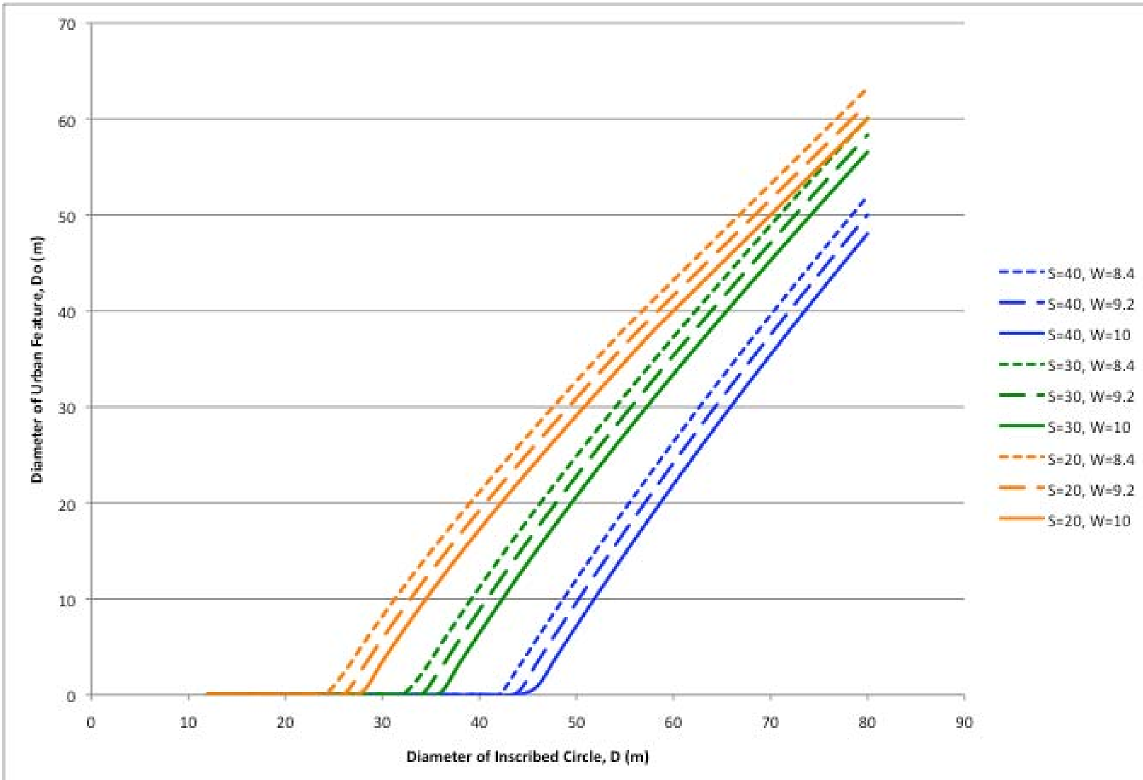


Figure 3.4 Double Lane Roundabout

3.3: MODEL VALIDATION

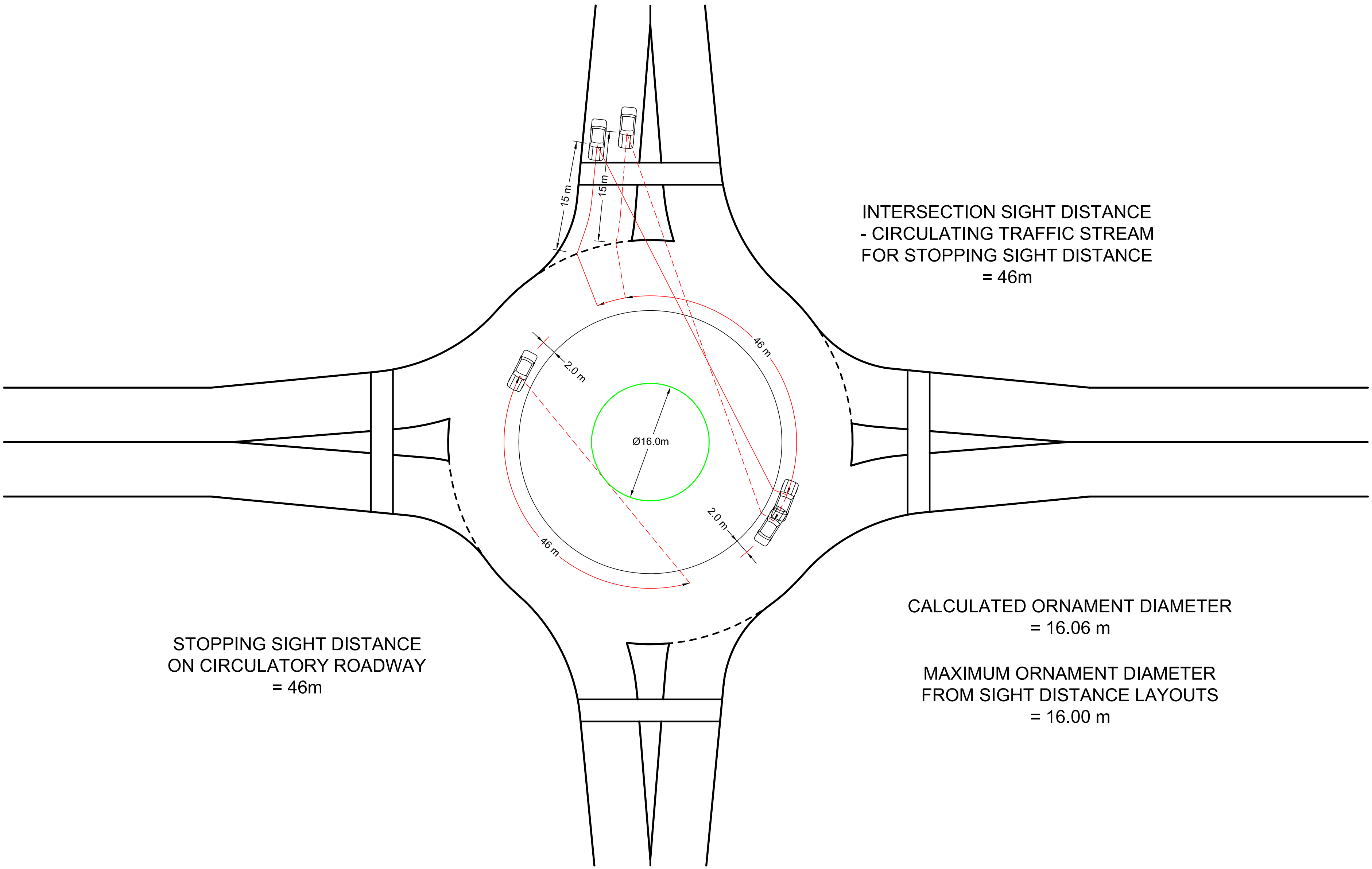
If the inscribed circle (D) of a double-lane roundabout is 55 metres and the width of the circulating roadway (w) is 9.6 metres. Estimate the diameter of an urban feature (D_o) that can be placed in the roundabout if the *SSD* is 46m and the speed is 40 kilometres per hour.

Solution: Using *Equation 3.5* (or charts – see Figures 3.3 and 3.4),

D_o = (55 -2*9.6 +4)*cos(630*46)/(11*(55-2*9.6+4))) = 16.06 m.

The maximum allowable diameter of the urban feature is estimated to be approximately 16.06 m and will accommodate a 46 metres sight distance. This sight distance will subtend an angle of 132.34 degrees from the centre of the roundabout. The angle subtended by the sight distance is less than 140 degrees and therefore within the binocular cone of vision.

For verification, the standard sight distance review (i.e., the manual CAD drawing approach or the typical trial and error methodology) was completed to confirm the results of *Equation 3.5* (or charts – see Figure 3.3 and Figure 3.4). As shown in Figure 3.5, the results of the trial and error approach confirmed that the maximum size of the ornament could exhibit an approximate diameter 16.0 m. Based on these results, the trial and error methodology (i.e., the current methodology) validates and/or confirms that the model is robust and is capable of providing the initial assessment of the size of an urban feature within a roundabout.



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Scale 1:750

Cone of Vision Impacts

Trial and Error Method

Exhibit

3.5

bunt & associates

4.0 CASE STUDY

4.1 EXISTING ROUNDABOUTS

In order to determine the practicality of the equation developed in Chapter 3, four existing roundabouts in the City of Calgary were analyzed. The City of Calgary provided the as built drawings for these roundabouts from which the diameters of the inscribed circles and urban features were determined. The evaluated roundabouts and their geometric characteristics are listed in Table 4.1.

Table 4.1: Observed Roundabouts

Location	Diameter of Inscribed Circle (m)	Number of Lanes	Width of Lane (m)	Urban Feature	Posted Speed (km/h)
Lansdowne	30.00	1	4.2	Landscape	30
Garrison Woods	38.40	1	9.2[20]	Sculpture	30
Discovery Ridge	60.00	1	10[21]	Rock Sculpture With Metal Fence	40
McKenzie Towne	80.00	2	10	Landscape	40

As shown in Table 4.1, the three single lane roundabouts have inscribed diameters that range between 30 m and 60 m. It is noted that the large range is a function of accommodating large trucks (truck apron) and/or transitioning between a single lane operation to a four-lane major roadway. The double-lane roundabout has an inscribed diameter of 80 m with drive lanes in the order of 10 m. Applying the derived relationship between the geometric elements and sight distance, the expected diameter of an urban feature in each of the four roundabouts was estimated in the section that follows. The data in Table 4.1 coupled with the posted speeds were used in the analysis. The results of the analysis are shown in Table 4.2.

4.2 SIZE OF URBAN FEATURE

As discussed previously, the size of an urban feature in a roundabout is dependent primarily on stopping sight distance; this in turn is dependent on the design speed of the inner lane of the roundabout. At higher speeds, longer stopping sight distances would be required to see, interpret and react to an obstruction within both the binocular and peripheral cones of vision.

[20] It is noted that the lane width exceeds the typical requirements for a single lane roundabout. The additional lane width is function of the design vehicle and its specific turning geometry requirements.
[21] Ibid

Table 4.2: Installed and Estimated Sizes of Urban Features.

Location	Diameter of Inscribed Circle (m)	# Lanes	Width of Lane (m)	Posted Speed (km/h)	Installed Diameter of Urban Feature (m)	Calculated Diameter of Urban Feature (m)
Lansdowne	30.00	1	4.2	30	18 Landscape	8.8
Garrison Woods	38.40	1	9.2[22]	30	3.5 Sculpture	5.8
Discovery Ridge	60.00	1	10[23]	40	15.5 -17.5 Stone Sculpture and Metal Fence	21.9
McKenzie Towne	80.00	2	10	40	50 Landscape	48

As shown in Table 4.2, the size of the landscape within the McKenzie's roundabout is almost the same as that indicated by the derived formula. It is recommended that a future urban feature for this roundabout should be less than 48 m in diameter. The size of the sculpture in Garrison Woods (3.5m) differs slightly from the calculated size of 8.8 m. Also, the size of the stone sculpture at Discovery Ridge (15.5-17.5m) is less than the estimated maximum of 21.9 m. It must be pointed out that it is generally okay to have smaller size of urban feature than estimated by the derived formula. When the urban feature is larger than estimated, the designer must ensure that the sight distance requirement is not violated.

4.3 SUMMARY

Four roundabouts of different sizes in the City of Calgary were evaluated. The sizes of urban features within them were compared with the estimated sizes. It was found that the diameters of urban features are almost equal to or lesser than the estimated sizes. This confirms that designers can use *Equation 3.5* to estimate the size of urban features to be placed in roundabouts. Care must be take when applying this formula directly to ensure that the urban features fall within the binocular cone of vision or at worst within the peripheral cone of vision.

[22] It is noted that the lane width exceeds the typical requirements for a single lane roundabout. The additional lane width is function of the design vehicle and its specific turning geometry requirements.
[23] Ibid

5.0 CONCLUSIONS

A method of evaluating the sizes of urban features in roundabouts was developed based on the cone of vision and stopping sight distance. The model was based on clearing obstructions along driver's sightlines as they drive along a horizontal curve. Existing methods used trial and error to establish the acceptable size of an urban feature to be placed in a roundabout. The developed model provided a relationship between the inscribed circle, width of the drive lanes, and stopping sight distance, which is a function of speed and the diameter of the urban feature.

As part of the deliverables, the report provided an easy to use equation with its boundary conditions, a graph that can be used in lieu of the equation and a comprehensive output in table format (see Appendix A) that can be used to determine the maximum size of an urban feature within a roundabout.

The equation developed was validated by the trial and error method and was found to be capable of predicting the sizes of urban features when geometric data are available. By applying the equation, it is expected that the iteration time would be reduced.

It is recommended that when this formula is applied, the resulting diameter is considered as the maximum value and not minimum. The sizes of the urban feature cannot be larger than calculated by the derived formula; they should be smaller than or equal to the calculated value.