Transportation Association of Canada

Synthesis of North American Roundabout Practice

December 2008

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TABLE OF CONTENTS

TABLE OF CONTENTS – CONTINUED

TABLE OF CONTENTS – CONTINUED

PAGE

TABLES

FIGURES

TABLE OF CONTENTS – CONTINUED

PAGE

APPENDICES

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EXECUTIVE SUMMARY

Modern roundabouts are circular intersections having their origins in the United Kingdom. Not to be confused with older traffic circles or rotaries, roundabouts are a more compact, safe and efficient form of intersection control being constructed in Canada in increasing numbers as an alternative to stop control or traffic signals.

This Synthesis of North American Roundabout Practice describes current practices and experiences with roundabouts. It forms an expanded counterpart to National Cooperative Highway Research Program (NCHRP) Synthesis 264, "Modern Roundabout Practice in the United States", published in 1998. The TAC synthesis contains the following chapters:

- Background Information
- Planning and Site Selection
- Design Methods and Guidance
- Design and Construction
- Safety Experience
- Operations Experience
- Rules of the Road
- Vulnerable Road Users
- Public Education and Acceptance
- System Considerations

Each section in a chapter presents a review of literature, for example roundabout guides and current practice, research and case studies, and is supplemented with selected international experience where appropriate. Next, each section outlines responses from a web-based survey of public road agencies in Canada and the United States on roundabout planning, design and operating practices. Finally, these two sources of information are synthesized into conclusions and, occasionally, suggested best practices.

A survey, conducted in the spring 2006, found a total of 59 modern roundabouts in seven Canadian provinces and territories and 459 roundabouts in 20 US states A total of 618 roundabouts are planned in these jurisdictions over the next five years. The classification of the existing and planned modern roundabouts is summarized in Table 1.

Most modern roundabouts in North America are single-lane designs in low-speed environments. Many of them may be in residential subdivisions. However, as Table 1 shows, an increasing number are being planned as multi-lane designs or on high-speed roads.

Table 1
Classification of Existing and Planned Roundabouts (All Jurisdictions Surveyed)

No. of Lanes on Widest Entry, Fastest Approach Speed	**Existing Roundabouts**		**Planned Roundabouts**	
	No.	**Percent**	**No.**	**Percent**
One lane, low speed	350	67%	293	48%
One lane, high speed	32	6%	80	13%
Two lanes, low speed	114	22%	173	28%
Two lanes, high speed	13	3%	50	8%
Three or more lanes, low speed	4	1%	8	1%
Three or more lanes, high speed	5	1%	14	2%
Totals	**518**	**100%**	**618**	**100%**

Roundabouts are usually constructed for three main reasons in order of their priority: safety benefits, capacity benefits, or environmental benefits. Safety benefits manifest themselves as a need for conflict or speed reduction. Capacity benefits display themselves as a reduction in delays or queues with corresponding access or land use benefits. Environmental benefits are produced by reducing fuel consumption and emissions or an improvement in local conditions or aesthetics. The main reason for constructing roundabouts in North America is still for greater intersection safety.

Some specific issues requiring further research were identified during the literature review and survey:

- A unified capacity model that closely relates geometry to capacity.
- Correlation of collisions with traffic volume and geometry.
- Collision prediction models for vulnerable road users.
- Conditions under which the circulatory road of a multi-lane roundabout should be marked, and quantification of the advantages and disadvantages of circulatory road marking in terms of lane consciousness and the space needs of trucks.
- Human factors testing on the use and recognition of special signs and markings for roundabouts, e.g. navigation signs, broken line versus “shark’s teeth” yield line markings, and standard versus “fishhook” lane designation signs and pavement arrows for multi-lane roundabouts.

Education is essential for increasing public acceptance of modern roundabouts and understanding how they operate. This is particularly the case with respect to rules of the road at multi-lane roundabouts. There have been some efforts to develop regulations and guidelines for roundabout use but a national campaign would greatly aid the widespread acceptance of roundabouts.

Modern roundabouts can have a wide variety of applications, from arterial corridors and highway interchanges to locations near signalized and unsignalized intersections, railway crossings, and access points. Survey experience in North America reveals most agencies are considering modern roundabouts not just as a special solution with limited applications, but as an alternative to traffic signals and stop controlled intersections.

In the United Kingdom, roundabouts are the default control at freeway terminals, four-way intersections and three-way intersections with sufficient side street traffic volumes. There, the engineering community considers traffic signals, at least in rural areas, to be dangerous, as they allow for the possibility of right angle collisions at high-speed. Stop signs are rare and require approval from the Department for Transport. The widespread use of Yield signs and roundabouts has resulted in a road network where, during off-peak periods, it is possible to travel long distances without having to stop. Despite this high level of mobility, the UK has the lowest rate of traffic fatalities among industrialized countries, with a collision rate significantly lower than Canada.

Select literature, published research, design guides and case studies concerning modern roundabouts are recommended for further reading.

Guides

1. Austroads, *Guide to Traffic Engineering Practice, Part 6 Roundabouts, 2nd Edition*, National Association of Australian State Road Authorities, 1993.

2. Brown, M., *State of the Art Review - The Design of Roundabouts*, Department of Transport, Transport Research Laboratory, 1995

3. Federal Highway Administration (FHWA) *Roundabouts: An Informational Guide*, 2000.

4. *Guide for the Design of Roadway Lighting, 2005 Edition*, DMD and Associates Ltd. for the Transportation Association of Canada

5. HMSO, Local Transport Note 1/94, *The Design and Use of Directional Informatory Signs*, 1994

6. Kansas Department of Transportation, *Kansas Roundabout Guide*, 2003.

7. Ourston Roundabout Engineering Inc, *Roundabout Design Guidelines*, 2001.

8. Quebec Ministère des Transports (MTQ), *Roundabouts: A Different Type of Management Approach*, 2005.

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10. Agg, H. *Directional Sign Overload*, TRL Project Report 77, United Kingdom, 1994.

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16. Maycock, G. and Hall, R. *Accidents at 4-Arm Roundabouts*, Transport Research Laboratory Report LR1120, United Kingdom, 1984.

17. National Cooperative Highway Research Program (NCHRP) Project 3-65, *Applying Roundabouts in the United States*, Status Report, July 2004

18. Persaud, B. et al, *Crash Reductions Following Installation of Roundabouts in the United States*, Insurance Institute of Highway Safety (IIHS), 2000.

19. Ritchie, S. and Lenters, M. *High Speed Approaches at Roundabouts,* National Roundabout Conference, Vail, Colorado, 2005.

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22. Service d'Études Techniques des Routes et Autoroutes (SETRA), Accidents en Carrefours à sens giratoire – étude d'enjou, France, 1999.

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24. Zegeer, C. et al, *Safety Effects of Marked Versus Unmarked Crosswalks at Uncontrolled Locations*, US Department of Transportation, FHWA, 2005.

Case Studies

25. Crown, R.B. *Entryway Roundabout: Review of Operation and Safety*, City of Clearwater, 2001.

26. Inman V. *Field Observations of Path and Speed at Double-Lane Roundabouts*, FHWA 2002.

27. Lenters, M. Safety Auditing Roundabouts, Annual Conference of the Transportation Association of Canada, Quebec City, 2004.

28. Ourston, L. *Wide Nodes and Narrow Roads*, TRB Annual Meeting, Washington, DC, 1993.

29. Sargeant, S. *Performance Evaluation of Modern Roundabouts on South Golden Road*, University of New Brunswick, 2002.

RÉSUMÉ

Le carrefour giratoire moderne est une intersection circulaire originalement conçue au Royaume-Uni. À ne pas confondre avec l'ancien rond-point, le carrefour giratoire offre un moyen de contrôle de la circulation plus compact, sécuritaire et efficace. Au Canada, il s'en construit de plus en plus en remplacement d'intersections avec signaux d'arrêt ou feux de circulation.

Le présent document, intitulé *Synthesis of North American Roundabout Practice* (Synthèse des pratiques liées aux carrefours giratoires en Amérique du Nord) propose une description des pratiques et des expériences courantes en matière de carrefours giratoires. Il constitue essentiellement la contrepartie plus détaillée du document *Synthesis 264 – Modern Roundabout Practice in the United States*, publié par le National Cooperative Highway Research Program (NCHRP) en 1998. Produit par l'ATC, ce nouveau document de synthèse contient les chapitres suivants :

- l'historique;
- la planification et la sélection des emplacements;
- les méthodes de conception et les lignes directrices;
- la conception et la construction;
- la sécurité;
- le fonctionnement;
- les règles de la route;
- les usagers de la route vulnérables;
- l'éducation du public et l'acceptation;
- les facteurs liés au système.

Chaque chapitre documente un aspect particulier des carrefours giratoires, incluant un aperçu des guides et pratiques courantes, de la recherche et des études de cas pertinents. Cet aperçu est suivi, selon le cas, d'exemples recueillis à l'échelle internationale. Vient ensuite un sommaire des résultats d'une enquête sur site Web effectuée auprès d'organismes publics du transport routier canadiens et américains au sujet des pratiques de planification, de conception et de fonctionnement liées aux carrefours giratoires. Enfin, l'ensemble des informations recueillies est synthétisé sous forme de conclusion et lorsque opportun, de pratiques exemplaires proposées.

Une enquête effectuée au printemps de 2006 a permis d'identifier un total de 59 carrefours giratoires modernes dans sept provinces et territoires du Canada et 459 carrefours giratoires dans 20 états des É.-U. De plus, on planifie l'aménagement de 618 nouveaux carrefours giratoires dans ces juridictions au cours des cinq prochaines années. Le Tableau 1 présente une classification des carrefours giratoires modernes existants et planifiés.

La plupart des carrefours giratoires modernes en Amérique du Nord sont à une seule voie, et se situent généralement dans des environnements à basse vitesse, notamment en milieu résidentiel. Cependant, comme le démontre le Tableau 1, un nombre croissant de carrefours giratoires à voies multiples sont planifiés sur des routes à grande vitesse.

Tableau 1
Classification des carrefours giratoires existants et planifiés (toutes juridictions recensées)

Nombre de voies sur l'entrée la plus large, vitesse d'approche la plus rapide	**Carrefours giratoires existants**		**Carrefours giratoires planifiés**	
	Nombre	**Pourcentage**	**Nombre**	**Pourcentage**
Une voie, basse vitesse	350	67 %	293	48 %
Une voie, haute vitesse	32	6 %	80	13 %
Deux voies, basse vitesse	114	22 %	173	28 %
Deux voies, haute vitesse	13	3 %	50	8 %
Trois voies ou plus, basse vitesse	4	1 %	8	1 %
Trois voies ou plus, haute vitesse	5	1 %	14	2 %
Totaux	**518**	**100%**	**618**	**100%**

Les trois principaux motifs cités pour l'aménagement de carrefours giratoires sont, en ordre d'importance, les avantages liés à la sécurité, au débit et à l'environnement. En matière de sécurité, les carrefours giratoires permettent de diminuer la vitesse de circulation et de réduire les conflits entre usagers de la route. En ce qui a trait au débit, ils permettent de réduire la congestion routière et le refoulement de la circulation aux intersections, ce qui comporte des avantages connexes en matière d'accès et d'utilisation des terrains. Les avantages liés à l'environnement se manifestent sous forme de réduction de la consommation de carburant et des émissions, ainsi qu'une amélioration de l'esthétique des lieux et des conditions locales. En Amérique du Nord, les carrefours giratoires sont le plus souvent aménagés en vue de rehausser la sécurité d'une intersection.

L'enquête et l'examen de la documentation ont permis de dégager certaines questions particulières requérant une recherche plus approfondie :

- Le besoin d'élaborer un modèle de capacité unifié qui relie étroitement la géométrie à la capacité.
- L'étude du rapport entre les collisions, la géométrie et le débit routier.
- Les modèles de prédiction des collisions pour les usagers de la route vulnérables.
- Les conditions en vertu desquelles la voie circulatoire d'un carrefour giratoire à plusieurs voies devrait être marquée, et la quantification des avantages et des inconvénients du marquage de la voie circulatoire en rapport à la prise de conscience de la voie et des besoins d'espace des camions.
- La vérification des facteurs humains liés à l'usage et la reconnaissance de la signalisation et des marquages de chaussée particuliers aux carrefours giratoires à plusieurs voies, p. ex., les panneaux de circulation, les marquages en ligne discontinue versus en ligne Cédez « en dents de requin », et les panneaux de désignation de voies standards versus « en hameçon » et les flèches sur la chaussée.

Il est essentiel de placer l'accent sur l'éducation en vue de favoriser l'acceptation des carrefours giratoires modernes par la population et d'accroître la compréhension de leur fonctionnement. Cela s'avère d'autant plus important en ce qui concerne les règles de la circulation routière dans les carrefours giratoires à voies multiples. On a documenté dans certaines régions des initiatives d'élaboration de directives et de règles d'usage liés aux carrefours giratoires. Toutefois, une campagne nationale contribuerait grandement à l'acceptation des carrefours giratoires par une plus grande proportion de la population.

Les carrefours giratoires modernes peuvent se prêter à une gamme variée d'applications, incluant les corridors artériels et les échangeurs autoroutiers, ainsi que les emplacements situés à proximité d'approches de carrefours avec ou sans feux de circulation, de passages à niveau et de points d'accès. Les résultats d'enquêtes effectuées en Amérique du Nord indiquent que la plupart des organismes concernés étudient la possibilité d'utiliser les carrefours giratoires modernes non seulement comme une solution particulière à applications limitées, mais comme solution de rechange aux intersections contrôlées par des panneaux d'arrêt ou des feux de circulation

Au Royaume-Uni, les carrefours giratoires constituent la solution d'usage pour le contrôle de la circulation aux points terminaux des voies rapides, aux intersections à quatre voies et aux intersections à trois voies où le débit routier des voies secondaires est assez élevé. En règle générale, les ingénieurs routiers britanniques estiment que les intersections avec feux de circulation présentent un danger, du moins en milieu rural, étant donné qu'ils se prêtent à des collisions à angle droit à grande vitesse. Les panneaux d'arrêt sont rares et exigent l'approbation du ministère des Transports. L'utilisation répandue des signaux « Cédez » et des carrefours giratoires a eu pour effet la création d'un réseau routier où, en dehors des heures de pointes, il est possible de parcourir de longues distances sans devoir s'arrêter. Malgré ce haut niveau de mobilité, le R.-U. possède le taux le plus bas de mortalité de la route parmi les pays industrialisés, avec un taux de collision considérablement plus bas que celui du Canada.

À ceux qui désirent approfondir davantage leur connaissance des enjeux liés aux carrefours giratoires modernes, les auteurs proposent la lecture des ouvrages, rapports de recherche, guides de conception et études de cas suivants :

Guides

1. Austroads, *Guide to Traffic Engineering Practice, Part 6 Roundabouts, 2nd Edition*, National Association of Australian State Road Authorities, 1993.

2. Brown, M., *State of the Art Review - The Design of Roundabouts*, Department of Transport, Transport Research Laboratory, 1995

3. Federal Highway Administration (FHWA) *Roundabouts: An Informational Guide*, 2000.

4. *Guide de conception des systèmes d'éclairage routier, édition 2005*, DMD and Associates Ltd. au nom de l'Association des transports du Canada

5. HMSO, Local Transport Note 1/94, *The Design and Use of Directional Informatory Signs*, 1994

6. Kansas Department of Transportation, *Kansas Roundabout Guide*, 2003.

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10. Agg, H. *Directional Sign Overload*, TRL Project Report 77, United Kingdom, 1994.

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16. Maycock, G. and Hall, R. *Accidents at 4-Arm Roundabouts*, Transport Research Laboratory Report LR1120, United Kingdom, 1984.

17. National Cooperative Highway Research Program (NCHRP) Project 3-65, *Applying Roundabouts in the United States*, Status Report, July 2004

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22. Service d'Études Techniques des Routes et Autoroutes (SETRA), Accidents en Carrefours à sens giratoire – étude d'enjou, France, 1999.

23. Weber, P and S. Ritchie, *Internationally Recognized Roundabout Signs*, TRB National Roundabout Conference, Vail, Colorado, 2005.

24. Zegeer, C. et al, *Safety Effects of Marked Versus Unmarked Crosswalks at Uncontrolled Locations*, US Department of Transportation, FHWA, 2005.

Études de cas

25. Crown, R.B. *Entryway Roundabout: Review of Operation and Safety*, City of Clearwater, 2001.

26. Inman V. *Field Observations of Path and Speed at Double-Lane Roundabouts*, FHWA 2002.

27. Lenters, M. Safety Auditing Roundabouts, Congrès annuel de l'Association des transports du Canada, Québec, 2004.

28. Ourston, L. *Wide Nodes and Narrow Roads*, TRB Annual Meeting, Washington, DC, 1993.

29. Sargeant, S. *Performance Evaluation of Modern Roundabouts on South Golden*

1.0 BACKGROUND

TRAFFIC CIRCLES AND MODERN ROUNDABOUTS

Modern roundabouts had their origins with traffic circles. Traffic circles were originally built as civic features that terminated vistas and incorporated fountains, monuments and various architectural features. They became an integral part of the North American transportation network after the Columbus Circle, designed by Philip Eno, opened in New York City in 1905. Numerous traffic circles, and later rotaries, were built in Canada and the United States in the following decades.

Although the terminology is imprecise, we refer to traffic circles as having intersecting roads arranged radially about the circle. Columbus Circle and l'Arc de Triomphe in Paris are examples. They require drivers to enter facing the central island, then turn while in the circle to go around it. Rules about right of way are vague. Rotaries, in contrast, allow drivers to enter to the right of the central island on a tangent at high speed. Circulating drivers yield to those entering, or each have their own lanes and weaving takes place. In either case, lengthening the distance between successive entries and exits increases capacity. The trade-off is that rotaries became large, fast and unsettling to drive. There are also numerous hybrid traffic circle/rotary intersections where, for example, north-south traffic can enter at high speed while east-west traffic enters facing the central island and yields on entry. Capacity is still limited because some circulating traffic is stored in the circle. These hybrids are usually called traffic circles.

Most traffic circles and rotaries have been reconstructed or replaced. An example of a large rotary being replaced with a roundabout in Kingston, New York, is shown in Figure 1.1. The smaller modern roundabout is proving to be safer and has more capacity than the former rotary.

In the United Kingdom circular intersections were never abandoned but were refined through research. Experiments with varying designs were continuously conducted to resolve operational and safety issues, and in 1966 the "yield at entry" rule was introduced, creating the first modern roundabout. Further experiments to improve capacity and safety were conducted in the 1970s, by which time roundabouts were being implemented in Australia and France and, eventually in other European countries. Today, there are several thousand modern roundabouts in the UK and France, with hundreds more in Germany, Switzerland, Sweden, Norway, the Netherlands, Australia, New Zealand, Israel, and dozens of other countries. The first modern roundabouts in North America were constructed in the US in the early 1990s.

Table 1.1 summarizes the differences between modern roundabouts and traffic circles (or rotaries), as adapted from a 2005 guide published by the Québec Ministère des Transports.

Figure 1.1
Rotary Being Replaced With Modern Roundabout, Kingston, New York

Photo: New York Department of Transportation

Table 1.1
Comparison of Modern Roundabouts and Traffic Circles

Characteristics	Modern Roundabouts	Traffic Circles
Entry Control	Entering vehicles must yield. Circulating vehicles have priority.	Entering vehicles have priority. Some traffic circles use Stop signs or traffic signals.
Splitter Islands	Installation is required.	Installation is optional.
Parking	Parking is not allowed in the circulatory road or on the approaches.	In large traffic circles parking is allowed within the circulatory road.
Pedestrian Access	Pedestrian access to the central island is strongly discouraged. Pedestrians can cross only behind the yield line.	Pedestrian access is sometimes allowed to the central island.
Deflection	Deflection at entries force approaching vehicles to slow down.	No deflection is required at entries, which are perpendicular or tangential to the circulatory road. This encourages high speeds at entry.
Turning Movement	All vehicles circulate counter-clockwise around the central island.	At mini-traffic circles, left-turning vehicles can sometimes pass to the left of the central island.

Source: *Roundabouts: A Different Type of Management Approach,* Ministère des Transports du Québec, 2005

An informational guide on roundabouts published by the US Federal Highway Administration in 2000, known hereafter as the "FHWA guide", classifies modern roundabouts into six categories: mini-roundabouts, urban compact, urban single-lane, urban double-lane, rural single-lane and rural double-lane. While it should be noted that roundabouts can combine features from different categories, mini-roundabouts are different from other modern roundabouts because they have a fully mountable central island. Also, modern roundabouts can have more than two-lane entries and rural roundabouts tend to be larger and designed for higher prevailing speeds on the approaches, when compared to their urban counterparts.

THE TAC SYNTHESIS

This synthesis consists of a literature review of North American guidelines, research and case studies related to modern roundabout practice, as well as the results of a 2006 survey of roundabout experience from public road agencies across North America. In this document the terms modern roundabout and roundabout are used interchangeably. When a circular intersection is not in conformance to modern roundabout operating principles, it is referred to herein as a non-conforming rotary or traffic circle.

Each section in a chapter presents a review of literature, for example modern roundabout guides and current practice, scientific research and case studies, and is supplemented with selected international experience where appropriate. Next, each section outlines the survey responses and notes where the described practice is supported by responding agencies. The two sources of information are synthesized into conclusions and, occasionally, suggested best practices. Lists of specific references are cited at the end of each chapter and a general list of references is contained in a bibliography of North American sources at the end of the report, which readers are encouraged to review as an extension of this report.

This synthesis builds upon the 1998 U.S. National Cooperative Highway Research Program (NCHRP) Synthesis 264, *Modern Roundabout Practice in the United State.* NCHRP Synthesis 264 presented information on the planning, design and operation of modern roundabouts in the United States through an extensive literature review and the results of a survey of nine state departments of transportation representing 38 existing or planned roundabouts.

To prepare this TAC synthesis, 109 public road agencies across North America were asked to respond to a web-based survey on modern roundabout planning, design and operating practices. The survey included provincial and state level governments as well as municipal, county and regional governments.

Responses were received from 59 agencies, yielding a response rate of 54% for the survey. Approximately 500 modern roundabouts across North America were identified in the survey. Most were located in the US in Colorado, Florida, Kansas, Maryland, Washington, Wisconsin and Utah. Canada reported 59 modern roundabouts, mostly in Quebec and British Columbia, in the following context: 46 roundabouts are one-lane, low speed, 1 roundabout is one-lane, high speed (over 70 km/h), 10 are two-lane, low speed, and 2 are two-lane, high speed (over 70 km/h).

A copy of the survey, and a list of the agencies that responded, are included in Appendix A of this report.

SURVEY RESULTS

The geographic distribution of the agencies surveyed was as follows:

- Western United States: 35%
- Midwestern United States: 20%
- Central and Eastern Canada: 13%
- Western Canada and Prairies: 11%
- Northeastern United States: 11%
- Southern United States: 10%

Greater significance was given to responses from agencies with more experience, as indicated by the complexity of their modern roundabout projects and the volume of past experience. These agencies are likely developing heuristics as a basis of formulating best practices.

In order to categorize the responses according to this criterion, agencies were asked to classify the existing roundabouts in their jurisdictions by number of lanes on the widest entry, and the fastest approach speed. Approach speeds were considered high if over 70 km/h, although a distinction between posted speeds or actual operating speeds was not sought. During the survey, the information about existing roundabouts was taken into account to weigh the responses. Coefficients used in weighing the importance of a respondent's feedback were as follows:

- Roundabout with one lane, low speed: 1
- Roundabout with one lane, high speed: 1.5
- Roundabout with two lanes, low speed: 2
- Roundabout with two lanes, high speed: 2.5
- Roundabout with three or more lanes, low speed: 3

- Roundabout with three or more lanes, high speed: 3.5

Three groups of respondents were identified. The first group were those jurisdictions with a total "sum" of 10 and higher, called the "high" group. The second group were those jurisdictions with a total "sum" between 1 and 10, and the third group were those jurisdictions with no experience in modern roundabout practice. For each part of the survey, the responses to questions were analyzed with and without separation into these categories.

It should be noted that for many questions, the survey results did not add to 100%, as these questions could be responded to with more than one answer.

The survey found that 51 agencies have at least one modern roundabout in their jurisdiction. Accounting for experience using the weighting factors, 18 agencies had a total "sum" of 10 and higher. The top 3 were West Jordan, Utah with a total sum of 132.5, Washington State with a total sum of 103.5, and Colorado Springs, Colorado with a total sum of 32.0. These were considered the "high" group. There were 33 jurisdictions with a total sum between 1 and 10, indicating limited experience with modern roundabouts. Examples were Brandon, Manitoba, Vail, Colorado, and St. George, Utah. There were 58 agencies that either did not complete the survey or reported no existing modern roundabouts in their jurisdictions.

It should be noted that in ranking the level of experience of an agency, the survey did not take into account the duration of that experience and thus may have overlooked the importance of long time observations of certain roundabouts. Avon, Colorado, is an example of such a jurisdiction where there are fewer modern roundabouts than, say, West Jordan, Utah, but the roundabouts have been in place since 1997.

Questions 5 to 8 had responses as follows:

5. Most of the existing modern roundabouts had been constructed at Local or Collector Road Intersections, or Arterial Road Intersections. About half that number of agencies reported constructing them at Freeway Ramp Terminals and Highway Intersections.

6. Most of the existing modern roundabouts had been constructed at intersections previously under stop control. Fewer had been constructed at new intersections, and the fewest had been constructed at intersections previously under traffic signal control.

7. According to the agencies surveyed, there are currently 518 modern roundabouts in their jurisdictions, and 618 modern roundabouts planned over the next 5 years. The classification of these modern roundabouts is summarized in Table 1.2.

   Of the 518 existing modern roundabouts in the survey, 73% are single-lane and 27% are multi-lane. Of the 618 modern roundabouts planned by these jurisdictions, 61% are single-lane and 39% are multi-lane.

8. Similar to reports of existing modern roundabouts, most of the planned roundabouts will be constructed at Local or Collector Road Intersections, or Arterial Road Intersections, with about half that number of agencies planning to construct them at Freeway Ramp Terminals and Highway Intersections.

INTERPRETATION AND CONCLUSIONS

In 1997, through NCHRP Synthesis 264, a survey was conducted of US state departments of transportation, Canadian provinces, and US municipalities and counties known to have modern roundabouts. At that time, nine US states (California, Colorado, Kansas, Maine, Maryland, Massachusetts, Mississippi, New Jersey, and Vermont) reported having roundabouts in operation, under construction, or in the design process. Information was received on 31 modern roundabout sites, representing 38 individual modern roundabouts. No Canadian road agencies reported having any modern roundabouts at that time.

A total of 518 existing modern roundabouts were identified in the survey conducted through this synthesis. This represents an increase in modern roundabout usage in North America of well over 100% per year in the nine years since NCHRP Synthesis 264. The 518 modern roundabouts are in 20 states and seven provinces or territories. In Canada there is at

least one modern roundabout in Alberta, British Columbia, Manitoba, Ontario, Prince Edward Island, Quebec, Saskatchewan, Nova Scotia and the Yukon Territory.

Table 1.2
Classification of Existing and Planned Modern roundabouts (All Jurisdictions Surveyed)

No. of Lanes on Widest Entry, Fastest Approach Speed	**Existing Modern Roundabouts**		**Planned Modern Roundabouts**	
	No.	**Percent**	**No.**	**Percent**
One lane, low speed	350	67%	293	48%
One lane, high speed	32	6%	80	13%
Two lanes, low speed	114	22%	173	28%
Two lanes, high speed	13	3%	50	8%
Three or more lanes, low speed	4	1%	8	1%
Three or more lanes, high speed	5	1%	14	2%
Totals	**518**	**100%**	**618**	**100%**

Most modern roundabouts in North America are single-lane designs in low-speed environments. Many of them may be in residential subdivisions. However as Table 1.2 shows, an increasing number are being planned as multi-lane designs or on high speed roads.

Following completion of the survey an additional response was received on behalf of agencies in British Columbia reporting there are over 30 modern roundabouts in BC. The Insurance Corporation of British Columbia helped to develop 20 of them. Although no further survey details were provided, it is recognized that agencies in BC have significant collective experience compared to other Canadian provinces, with the exception of Quebec.

REFERENCES

1. Quebec Ministère des Transports (MTQ), *Roundabouts: A Different Type of Management Approach*, 2005.

2. Federal Highway Administration (FHWA) *Roundabouts: An Informational Guide*, 2000.

3. Jacquemart, G. *Modern Roundabout Practice in the United States*, National Cooperative Research Program (NCHRP) Synthesis 264, 1998.

2.0 PLANNING AND SITE SELECTION

REASONS FOR USING MODERN ROUNDABOUTS

Modern roundabouts can be considered when planning a new intersection or modifications to an existing intersection or interchange, in response to congestion or safety problems. There are numerous reasons to consider roundabouts:

- **Safety:** Modern roundabouts have been proven to reduce the number and severity of collisions compared to stop control or traffic signals. More information on safety experience at roundabouts is provided in Part 5.
- **Traffic calming:** Roundabouts can function as traffic calming measures by reducing vehicle speeds through geometric design. Roundabouts have also successfully been used at the transition between rural and urban, or high-speed and low-speed areas as their presence informs drivers of a change in the driving environment.
- **Improved access:** Because of lower speeds, access does not have to be restricted to the same extent close to roundabouts compared to traffic signals. Roundabouts can facilitate safe U-turns. A roundabout at either end of a commercial corridor can be used for U-turns, and a small number of all-moves driveways in between the roundabouts can be converted to a larger number of right turns only accesses. Queues are usually shorter with roundabouts, and can therefore be less likely to impact nearby access driveways or structures such as overpasses or underpasses.
- **Intersection efficiency and reduced vehicle delay:** Roundabouts usually operate with lower delays than other forms of intersection control. When there are queues on one or more approaches, traffic within the queues usually continues to move and is more tolerable to drivers than a stopped or standing queue.
- **Environmental factors:** Although no reliable methods of comparison are currently in use, it is likely roundabouts reduce fuel consumption and lessen vehicle emissions by reducing vehicle delays, acceleration/deceleration, and time spent idling.
- **Aesthetics:** Roundabouts can offer opportunities for landscaping and creating gateways or centrepieces for communities.

Roundabouts treat all movements at an intersection equally in terms of right of way priority. Drivers on each approach are required to yield to circulating traffic, regardless of whether the approach is a local street or major arterial. For this reason roundabouts can generate less overall delay, fuel consumption and emissions than traffic signals depending on traffic volumes and distribution between the major and minor roads. In many cases, roundabouts operate more efficiently than fixed-time signals. According to the FHWA guide, semi-actuated signals can operate more efficiently than roundabouts if minor road volumes are low. However, when volumes increase, actuated signals tend to operate more like fixed-time signals. Roundabouts tend to be most efficient when the major and minor road traffic volumes are approximately equal, although intersections with unequal volume distributions should not be precluded from consideration for roundabouts as there may be other benefits, such as safety.

In terms of costs, compared to signalized intersections roundabouts do not require power for signal equipment, periodic light bulb and detection maintenance and regular signal timing updates. They continue to function during power failures. Depending on the landscaping provided, roundabouts can have higher landscape maintenance costs. Illumination costs for roundabouts and signalized intersections tend to be similar.

PLANNING AND SITE SELECTION

Agencies have indicated a variety of additional considerations that should be taken into account when assessing the suitability of modern roundabouts.

- **New versus existing intersections:** New locations offer more flexibility for the designer and there are fewer issues with utilities, access management and traffic control. Existing locations usually offer a constrained site with design challenges, the potential for compromised operations due to design trade-offs, and potential complexity and cost issues with utilities and traffic control. However, existing locations also offer the potential for the modern roundabout to solve an actual capacity or safety problem.
- **Urban versus rural intersections:** Rural locations tend to be isolated with lower traffic volumes, higher approach speeds and fewer right-of-way impacts. Urban locations tend to be the opposite, and may be close to other intersections.
- **Local history:** A location can be close to other roundabouts where the public recognizes and accepts them. A location can also represent the first roundabout in an area, requiring greater emphasis on public outreach and education. A location can be in an area with real (or even perceived) bad experience with roundabouts, necessitating extensive effort to correct previous mistakes and overcome misconceptions.

It can be difficult to determine whether a roundabout will be effective, or whether a single-lane or multi-lane roundabout will be required, based on traffic volumes alone, without undertaking a capacity analysis. This is because the proportion of right turns or left turns in the entering traffic streams can greatly impact the capacity of a roundabout. Capacity analysis methods and the link between capacity and geometry are discussed in Part 3. Vehicle queuing in relation to corridors and modern roundabout interchanges is discussed in Part 10.

According to the *Kansas Roundabouts Guide* (2003), roundabouts are often advantageous over other types of traffic control at the following locations:

- Intersections with historical safety problems.
- Roads with excessive speeds, or where traffic calming is desired.
- Intersections with high traffic volumes during peak hours but relatively low traffic volumes during non-peak hours.
- Intersections with relatively balanced traffic volumes.
- Intersections with a high percentage of turning movements.
- Existing two-way stop-controlled intersections with high side-street delays (particularly those that do not meet signal warrants).
- Intersections that must accommodate U-turns.
- Intersections where widening one or more approach may be difficult or costly, such as at overpasses or underpasses.
- Intersections where traffic growth is expected to be high and future traffic patterns are uncertain.
- Locations where the speed environment of the road changes (i.e. between urban and rural areas, or residential and commercial uses).
- Intersections that form a gateway or entry to a neighbourhood, commercial development or urban area.

There are location and site conditions that can be problematic for installing roundabouts. Some constraints can also be problematic for other intersection alternatives as well. According to the 2003 *Kansas Roundabouts Guide*, problematic site conditions, such as those listed below, should not necessarily preclude a roundabout from consideration, but should warrant extra caution:

- Locations in close proximity to a signalized intersection where queues may spill back into the roundabout.
- Intersections located within a coordinated arterial signal system, as roundabouts can disrupt traffic platoons.
- Intersections with a heavy flow of through traffic on the major street opposed by relatively high traffic on the minor street.
- Intersections having one-way streets or reversible traffic lanes.
- Locations with steep grades and unfavourable topography that may limit visibility and complicate construction.

- Intersections with heavy bicycle volumes.
- Intersections where visually impaired pedestrians are expected.

These indications or contra-indications for roundabouts as articulated in the Kansas guide can also be found in most other guides.

Often the most appropriate means to determine whether a new intersection could be constructed as a roundabout, or an existing intersection converted, is to undertake a formal study that compares a roundabout with traffic signals. The survey of practice found that many agencies are using business cases to compare traffic control alternatives. Quantitative comparisons can include safety performance, capacity analysis or operational performance, capital costs, and life-cycle costs. More qualitative comparisons can include provisions for vulnerable road users, emergency response, maintenance, traffic control and construction staging, corridor considerations, public education and acceptance, environmental impacts, and aesthetics.

A consolidated summary of performance measures for such a comparison is listed in Table 2.1, which was prepared for the State of Wisconsin to aid in selecting criteria and depth of study. The summary was prepared in response to concerns over studies becoming too elaborate in some cases, and too simplistic in others where more rigorous review was warranted.

Several jurisdictions employ a checklist approach to screening location needs and verifying the feasibility of roundabouts. One road authority in Ontario, the Region of Waterloo, requires a Traffic Control Study comparing modern roundabouts and traffic signals under the following conditions:

- At all new or existing intersections where traffic signals are warranted or expected to be warranted in the future.
- At existing intersections where capacity or safety problems are being experienced.

Table 2.1
Performance Measures for Intersection Alternatives Assessment

Performance Measure	**Priority and Level of Effort**	
Quantitative Criteria	**Minimum Study**	**Additional In-Depth Study**
Safety	Collision Frequency Reduction (Injury + Fatal Crashes/Year)	Present Value of Annual Collision Savings
Capacity	Level of Service, Delay, Queue Reach	Delay vs. Time Cost
Construction	Construction Year Costs	Economic Analyses With Project Life Cycle Assessment
Right-of-Way	Cost Assessment	Future Development Opportunities
Maintenance	Signals Maintenance vs. Roundabout Marking, Lighting	Present Value of Life Cycle Cost
Construction Staging	Cost/Complexity	Detailed Planning and Costing
Geometry	Design Vehicle Space, Stopping Sight Distance, Intersection Sight Distance, etc.	
Railways	Queuing Distance, Crossing Duration	Equipment Costs
Access Management	Driveway Location and Restrictions	Development Yield Impacts
Qualitative Criteria	**Minimum Study**	**Additional In-Depth Study**
Users	Pedestrians, Bicyclists, Mobility or Visually Impaired Persons	
School Sites	Crossing Guard Requirements, Crossing Locations	
Transit	Stop Locations	
Emergency Services	Ease of Response	
Air Quality	Emissions Based on Delay Comparison	Cost of Fuel and Pollution Load Comparison
Environmental Impacts	Natural, Social Impacts	Detailed Environmental Inventories
Aesthetics	Cost and Visibility	

Source: Ourston Roundabout Engineering, Inc.

The New York State Department of Transportation (NYSDOT) requires that modern roundabouts be constructed at all new intersections on the state highway system unless it can be proven that an alternative, such as traffic signals, is preferred for capacity or safety reasons. The Ministry of Transportation in British Columbia recently implemented a similar policy, where a roundabout must fail the needs test to be rejected before other alternatives are considered.

SURVEY RESULTS

In Part 2 of the survey conducted as part of this synthesis project, agencies were asked to identify the main reasons for constructing or planning roundabouts, what had determined the need for roundabouts, and why had some sites been rejected as candidates for roundabouts.

1. Greater safety was the main reason cited for constructing modern roundabouts (43% of all responses and 83% of the "high" group). Other popular reasons included delay or queue reduction, speed reduction/traffic calming, and unusual intersection layout. Among the jurisdictions with high numbers of modern roundabouts, 39% cited requests from the public as a reason. A request from the public was cited in only 9% of the responses for those jurisdictions with less than 10 modern roundabouts. Of Canadian agencies, 46% cited greater safety and 27% cited delay or queue reduction as the rationale for using a modern roundabout.

2. The main determinant of the need for a roundabout was traffic volumes or capacity analyses. Collision history was also an important factor, as was the construction of a new intersection.

3. The main reason cited for intersections being rejected as candidates for roundabouts was insufficient space or right-of-way, followed by traffic volumes too high. Public opposition was cited as a cause of rejection for 56% of those jurisdictions with a high number of roundabouts.

INTERPRETATION AND RECOMMENDATIONS

Modern roundabouts are usually constructed for one or more of three key reasons: safety, capacity, or environmental benefits. Safety benefits manifest themselves as a need for conflict or speed reduction. Capacity benefits manifest themselves as a reduction in delays or queues with corresponding access or land use benefits. Environmental benefits manifest themselves as a reduction in fuel consumption and emissions or an improvement in local conditions or aesthetics.

As found in the NCHRP Synthesis 264, improving safety is currently the main reason for constructing roundabouts in North America. Another important consideration is to increase capacity or lessen delays and queues. The third consideration is environmental benefits. With increasing concerns over greenhouse gas emissions, the price of fuel and the reliability of power supplies, environmental reasons may play an increasingly important role in the consideration of modern roundabouts in the future.

With regard to site selection, it is recommended that sites within a jurisdiction with known capacity or safety problems be considered for roundabouts first. Success at these sites will make future roundabout projects within that jurisdiction easier to initiate.

REFERENCES

1. Federal Highway Administration (FHWA) *Roundabouts: An Informational Guide*, 2000.

2. Rodegerdts, L. Presentation at Minnesota Roundabouts Conference, Minneapolis, Minnesota, 2006.

3. Kansas Department of Transportation, *Kansas Roundabout Guide*, 2003.

3.0 DESIGN METHODS AND GUIDANCE

It is recognized that some agencies in North America develop simple roundabout designs intended for low volume applications without any capacity analysis. Once traffic volumes are significant, most agencies undertake a modern roundabout capacity analysis as part of the design process. Based on survey responses from agencies with extensive roundabout experience, such as Quebec, Colorado, New York, Washington and Wisconsin, the emerging design method is to "model it first, draw it next". These agencies recognize the need to identify traffic constraints and model the relationship between capacity and geometry before developing a modern roundabout layout. This design method requires patience and discipline to withstand iterations of modelling capacity, drawing a layout, then refining the layout. The Association québécoise du transport et des routes (AQTR) teaches this "model it first, draw it next" method in their advanced modern roundabout design course. Accordingly, significant emphasis has been placed on analysis methods and research that lead to development of design parameters to lay out modern roundabout geometric designs.

CAPACITY ANALYSIS METHODS

Modern roundabout capacity is measured entry by entry, as a function of entering and circulating traffic streams that conflict for movement priority. There are two main roundabout capacity analysis methods in use in North America. The analytical method estimates entry capacity based on gap acceptance theory. The empirical method estimates entry capacity based on regression equations from field data. The main outputs of these capacity analysis methods are average and maximum delay. Unlike volume to capacity (V/C) ratio, delays relate most directly to a user's perceived level of service at a roundabout.

The empirical capacity method was developed by the Transport Research Laboratory (TRL) in the United Kingdom, as documented in LR942 published in 1980 by Kimber. It uses linear regression to best-fit observed entry and circulating flows based on direct measurement at 86 roundabouts with a wide range of geometric parameters operating at capacity, and further test track runs at the TRL facilities. Kimber originally sought to develop a gap-based model to predict modern roundabout capacity, but realized that other capacity mechanisms were also taking place at the modern roundabouts under observation.

The empirical model relates the capacity of an entry to the circulating flow past that entry, plus the effect of six geometric parameters: inscribed circle diameter (ICD), entry width, road half width, effective flare length, entry radius and entry angle. Following the initial research, the methods were validated to confirm the suitability of the parameters. The most recent was in the UK at 35 modern roundabouts in 1997, which concluded that no changes to the original linear regression equations were necessary.

There are two empirical capacity methods used in France. The method for rural areas was developed by SETRA in 1987, and the method for urban areas was developed by CETUR (now CERTU) in 1988. The underlying research is based on counts during saturated periods at 45 modern roundabouts. The two models are similar in that they express entry capacity as a function of impeding flow (as opposed to circulating flow in the UK and Australian methods). The impeding flow is a summation of circulating flow plus a proportion of the exiting flow at the same leg of the intersection.

In Australia, the analytical method based on gap acceptance theory is used. It is described in the 1993 Australian roundabout design guide (Austroads Part 6), and is based on research in 1989 by Troutbeck. Headways are calculated as a function of the diameter of the roundabout, the number of entering lanes and circulating lanes, and the circulating flow. Critical acceptance gaps (the minimum gap for entry) are dependent on the follow-up time, the circulating flow, the number of circulating lanes, and the average entry lane width. Useful gaps (long enough for a vehicle to enter) are dependent on the proportion of vehicles that are bunched and the portion of non-bunched vehicles.

The Australian capacity methodology as applied to modern roundabouts is similar to the gap acceptance methodology used in the *Canadian Capacity Guide* (CCG) and the *Highway Capacity Manual* (HCM) for signalized and unsignalized intersections.

Capacity analysis models have been developed in other countries, such as Germany and Switzerland. While the analytical procedures of the methods from the various countries are not overly complex, they are repetitive and time consuming, so most have been made practical by employing computer programming as found in software packages such as RODEL and ARCADY in the UK, GIRABASE in France, and SIDRA (now aaSIDRA) in Australia.

Simulation models such as CORSIM, VISSIM and PARAMICS can be used to model roundabout capacity, but in most cases their underlying methodology or accuracy for roundabouts has not been proven. They can be useful in illustrating roundabout operation through their animation procedures.

Pedestrians and bicyclists can be accounted for in some of the roundabout capacity analysis methods. Both can affect motor vehicle capacity in high enough volumes. References in the FHWA guide verify that pedestrian volume must be well over 100 per hour before any effect on capacity is noticed. Counterintuitively, during peak times pedestrians have little effect on vehicular capacity because pedestrians can cross between vehicles queued at the yield line. In other words, during these times pedestrian capacity is greater than yield line capacity.

OPERATIONAL ANALYSIS AS THE BASIS FOR DESIGN (NCHRP REPORT 572 IN THE UNITED STATES)

The National Cooperative Highway Research Program undertook a study of roundabouts between 2003 and 2005. The study developed a set of operational, safety and design tools for roundabouts using a small sample of US field observations. Their findings regarding capacity of some US roundabouts will likely be incorporated into the next edition of the US *Highway Capacity Manual* (HCM). The NCHRP Report 572 safety findings are discussed in Part 5. The operational findings from the May 2006 draft report are presented and discussed in this chapter.

The database on which the operational findings are based draws on approximately 300 minutes of observations of entering and circulating traffic at 31 modern roundabouts in 2003. The authors acknowledged that the capacity data set was not robust enough to corroborate some of the features of roundabout capacity that other more intensive research had revealed. Studies of roundabout capacity in countries having more experience with roundabouts are based on larger data sets. For example, the set used to develop the UK capacity model consisted of over 10,000 minutes of at-capacity operation for a multitude of roundabout configurations from minis to large circles with four-lane entries.

The July 2004 status report for NCHRP 572, but not the May 2006 draft report, discussed the merits and concerns associated with the analytical (gap acceptance) and empirical methods as the basis for a roundabout capacity analysis method for the US. With respect to a gap acceptance model, the status report notes the following concerns:

- Whether the distribution of gaps in traffic streams is truly random.
- Inconsistent gap acceptance occurs in practice. For example, a driver may reject a large gap only to accept a smaller gap later. There are various reasons for this, including inattention and pressure from other drivers.
- Estimation of a critical gap is difficult. Further, the value that applies in one location or period in time may not apply in others.
- Geometric parameters and their effects on roundabout operations are not directly taken into account.

With respect to empirical regression models, the status report mentions that such models take into account the influence of geometric parameters automatically and that details about driver behaviour are unnecessary, but it notes the following limitations:

- Such models may have poor transferability to other countries.
- They provide no real understanding of the underlying traffic flow theory.
- Creation of an accurate model that also includes the effects of geometric parameters

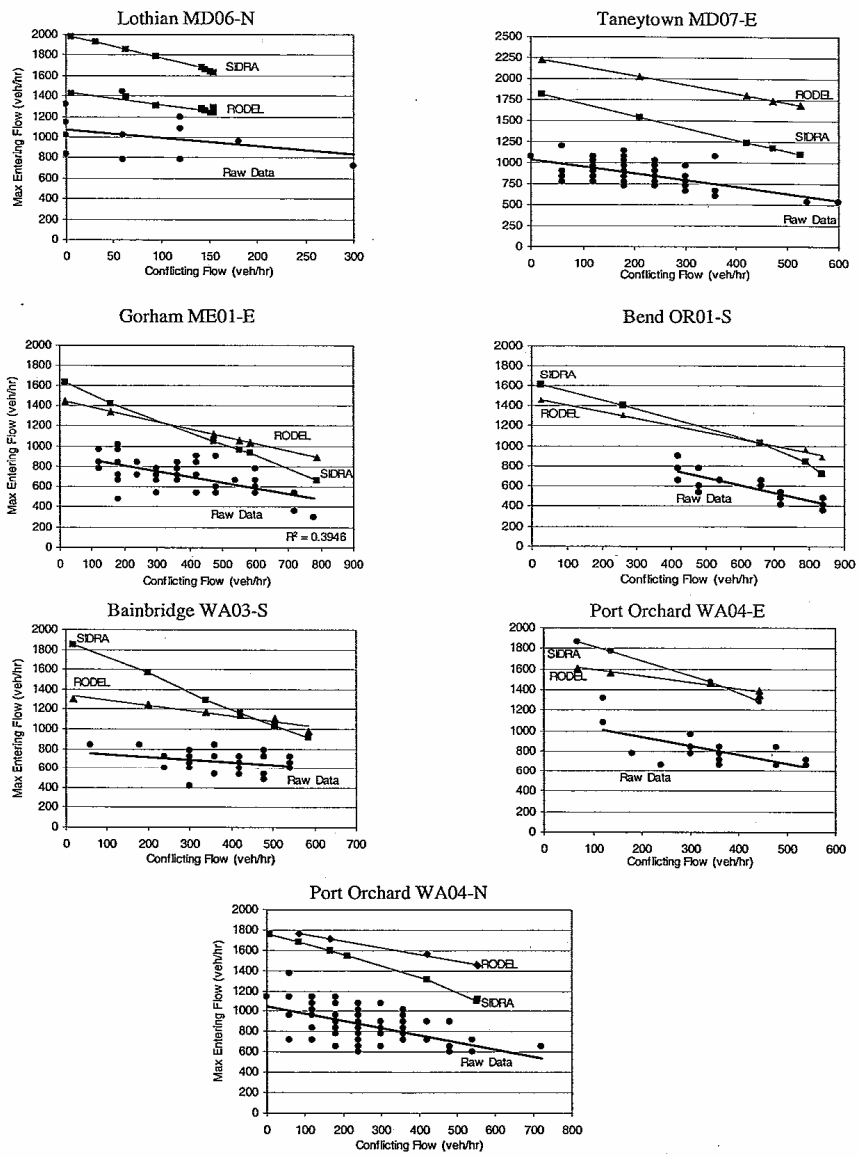
must be based on saturated conditions. This requires sites with continuous queuing and varying geometric parameters operating at capacity for sustained periods of time, something that has is not happening in some of the North American modern roundabouts.

- The data collection effort required is large and expensive.

The US sample, graphs of maximum entering flow versus circulating flow for the actual field data were developed and compared to the aaSIDRA and RODEL predictions. Examples are shown in Figure 3.1.

The data observed in the field indicated the roundabouts were not operating near their capacities using either model. The authors of the study opine that some of the roundabouts were not experiencing sustained at-capacity conditions sufficient to develop the operations that were predicted.

Figure 3.1
Actual and Predicted Entry Capacities from NCHRP 572



Source: NCHRP 572 Draft Report, May 2006

The capacity lines generated with aaSIDRA and RODEL are both higher than the actual data, although the slope of the line generated using RODEL follows the actual data more closely. In consultation with the authors it was suggested that RODEL could be calibrated for North American conditions by adjusting the y-intercept of the capacity lines. If a method of calibration is proposed initially to model a future horizon year, it is possible that by the time the forecast traffic levels are realized driver familiarity will have increased to the point where model results will eventually be observed without the need for calibration.

The authors acknowledge that over time as familiarity with roundabout operation increases, along with traffic volumes, the roundabouts observed in the initial study will develop higher capacities. Such a phenomenon is consistent with historically observed trends in capacity at freeway facilities and signalized intersections, although is has not been observed thus far through NCHRP 572.

The May 2006 draft report proposes capacity models for single-lane roundabouts and for the critical lane of two-lane roundabouts based on a calibration of the actual data collected during the study. They are dependent on critical and follow-up headways as per a gap acceptance methodology, but do not include the effects of any geometric parameters.

For single-lane modern roundabouts, the study generated an equation to calculate entry flow using:

$$q_{e,max} = 1130\ e^{-0.0010qc}$$

Due to a lack of data for two lane entries and due to the fact that most of the time the modern roundabouts observed did not exhibit saturation of both lanes, a capacity method employing the concept of a critical lane was generated. For the critical lane of two lane entries, entry flow can be found using the equation:

$$c_{crit} = 1230\ e^{-0.0008qc}$$

where $q_{e,max}$ = maximum entry flow (vph);
c_{crit} = maximum entering flow of the critical lane (vph); and
q_c = circulating flow (vph).

The NCHRP 572 operational findings are likely to be incorporated into the next edition of the HCM. The draft roundabout chapter of the HCM provides some discussion of the limitations of the NCHRP 572 database. It mentions that simple gap acceptance models may not capture all the observed behaviour at roundabouts, and that more complex gap acceptance models that incorporate headway modification, gap forcing and priority reversal are difficult to calibrate. It states that, “Based on recent analysis of US field data, simple, lane-based, empirical regression models are recommended for both single-lane and double-lane roundabouts.”

The draft chapter of the HCM does not specify whether the empirical models should incorporate any specific geometric parameters, nor is there significant geometric variation among the roundabouts in the NCHRP 572 data set. It also notes there are few roundabouts in the US exhibiting sustained at-capacity operation. Because of these reasons, and the time and cost involved in producing a robust empirically based regression model, the HCM is expected to adopt the models proposed in NCHRP 572.

DESIGN GUIDES

In 1995 Ourston and Doctors (now Ourston Roundabout Engineering, Inc.) published *Roundabout Design Guidelines*, the first roundabout design guide for North American practice. Prepared for Caltrans, the guide was never released as a State guide. It is largely a reprint of the UK Department for Transport design guide TD 16/93 and it follows the UK empirical methodology and recommends ARCADY and RODEL for capacity analysis. The guide addresses geometric design from mini-roundabouts to roundabouts with four-lane entries.

The first guide to be published by a state agency was *Roundabout Design Guidelines* (Maryland Department of Transportation, 1995). It follows the gap acceptance methodology currently in use in Australia, and recommends the use of SIDRA for analysis. It suggests appropriate and inappropriate use of roundabouts and provides information for both single-lane and multi-lane implementation.

The *Florida Roundabout Guide* (Florida Department of Transportation, 1998) i recognized for its detailed section addressing roundabout justification and appropriateness. It deals with a variety of issues but concentrates on single-lane roundabouts. The guide follows

the gap acceptance methodology used in Australia, and after presenting a comparative review of SIDRA and RODEL concludes that a gap model is superior for design and appropriate for analysis.

Modern Roundabouts for Oregon (Oregon Department of Transportation, 1998) examines the available roundabout guides from the UK and Australia, as well as the Maryland and Florida guides, and supplements the findings with recent studies and recommendations for Oregon.

The FHWA publication *Roundabouts: An Informational Guide* (FHWA, 2000) s the most widely known and used guide in North America. It offers design advice based on information gathered from a number of countries, including the UK, Australia, France and Germany, as well as information on policy development and planning. There has been a tendency for many road authorities to reference the FHWA guide as a design guide or design standard. However, as its title suggests, it is an informational guide.

The states of Arizona, California, Kansas, Missouri, New York, Pennsylvania, Washington, Wisconsin and Utah have since published roundabout design guidelines or bulletins. The majority of the guides are short documents that act as a supplement to the FHWA guide, or list certain exceptions to the guide. They present more current studies, and allow a state to set their own policies such as using a specific software package for analysis.

The Kansas and Wisconsin guides are detailed documents that are good supplements to the FHWA guide in that they provide how-to information on multi-lane design, circulatory road striping and illumination that is not otherwise covered.

In Canada modern roundabout guides are largely a selective extraction from other US and European guides. The following is a summary of Canadian guides:

- A section on modern roundabouts has been added to TAC's 1999 *Geometric Design Guide for Canadian Roads* that contains information on geometric elements and capacity, generally based on UK experience, and safety in North America. The guide is currently being updated to include a design domain section.
- *Roundabouts: A Different Type of Management Approach* was published by the Quebec Ministry of Transport in 2002 and released in English in 2005. The Quebec guide generally follows the outline of the FHWA guide, but adds experience in France and from roundabouts installed in the US and Quebec.
- The BC Ministry of Transportation issued a technical bulletin on the planning and design of roundabouts in 2003. The bulletin draws from the FHWA guide and French sources, and highlights UK and continental Europe design practices (discussed in the next section).

Table 3.1 lists some of the guides in use in North America, and indicates whether they are supported by software and provide for various design checks.

U.K. AND CONTINENTAL EUROPE DESIGN

In the UK, many roundabouts were built or modified during the 1970s when alleviating traffic congestion was seen as a priority. Also, the UK has a traffic density much higher than many neighbouring countries, and thus higher traffic volumes for most intersections. Most modern roundabouts in the UK have entries and exits that are multi-lane or that flare at the roundabout to provide extra lanes for high capacity in a compact space.

When modern roundabouts were constructed in other European countries such as France and Germany during the 1980s, less of a priority was placed on achieving high capacity and more was placed on maximizing safety for all users. Therefore modern roundabout designs in continental Europe tend to be single-lane and have geometric characteristics that emphasize safety over capacity. Table 3.2 summarizes some of these differences.

Table 3.1
Comparison of Selected Roundabout Guides in North America

Guide and Date of Issue	Capacity Method(s)	Software	Design Checks	Comments
Ourston, 1995	▪ UK (empirical)	▪ RODEL ▪ ARCADY	2,3,7,8,10,11	Design checks 4,5,6,9 not included.
Maryland, 1995	▪ Australian (gap acceptance)	▪ SIDRA	2,3,4,9,10	Design checks 5,6,7,8 not included.
Florida, 1996	▪ Australian (gap acceptance)	▪ SIDRA	2,3,4,9,10	Design checks 5,6,7,8 not included.
Oregon, 1998	▪ UK (empirical) ▪ Australian (gap acceptance)	▪ RODEL ▪ ARCADY ▪ SIDRA	2,3,4,5,6,7,8,10,11	All design checks included, except 9.
FHWA, 2000	▪ UK (empirical) ▪ Australian (gap acceptance)	▪ RODEL ▪ ARCADY ▪ SIDRA	2,3,4,5,6,7,8,9,10,11	All design checks included.
Quebec, 2002	▪ UK (empirical) ▪ Australian (gap acceptance)	▪ RODEL ▪ ARCADY SIDRA ▪ GIRABASE ▪ HCS	2,3,4,5,6,7,8,9,10,11	All design checks included.
BC Technical Bulletin, 2003	▪ UK (empirical) ▪ Australian (gap acceptance)	▪ RODEL ▪ ARCADY ▪ SIDRA	2,3,4,5,9,10	Design checks 6,7,8,11 not included.
Kansas, 2003	▪ UK (empirical) ▪ Australian (gap acceptance)	▪ RODEL ▪ ARCADY ▪ SIDRA	2,3,4,5,6,7,8,9,10,11	All design checks included.
Wisconsin, 2004	▪ UK (empirical)	▪ RODEL	2,3,4,5,7,8,9,10,11	All design checks included.

Key to Design Checks:

1	None	5	Exit speed	9	Min. pedestrian refuge size
2	Design vehicle	6	Speed consistency	10	Sight distances
3	Entry speed	7	Entry path overlap (multi-lane)	11	Grading
4	Circulating speed	8	Exit path overlap (multi-lane)		

It should be noted that the next version of the UK design guide, the replacement to TD 16/93, is expected to shift the emphasis toward safety of all users. It will endorse more compact designs with single-lane entries and exits. It should also be noted that some continental Europe countries, primarily France, are increasingly installing multi-lane roundabouts at higher-volume intersections in response to congestion issues.

DESIGN CHECKS

Deflection of Roundabout Entry Paths

The most important factor influencing the safe operation of a roundabout is deflection, principally of a vehicle's entry path. Too little deflection means drivers can enter a roundabout without reducing speed or yielding to those circulating. Too much deflection results in reduced capacity and oncoming drivers being taken by surprise.

The speed of the deflected path is calculated using the equation:

$$V = [127\ R\ (e + f)]^{0.5}$$

where V = design speed (km/h);
R = min. radius on deflected path (m);
e = road superelevation (m/m); and
f = side friction factor.

Table 3.2
Comparison of UK and Continental Europe Roundabout Design

Design Feature	UK Practice[1]	Continental Practice[2]
Approaches	Ideally perpendicular to roundabout centre, although can be skewed if design checks are met.	Perpendicular to roundabout centre, preferably curved.
Entry Width	Usually multi-lane, greater than 6 m. Good practice is to add at least one extra lane for capacity or space for trucks.	Usually single-lane, 4m.
Entry Radius	Desirable 20m.	*Not specified, but tight geometry required (approximately 10 m from drawings).*
Entry Angle	If possible, between 20 and 40 degrees.	*Not specified, but tight geometry required (approximately 40 to 80 degrees).*
Entry Path Curvature	The tightest radius of straight-ahead entry path shall not exceed 100m.	*Not specified but, from drawings, not to exceed 100m.*
Exits	Easy exits (not perpendicular) encouraged with increased exit radius and space for faster vehicles to overtake.	Perpendicular to roundabout centre.
Exit Radius	Minimum 20m, desirable 40m.	*Not specified, but tight geometry required (approximately 10m).*
Exit Width	Where possible, allow for one extra lane for capacity.	Single-lane usually less than 5m.
Inscribed Circle Diameter (ICD)	Minimum 28m, although greater than 100m may be acceptable.	Minimum 25m, maximum 35m.
Central Island Diameter	Minimum 4m.	Minimum 16m, maximum 25m.
Circulatory Road	Usually between 1.0 and 1.2 times the maximum entry width. If the ICD is over 36m then the geometry varies.	Single-lane width between 5 and 7m.

1 TD 16/93, UK Department for Transport (1993).
2 Schoon and Van Minnen (1993), Kjemtrup (1993).

The FHWA guide describes a number of possible fastest-paths through a modern roundabout: the entry path, circulating path, exit path, left turn path, and right turn path. The radii associated with them are termed R1 to R5, respectively. It is desirable to minimize differences between these radii to limit speeds between successive geometric elements.

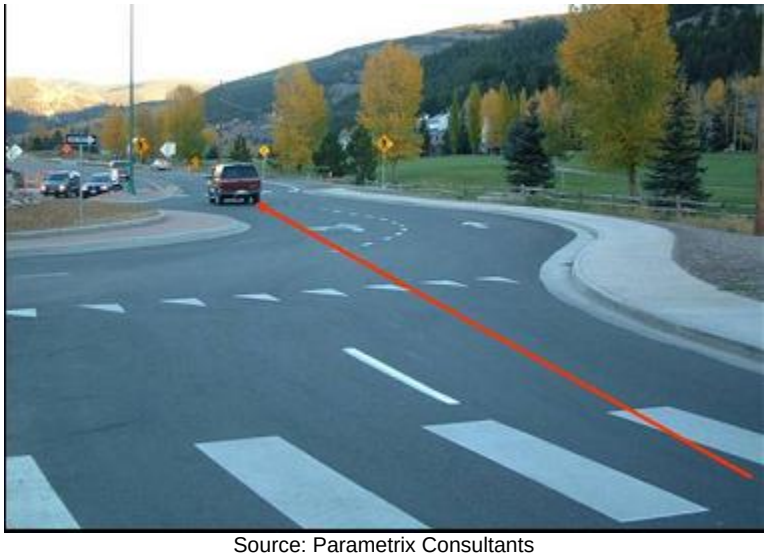
A fastest-path speed is the theoretical fastest possible speed at which a driver can negotiate a roundabout, in the absence of other traffic and ignoring all signs and pavement markings. Less than 30% of all drivers can actually drive a fastest-path through a modern roundabout according to a study published by the authors of the FHWA guide.

The entry path radius, or curvature, is a critical measure of a roundabout's potential safety. The appropriate amount of entry path curvature depends on many factors, including traffic volumes and distribution between entries, approach speeds, and site context.

Entry path radius is not the same as entry radius, as evident in Figure 3.2 and 3.3. Entry radius comes from the geometric design of a roundabout entry, while entry *path* radius comes from the composition of the design (arrangement of entry alignment and circle location) and is a result of a vehicle path through a roundabout entry.

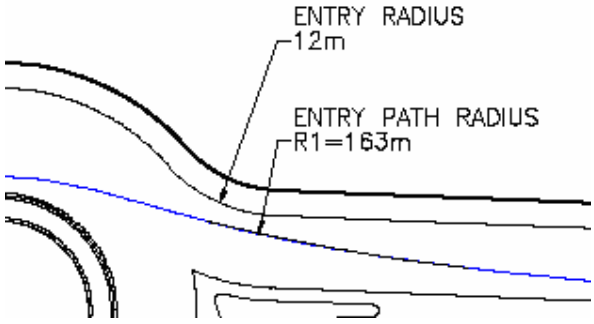
The exit path radius is also important, particularly for multi-lane roundabout safety. There is a tendency to limit this radius though restrictive exit geometry to keep speeds low at the pedestrian crossings at an exit. This practice is prescribed in the FHWA guide. However, subsequent studies by the authors of the FHWA guide have shown that exit speeds are limited by the amount of acceleration between circulating path at the central island and the exit, and thus the actual exit path radius does not usually play a part in achieving deflection. In fact, small exit path radii can limit sight distance between an exiting driver and a pedestrian waiting to cross at the crosswalk.

Figure 3.2
Too Little Entry Path Deflection



Source: Parametrix Consultants

Figure 3.3
Entry Radius and Entry Path Radius



Graphic: Ourston Roundabouts Canada

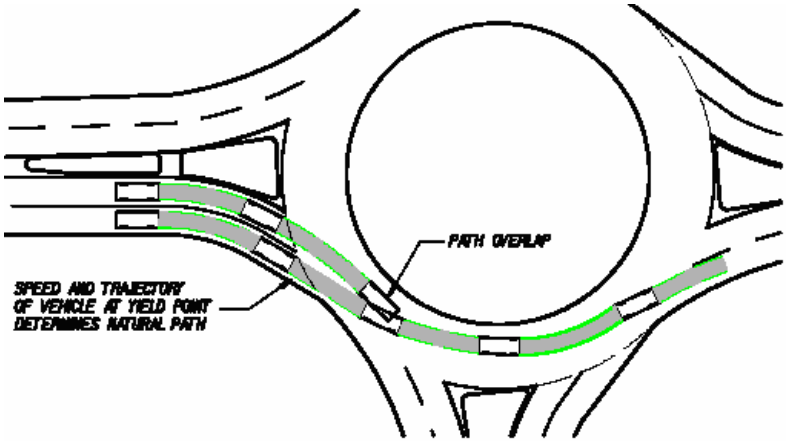
It becomes more difficult to obtain enough deflection with multi-lane designs, as the larger diameter, wider entries and wider circulatory road allow drivers to cut across lanes to lessen the amount of deflection they are subjected to.

Path Overlap

Another factor influencing the safe operation of multi-lane roundabouts is that of path overlap on the entries or exits. The natural path of vehicles can be determined by assuming drivers stay within their lane up to the yield point. At the yield point, they will maintain their natural trajectory into the circulatory road and through to the exit. If the roundabout geometry tends to lead vehicles into the wrong lane, this can result in path overlap as drivers cut across each other's paths. Figure 3.4 shows an example of entry path overlap. Path overlap can occur at roundabout exits as well.

Exit path overlap was a cause of numerous minor collisions at the Entryway Roundabout in Clearwater, Florida, when it opened in 1999. After the roundabout was modified, collisions decreased from 262 in the 6 months before (a frequency of 524 per year) to 3 in the 18 months after (a frequency of 2 per year) according to the City of Clearwater. This represented a collision reduction of 99%. The modifications consisted mainly of minor geometric changes to relax the

Figure 3.4
Example of Entry Path Overlap



Source: Wisconsin Department of Transportation Facilities Development Manual

exits to eliminate exit path overlap. Figure 3.5 illustrates exit path overlap caused by overly restrictive exit radii. Correct circulatory road markings were also a factor in the collision reduction, a subject discussed in Part 6.

Other Design Checks

Apart from the fundamental principles of speed and path, most guidelines agree on a set of ancillary design checks. Accommodation of the design vehicle, or largest motorized vehicle likely to use the intersection, is an important consideration, as its turning path requirements will dictate many roundabout dimensions. In general, roundabouts with a larger inscribed circle diameter (ICD) are needed to accommodate trucks while maintaining adequate deflection for smaller vehicles. Trucks may also be accommodated by installing a truck apron around the central island.

Most guidelines surveyed indicate pedestrian refuges on the splitter islands of a roundabout should be a minimum of 1.8 metres wide to accommodate a person pushing a stroller or walking a bicycle.

Figure 3.5
Exit Path Overlap

Photo: Ken Sides, City of Clearwater

As with all intersections adequate stopping sight distance is important, both horizontally and vertically. Stopping sight distance is critical for roundabouts because they rely on driver sight of the yield line, as opposed to signalized intersections where drivers can see signal heads.

Intersection sight distance must also be provided at the entries to enable drivers to perceive vehicles from other approaches and safely enter the roundabout. In North America, usual practice is to use the design speeds from the fastest-path evaluation to calculate intersection sight distance requirements. However, in the UK consideration is given to limiting entry speeds by restricting sight distance to the left on entry (right in the UK) to 15 metres though the use of landscaping.

RESULTS OF SURVEY

In Part 3 of the survey, the agencies surveyed were asked about modern roundabout design methods, including the use of computer software and design guidelines.

1. In terms of capacity analysis procedures used or required, most agencies cited RODEL (19% of all responses and 50% of the "high" group), the "FHWA Guide Analysis Procedure" (18% of all responses and 33% of the "high" group), or aaSIDRA (17% of all responses and 22% of the "high" group).

2. In terms of design guidance, most users subscribe to the FHWA guide. Some used local practice or guidelines from other countries such as the UK, Australia or France.

3. If a successor to the FHWA guide is created as planned for 2008, most agencies report a variety of information and guidance they would want to have added. Detailed Design Guidance was most often mentioned, followed by Traffic Guidance (signs and markings), Planning Advice, Operations Information, and Multi-Lane Design Guidance.

4. As for design checks, most agencies looked for Design Vehicle Turning Space, Sight Distance, and Circulating Speed. Many also asked for checks of Entry Speed, Exit Speed, Minimum Pedestrian Refuge Size, Grading, Entry Path Overlap and Exit Path Overlap (multi-lane roundabouts), and Speed Consistency.

5. The survey asked an open-ended question about what other capacity or design guidance would be helpful. Twenty-five (25) agencies responded with suggestions covering the following topics:

   - More information on software such as RODEL, ARCADY or aaSIDRA. A couple of comments included a need to update RODEL to be windows-based, and a proposed best practice requiring use of RODEL with additional performance measures for pollutants and energy use.
   - More information on VISSIM and other simulation software useful for modelling corridors.
   - More design layout advice – circle size, location, radii.
   - More consideration for truck design, and impacts of trucks on capacity.
   - More details on apron design, height of apron, colour and texture of surface, etc.
   - More discussion on mini-roundabout applications, capacities and safety.
   - Pedestrian crossing design guidance, such as angle of crossing to splitter island, concrete patterns, location of raised domes, etc.
   - More details on roundabout signs, in particular diagrammatic signs.
   - More information on pavement markings, in particular use of "Yield" word on pavement, markings in relation to a left turn around the central island, etc.
   - Signs and markings for higher speed multi-lane roundabouts.
   - More guidance on entry path overlap on multi-lane roundabouts particularly when the roundabout has striping on the circulatory road, and guidance on spiral striping of multi-lane roundabouts.
   - Advice on landscaping and illumination.
   - Information on roundabouts in series or in operation with signals.

INTERPRETATION

The two most popular software packages in North America for capacity analysis of modern roundabouts now, and at the time of NCHRP Synthesis 264, are RODEL and aaSIDRA. In

1997 aaSIDRA accounted for 46% of the software used, and RODEL accounted for 14%. At that time 28% reported as using no software.

Of note is the popularity of the "FHWA Guide Analysis Procedure", even among those jurisdictions having a large number of roundabouts. The procedure is a set of graphs in the FHWA guide for single-lane and multi-lane roundabouts of various categories (urban compact, rural single-lane, etc.), plus delay calculations from the HCM. Each graph shows maximum entering flow versus circulating flow, and a capacity line derived from various sources but primarily based on the UK empirical design method. Each graph applies to a certain set of geometric parameters, of which only one (the ICD) is stated in the accompanying text.

Most agencies use or require use of the FHWA guide. Several of the responses indicated that additional design guidance and advice would be helpful. An update to the FHWA guide is currently being planned that may address many of these requests.

CONCLUSIONS AND RECOMMENDATIONS

North American roundabout designers are discovering, through case studies such as the one conducted to repair the Entryway Roundabout in Clearwater, Florida, that strong relationships exist between capacity analysis, the geometry of a modern roundabout, and how it operates. Unfortunately, it will be costly and demanding to develop a robust capacity model for roundabouts in North America.

The preliminary findings in NCHRP 572 have indicated that both the gap acceptance and empirical analysis methods tend to overestimate capacity. This is because:

- Many of the roundabouts observed did not have effective geometry. In other words, there were aspects of the geometric design that were acting to limit capacity, such as two-lane entries that for various reasons were being treated by drivers as a single lane.
- Almost all of the roundabouts studied had yet to experience sustained at-capacity operation. At-capacity operation of an entry is characterized by several capacity mechanisms that gap models cannot effectively simulate and that empirical models depend upon to define true at-capacity operation.

Most of the sites in the database are less than five years old. In many instances during peak periods, driver responsiveness is not at the point where at-capacity mechanisms such as headway modification, gap forcing and priority reversal are being used. It is likely that as familiarity and traffic volumes increase, those roundabouts will develop higher capacities. This is already being observed for periods of time at a few high-volume roundabouts in the US.

It should be noted there are safety implications to analysis methods that underestimate roundabout capacity. They can lead to the construction of multi-lane roundabouts (with wider entries and circulatory roads, faster speeds, and increased conflicts) where a single-lane roundabout will suffice. They can also lead to the rejection of potential roundabout sites because of opposition or reluctance to introduce a multi-lane roundabout instead of a single-lane roundabout.

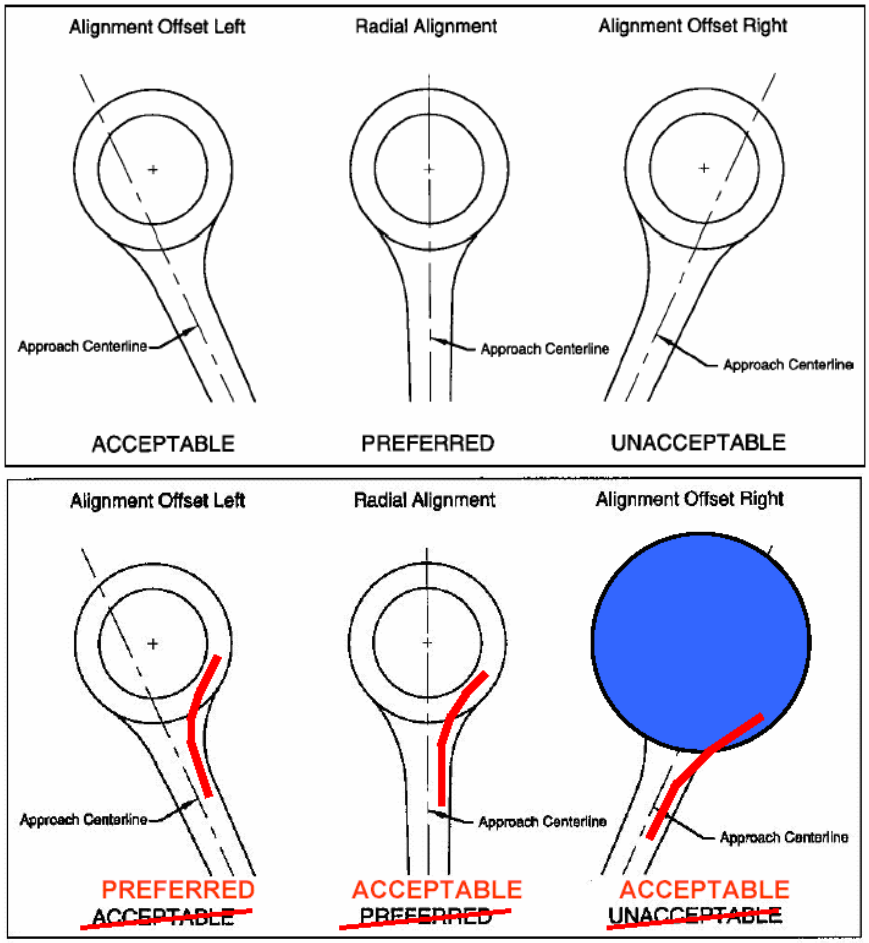
Currently, the use of capacity analysis models and guides from other countries is showing that capacity and safety predictions are tending not to exhibit different trends compared to North American practice. For a short period it was thought that North American drivers might not adjust to roundabouts, but experience is showing that it is more about the design than the driver.

Good modern roundabout design is more than the execution of software, the application of design guides, and a series of design checks. It requires a heuristic principles-based approach that starts with iterative conceptual design. This is a true creative process involving composition where guides are of limited help. Adding details in later design stages involves geometric refinement where guides can be of assistance.

An example of the limitations of design guides is provided in Exhibit 6-18 of the FHWA guide, as illustrated in Figure 3.6.

The top diagram shows that a radial alignment of the legs of a roundabout is preferred, and an alignment offset to the right of centreline is

Figure 3.6
Rule of Alignment vs. Principle of Deflection



Source: FHWA Roundabouts: An Informational Guide and Barry Crown

unacceptable. However, it does not explain why this is the case. A rule about roundabout alignment is being described when the subject should be the principle of entry deflection. If the principle is deflection, then the offset left alignment creates the most entry deflection (red curve in the bottom diagrams) and should be preferred. The offset right alignment could create sufficient deflection if the roundabout is made larger. If it is not possible to make the roundabout larger, only then will the offset right alignment likely be unacceptable. The point of the discussion is that an understanding of the principle of deflection is much more important than the inflexible application of a set of rules.

Roundabout designers are realizing that good roundabout design avoids operating problems that stem from the following:

- A poor understanding of the way site context influences design.
- Recognition of the operating effects of geometric design choices.
- Overall composition is often overlooked in the pursuit of geometric design details.

Based on the literature review and feedback from surveys, some roundabout designers are seeking further assistance on how to compose roundabouts, or assemble the geometric elements in such a way as to achieve the desired operating conditions. They are asking that future guides give advice on:

- Predictive relationships between geometry, capacity and collisions.
- Principles of design composition.
- Principles of speed reduction.

- Principles of circle size and circle location.
- Principles of correct pavement marking for roundabouts.

Roundabouts design should be principles-led, in response to solving an identified intersection problem, whether that problem involves minimizing cost, maximizing safety, or maximizing capacity. Figure 3.7 shows the "objectives triangle".

Addressing these objectives usually involves trade-offs, and decisions about where a design should be situated within the objectives triangle. However, limiting roundabout design to address only one of these objectives is to not use roundabouts to their full potential.

This is an important time in the development of guidance for the implementation of roundabouts in North America. The UK, Australia and Europe have already experienced this initial period of roundabout implementation. Agencies in North America should try to benefit from their knowledge. They should attempt to use guides that have been proven by practice elsewhere, rather than selectively assemble various guides based on limited experience.

A COMPARISON OF TWO GUIDES

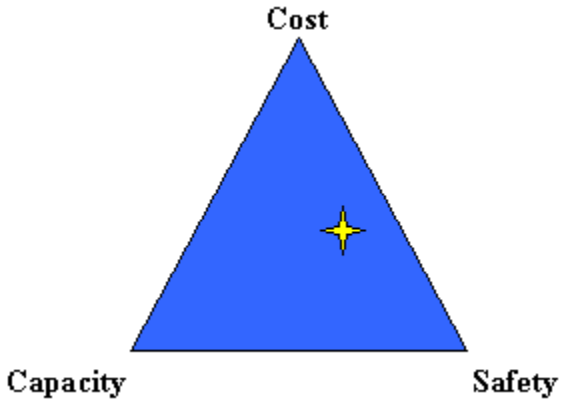
The Quebec roundabouts guide was developed after the FHWA guide and contains some similar material, but there are several notable distinctions that may be attractive for developing best roundabout practices in Canada, namely:

- Guidance on access location.
- Road classification as a criterion for site selection.
- A detailed step by step procedure for developing and checking layouts.

Other differences in guidance are apparent within the two documents. These, along with the foregoing distinctions, are summarized in Table 3.3 with the purpose of identifying useful design guidance and topics needing attention.

The FHWA guide is a relatively complete informational guide that describes a variety of available practices, but with limited emphasis on multi-lane roundabouts. The Quebec guide synthesizes research and design methods, and highlights the need to balance competing interests of cost, capacity and safety in developing roundabout designs. Both guides synthesize the practice of others and in many instances both provide a comparison of alternative methods from guides and research from other countries. Neither guide yet prescribes best practices in roundabout capacity and safety performance.

Figure 3.7
The "Objectives Triangle"



Source: Barry Crown

Table 3.3
Comparison of FHWA and Quebec Roundabout Guides

Topic of Interest	FHWA Chapter and Section Highlights	Quebec Guide Chapter and Section Highlights	Comparison Comments
Roundabout Categories	1 - Introduction 1.0 Section 1.6.1 Exhibit 1/7	2 - General Considerations	FHWA Exhibit 1-7 provides measures of differences between various categories, e.g. design speed, inscribed circle diameter, splitter island treatment and typical daily service volume
Policy Considerations Rules of the Road	2 - Policy Considerations	(Policies are covered generally in several chapters but there is no treatment of rules of the road)	The FHWA guide covers policy related issues, e.g. public education in more depth in a stand alone chapter. The Quebec guide addresses most of the same issues but in less detail.
Planning and Site Selection	3 - Planning (A thorough examination of site selection methodology (steps) including economic evaluation)	2 - General Considerations Section 2.2, Table 2.2-1 Suitability of Roundabouts by Road Category	The Quebec guide looks at road classification as a criterion for site selection. Emerging guides do this also but the generalization can be misleading where road classes are not borne out in practice.
Operations - Capacity	4 - Operation Section 4.3.5 Pedestrian Crossing Volume Effects on Geometry 4.4.4 Field Observations (evaluation of in-service operation - unique feature among guides)	3 - Traffic 3.1.1 Simplified Method (CERTU, SETRA and FHWA simplified methods ; delay by graphs from the NCHRP 264 synthesis)	Both guides discuss simplified and detailed analytical methods and associated computer software. The FHWA guide provides added detail in the simplified method to assess delays and queuing using the HCM (2000) methods.
Operations - Safety Vulnerable Road Users	5 - Safety 5.2.1.2 Double Lane Roundabouts (improper lane use conflicts) 5.4 Crash Prediction Models 6 - Geometric Design	4 - Road Safety (emphasis on crash reduction benefits for all users) 5 - Pedestrians 6 - Cyclists	The FHWA guide is superior in operations safety guidance. It addresses multi-lane conflicts and provides a robust (UK) crash prediction model that relates geometry to safety performance. The Quebec guide provides focused guidance on pedestrian and cyclist safety considerations. These topics are also covered in the FHWA guide in Chapter 6 - Geometric Design
Design Methods	6 - Geometric Design Section 6.2.1.5 Speed Consistency (Exhibits 6-13 and 6-14 relate roundabout category to design speeds) Exhibit 6-17 Key Dimensions for Non-motorized Users Exhibit 6-22 Circulatory Lane Widths (AASHTO reference and design vehicles)	7 - Geometry Figure 7.7-1 Splitter Island (a simplified design that isn't useful for unsymmetrical entries and exits) Figure 7.12-1 Non-Access Easements Section 7.13 Design Methodology	Both guides provide a description of the process of design but the Quebec guide includes detailed steps in the method of laying out a roundabout. The FHWA guide more extensively specifies details for design vehicles and circle size. Both guides share the error of specifying that the fast-path definition for multi-lane roundabouts assumes lane positioning. The Quebec guide provides guidance for locating access near a roundabout.
Signs and Markings	7 - Traffic Design and Landscaping Exhibit 7-5 Lane use control signing (incorrect geometry for the lane arrows shown)	8 - Landscaping Section 8.4 Basic Recommendations (Landscaping) 9 - Signing 10 - Lighting	The new TAC Lighting Guide supersedes these references. The Basic Recommendations, Section 8.4 of the Quebec guide presents a best practice for landscape treatments accounting for the safety interests of

Topic of Interest	FHWA Chapter and Section Highlights	Quebec Guide Chapter and Section Highlights	Comparison Comments
	Section 7.4 Work Zone Traffic Control (including construction staging)		all users.
System Considerations Interchanges Maintenance Case Examples	8 - System Considerations Section 8.4 Roundabout interchanges	11 - Maintenance Appendix 3 - Photographic Examples	The FHWA guide provides a cursory treatment of roundabout interchanges, closely spaced roundabouts, arterial networks, simulation modeling and rail crossing treatments at roundabouts. The Quebec guide highlights maintenance experience in Quebec. Appendix 3 - Photographic Examples is an excellent start to documenting unique designs and applications.

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4.0 DESIGN AND CONSTRUCTION

GEOMETRIC DESIGN ELEMENTS

As evident in the previous section, some of the more experienced agencies are requiring added emphasis to the modern roundabout composition – that modern roundabout design not a simple assembly of geometric elements. This requires knowing what aspects of the design are to be optimized (safety, capacity, cost) with respect to site context. Experienced agencies are indicating that emphasis on design composition, or the whole, is as important as the detailed geometric elements.

In this section, the geometric elements that are most widely considered, and their importance to agencies experienced with modern roundabouts, is presented. The experiences of road agencies with construction-related issues were also examined.

Approaches

It is on the approaches that drivers receive information identifying the appropriate speed and path to take to slow and safely navigate a modern roundabout. This can be accomplished through the geometry of the approach in several ways or in a combination of treatments such as: approach curvature, the introduction of an outer curb if the roundabout is in a rural environment, extension of the splitter island, the presence of approach signs and markings, and a central island made conspicuous by landscaping.

The geometry of the approach is critical on roads having high operating speeds. Two treatments for reducing approach speeds are shown in the FHWA guide. The first extends the splitter islands to the point at which drivers should be starting to decelerate. Higher approach speeds would warrant longer splitter islands. The second introduces a series of reverse curves of successively decreasing radius, as is the practice in Australia. See Figure 4.1. The Australian guide mentions that caution should be used with the reverse curve approach to ensure drivers do not change lanes rather than negotiate the curves, nor should the curves be superelevated as has been done in some jurisdictions so as to maintain high approach speeds.

The approaches are also where drivers are given the navigation and guidance information they need to make decisions once they reach the roundabout. This is accomplished through approach signs and markings, which are discussed in Part 6.

Right turn by-pass lanes can be implemented at roundabouts where right turn volumes are high, or to accommodate trucks. When entry traffic is high, the addition of a right-turn by-pass lane can eliminate the need for an additional entry lane or a larger roundabout. Right turn by-pass lanes can either have an acceleration lane at the exit, or terminate with a yield control. In general, design of by-pass lanes with free flowing exits is discouraged by many agencies where there are numerous pedestrians and bicyclists. In such instances the preferred design terminates with a yield condition rather than a merge.

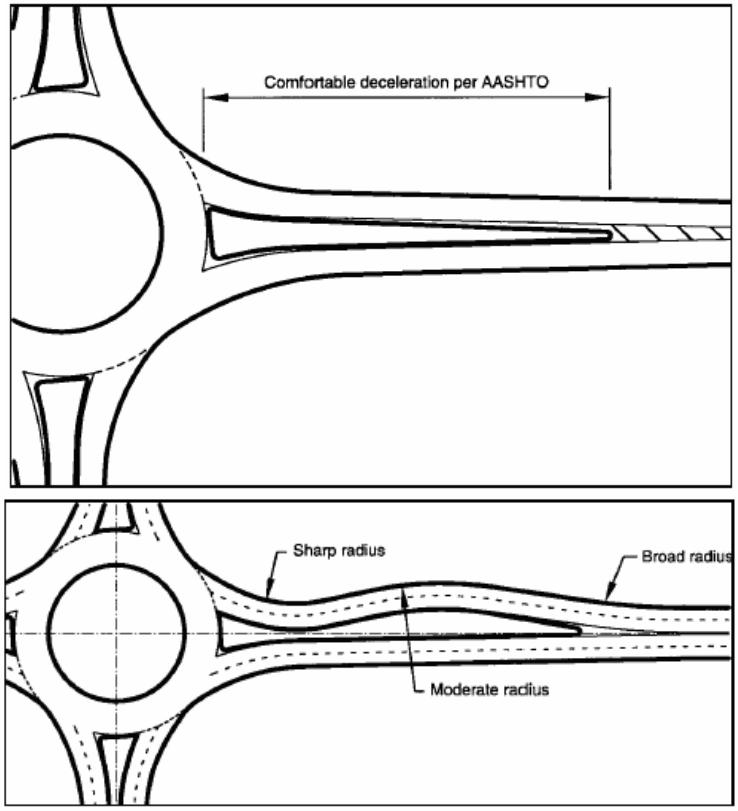
Entries

The favoured capacity analysis methods indicate that the capacity of an approach is not dependent purely on the number of entering lanes, but on the total width of the entry. Entries that are sufficiently wide are striped to designate separate lanes. The circulatory road may or may not be striped. This is also discussed in Part 6.

Although increasing entry width provides a corresponding increase in capacity, it also has the tendency to decrease safety. Wider entries or additional lanes allow faster entry speeds and increase the potential for entry-circulating collisions, usually the most common type at roundabouts. Entry width, particularly in single-lane designs, must also be sized to accommodate the design vehicle. Therefore, designing an entry involves a trade-off between capacity and safety.

The use of traffic signals to meter roundabout entries is uncommon in North America. Unless timings can be interconnected and responsive to downstream entry queuing, a traffic signal will

Figure 4.1
Geometric Treatments for High-Speed Approaches



Source: FHWA Roundabouts: An Informational Guide

tend to starve then overfeed an entry. Historically, where traffic signals are being used to control roundabout entries there is evidence of limited geometric design conformance. Thus, the potential for more subtle and likely more effective geometric design solutions has yet to be explored. The Entryway Roundabout in Clearwater, Florida, has a metered entry on one leg to allow traffic on other legs to enter the roundabout during certain peak time periods. The signal is actuated when a downstream entry queues back to an in-pavement detector.

Circulatory Road

The width of the circulatory road is determined from the ICD, the entry widths, and the turning requirements of the design vehicle. In single-lane designs the circulatory road should just accommodate the design vehicle, with a truck apron if necessary. In multi-lane designs the width should depend on the number and type of vehicles expected to circulate side by side. Usually the circulatory road of a two-lane roundabout is designed to allow two cars to circulate side by side, and it is expected that trucks will circulate one at a time and take up the entire width. In some jurisdictions roundabouts are designed so that a car and a truck can circulate side by side, or even two trucks. These roundabouts may not be able to achieve adequate entry path deflection.

Recently truck aprons have begun to appear on multi-lane roundabouts as well. This is due primarily to the way passenger car drivers tend to stay in their lane when there are pavement markings in the circulatory road.

The slope of the circulatory road should prevent water from collecting or pooling around the central island. For single-lane roundabouts it is common to slope the entire circulatory road to the outside. This can simplify design and raise the profile of the central island. Alternatively some agencies crown the circulatory road by

sloping one-half to two-thirds of the width towards the central island and the rest towards the outside. This provides several benefits including: helping to minimize icing from melt-water running off the central island; easing the effect of adverse cross-fall on the vehicle on the inside lane; and, preventing load shifting for heavy trucks. As with any intersection, good grading design is needed to avoid any such problems. As well, low points and inlets placed in the pedestrian crosswalks should be avoided.

The central island is important in determining the amount of deflection imposed on straight ahead vehicle paths. Its diameter is dependent on the inscribed circle diameter, circulatory road width and the width of the truck apron. The central island should have sufficient landscaping to clearly indicate to drivers they cannot pass straight through the intersection, but not too much to hinder sight of circulating and exiting traffic at the prevailing operating speeds. The central island should not present a hazard to out-of-control drivers by having immovable objects that can be struck by an errant vehicle. A modern roundabout in Santa Barbara, California was the site of a fatality because a vehicle collided into a central island toe wall higher than a regular curb (see Figure 4.2).

Central island truck aprons must be sufficiently high to discourage use by vehicles other than trucks, but not too high to cause load shifting or overturning. Some agencies have found that a truck apron designed with barrier curb and steep side slopes can shred the side walls of truck tires. The face of the mountable truck apron curb should be sloped, and not be too flat to allow use by smaller vehicles attempting to cut across the roundabout (see Figure 4.3). Truck aprons are usually constructed with contrasting materials to ensure they are clearly visible.

Pedestrian Crossings

Curb ramps should be provided at each end of a pedestrian crossing to connect to the sidewalk and to other crossings at the roundabout. Whether to mark the crossings is a subject covered in Part 8.

Figure 4.2
Example of Hazardous Central Island Toe Wall

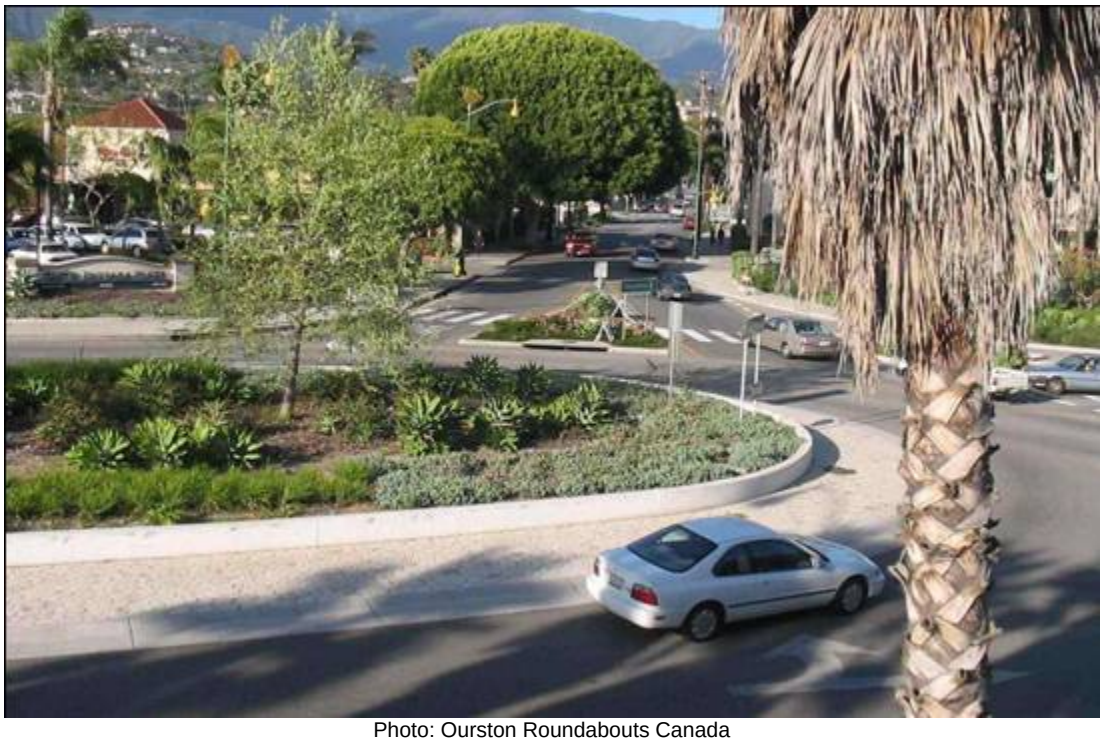


Photo: Ourston Roundabouts Canada

Figure 4.3
Example of Truck Apron Too Low to Discourage Use by Smaller Vehicles

Photo: Ourston Roundabouts Canada

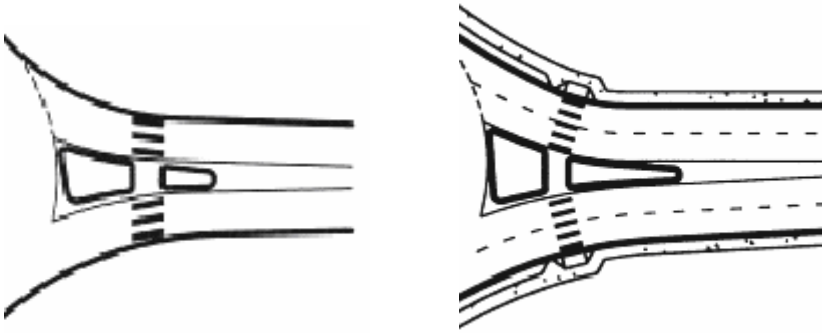
There are two approaches to aligning pedestrian crossings. Some agencies mark pedestrian crossings in a straight continuous alignment across the entire intersection approach. Other agencies angle them perpendicular to the direction of traffic so that a visually impaired pedestrian who departs perpendicular to the curb will stay within the crosswalk and have a shorter crossing distance. Examples of both are shown in Figure 4.4. The difference between the two methods becomes more noticeable as the number of entry and exit lanes increases.

CONSTRUCTION

Ideally when a roundabout is constructed at an existing location under retrofit conditions the entire intersection, or more than one leg, is closed to traffic. If that is not possible than the construction staging process can become complex and costly. A principle of construction staging is to encourage counter-clockwise circulation as early in the construction process as possible to educate drivers, as well as to reduce intersection crossing speeds and improve safety for construction workers.

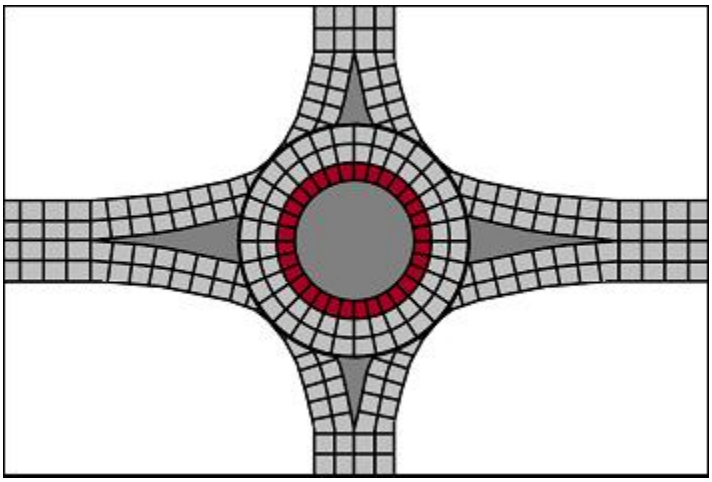
Roundabouts constructed using hot mix asphalt require stiff, travel resistant and rutting-resistant mixes to be placed on the circulatory road. Roundabouts constructed using concrete have improved grade control but require skid resistant treatment and specific jointing patterns as shown in Figure 4.5.

Figure 4.4
Straight and Angled Pedestrian Crossings



Source: FHWA Roundabouts: An Informational Guide

Figure 4.5
Typical Concrete Jointing Pattern for Roundabouts



Source: American Concrete Paving Association

A wide range of roundabout construction costs was reported through NCHRP Synthesis 264:

- At the low end, a roundabout can cost as little as $10,000 if installed by agency staff within an existing intersection, with construction of a central island and splitter islands but no outside curb work.
- At the high end, roundabouts built on state highways can cost over $500,000 if they require substantial amounts of grading and drainage, as well as long splitter islands and extensive curb work.
- An average cost of $250,000 was cited for 14 roundabouts not part of a freeway interchange or involving a conversion from an old traffic circle.
- The conversion of the I-70/Chamonix Road interchange in Vail, Colorado to a roundabout interchange cost a total of $6.4 million. This included construction of two roundabouts, reconstruction of the ramp terminals and frontage roads, drainage work, landscaping, traffic control, and design and engineering costs.

Roundabouts installed at existing intersections can require extensive and complex traffic control. According to the Maryland DOT, average traffic control costs for four recent roundabouts were 29% of the total construction cost because of high traffic volumes.

RESULTS OF SURVEY

In Part 4 of the survey, agencies were asked about roundabout design features, deficiencies and treatments, and construction costs and challenges they have experienced.

1. The most common design feature applicable to roundabouts in their jurisdiction was: Pedestrians Cross Perpendicular to Traffic (71% of all responses and 83% of the “high” group). This answer was not expected. The intent, along with a question asking whether Pedestrians Cross in a Straight Line, was to determine whether pedestrian crosswalks were straight or angled, as shown in Figure 4.4. A more even split between the two was expected, and thus the question may have been misunderstood.

   The other common design features were:

   - Entries Have More Deflection Than Exits (43% of all responses and 44% of the “high” group).
   - Tight Entry and Exit Radii to Control Speeds (35% of all responses and 22% of the “high” group).
   - Right Turn By-Pass Lanes (33% of all responses and 50% of the “high” group).

- Pedestrians Cross in a Straight Line (31% of all responses and 39% of the "high" group).

2. The most common design deficiency was Not Enough Deflection (33% of all responses and 44% of the "high" group). Other design deficiencies noted include Does Not Accommodate Design Vehicle, and Entry Path Overlap for multi-lane designs (18% of all responses and 39% of the "high" group). In general, the more experienced agencies also reported more design deficiencies. It is not known whether this was due to more deficiencies being evident or more experience in identifying them.

3. In terms of vertical design treatments, the most common responses were Circulatory Road Slopes Outwards (61% of all responses and 67% of the "high" group), and Truck Apron Uses Mountable Curb (47% of all responses and 56% of the "high" group). Few agencies appear to use a crowned circulatory road or bevelled curb on the truck apron. It should be noted that more agencies reported Truck Apron is sloped at 3% or Less than Truck Apron is sloped at More Than 3%.

4. As for special design treatments on high-speed approaches, the most common response was Enhanced Approach Signing (39% of all responses and 44% of the "high" group), followed by Extra Long Splitter Islands (37% responses received, 44% of the "high" group) and Extra Illumination (31% of all responses and 50% of the "high" group). Fewer agencies responded with Enhanced Central Island Signing or Enhanced Central Island Landscaping.

5. Agencies were asked an open-ended question about construction costs. Costs ranged from $50,000 to $2.5 million for new single-lane roundabouts (disregarding responses with very low costs that must have been for traffic calming circles), to $500,000 to $4.0 million for multi-lane roundabouts. Typical costs were about $450,000 for a single-lane roundabout and $650,000 for a multi-lane roundabout, although amounts varied considerably. The highest costs were for the roundabouts constructed in Franklin County, Ohio, and in Vail and Avon, Colorado, where these roundabouts incorporated large bronze statues in the central islands and extensive landscaping.

6. Agencies were asked an open-ended question about issues or challenges faced with construction and construction staging. Issues ranged from additional traffic control signing and maintenance of access, to inexperienced contractors, to dealing with construction staging and accommodation of high traffic volumes and trucks during construction. Some reported no particular difficulties, or that all their roundabouts were at new intersections.

INTERPRETATION AND RECOMMENDATIONS

The geometric design of the approaches to a modern roundabout is critical to ensure drivers are aware of the need to reduce speed before reaching the entry. High-speed approaches require additional curb work, signage and lighting in order to slow drivers well in advance. Several treatments for high-speed approaches (signs and pavement markings, central island landscaping) are discussed in Part 6.

Entry design involves trade-offs between achieving high capacity and optimal safety performance. Over 40% of the agencies responding to the survey indicated that the entries had more deflection than the exits. If this question was understood correctly, it may mean that more roundabouts have an alignment offset to the left of centreline, rather than a radial alignment on centreline. This is encouraging as it indicates a safe design practice on high-speed roads. On the other hand, the practice of using tight entry and exit radii to control speeds can be a problem with multi-lane designs. There are other ways to achieve deflection, such as offsetting approaches to the left of centreline. If an entry radius is too small, capacity can be reduced and tight entries and exits can result in path overlap in multi-lane roundabout entries.

The central island of a roundabout should be clearly visible to approaching drivers, but should not be a hazard. The truck apron, if provided, should have a bevelled curb as a compromise between a barrier curb and a mountable curb,

and a rise of 75 to 100 mm. The truck apron should be made of contrasting materials, and have a 1% to 2% slope. More agencies reported having truck aprons with a slope of 3% or less, than those who use an apron that is sloped 3% or more. Most agencies also reported the circulatory road slopes towards the outside of the roundabout.

Pedestrian crossings should be angled perpendicular to the direction of traffic so that visually impaired pedestrians departing perpendicular to the curb will stay within the crosswalk and have shorter crossing distances. The difference between this and straight continuous crosswalks becomes more noticeable with more entry and exit lanes. The change in direction associated with angled crosswalks may also lessen the likelihood that pedestrians and other users such as bicyclists cross an entire leg without looking for oncoming traffic.

A few agencies also reported the importance of modern roundabout design composition. Although they admit that this is an area of guidance that is difficult to describe, the advice that is being given to designers in addition to what is available from guides and training includes the following:

- Design is holistic – signs, markings, geometry, illumination and landscaping all contribute to the structuring of driver responses.
- Failure in one aspect of design cannot be compensated for by over-emphasizing another aspect. For example, inadequate entry path deflection cannot be mitigated by enlarging Yield signs to encourage drivers to yield.
- Often the design objectives of cost, capacity and safety conflict or compete and trade-offs are needed. Optimization of design, at times with specific emphasis on one of the three objectives, is required.
- Minor adjustments in geometry can result in significant changes in overall operational performance.
- Preparation of the initial layout drawing at a simple sketch level of detail can determine circle location and alignment of legs with the least amount of effort.
- Three elements must be determined in the preliminary stages: optimum circle size, optimum circle location, and optimum alignment and arrangement of the approaches.

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5.0 SAFETY EXPERIENCE

Maximizing intersection safety is the most frequently cited reason to install a modern roundabout. Roundabouts can improve safety by reducing the number and severity of collisions. This is done through eliminating or altering conflict types, and by reducing vehicle speeds and speed differentials.

ROUNDABOUT SAFETY PREDICTION

Although crash records at modern roundabouts in North America are limited, considerable research and data collection has been undertaken on safety at modern roundabouts in other countries. Most have simply reported before and after results with modern roundabout conversions. Some countries, such as the UK, Sweden and Australia, have also developed models for predicting collisions involving motor vehicles. These models tend not to predict collisions involving pedestrians or other road users. All results should be used judiciously, much more so than for capacity analysis methods, because of variation in the way collisions are reported between these countries and in North America.

The collision prediction model used in the UK was developed by the Transport Research Laboratory (TRL) as documented in LR1120 published in 1984 by Maycock and Hall. It uses a statistically derived formula based on a study of injury (including fatal) collisions at 84 modern roundabouts with varying geometric parameters in varying speed zones. As with the UK capacity model, the collision prediction model relates injury crashes to several geometric design parameters. It is available in the ARCADY software package.

The collision prediction model used in Australia was developed by Arndt in 1998. It uses several non-linear regression equations based on driver behaviour as reflected by speed and vehicle paths, as well as other significant predictors of crashes, and predicts crashes by type (single-vehicle, approach, entry-circulating, exit-circulating, sideswipe, and other). It is available in the ARNDT software package.

NCHRP 572 IN THE UNITED STATES

As mentioned earlier, NCHRP 572 is a study undertaken to develop a set of operational, safety and design tools for modern roundabouts calibrated to US field observations. The safety findings from the May 2006 draft report are discussed in this chapter. Operational findings are discussed in Part 3.

The May 2006 draft report for NCHRP 572 proposes two methods for predicting collisions at modern roundabouts in the US. One is an intersection-level model that uses regression equations from data collected at 90 modern roundabouts to estimate total and injury collisions from average annual daily traffic (AADT). Modern roundabouts are classified by number of approaches and number of circulating lanes. The results can be calibrated by using local collision data if available.

The total number of collisions at a modern roundabout with four approaches and two circulating lanes can be predicted with:

$$0.0038\ (AADT)^{0.7490}$$

The number of injury collisions at a modern roundabout with four approaches and one or two circulating lanes can be predicted with:

$$0.0013\ (AADT)^{0.5923}$$

The other model is based on intersection approach geometry and traffic flows. It uses traffic flows and several geometric parameters collected at 139 approaches selected from the same 90 modern roundabouts, and provides an estimate of total annual collisions by type per roundabout approach. At this time the approach-level model does not classify collisions as to property damage only, injury or fatality.

For total annual entry-circulating crashes:

$$e^{-7.2158}\ (AADT_e)^{0.702}\ (AADT_c)^{0.132}\ e^{(0.051E-0.028\theta)}$$

For total annual exit-circulating crashes:

$$e^{-11.6805}\ (AADT_e)^{0.280}\ (AADT_c)^{0.253}\ e^{(0.022ICD+0.111Cw)}$$

For total annual approach area crashes:

$e^{-5.1527} (AADT_e)^{0.461} e^{(0.03V)}$

where $AADT_e$ and $AADT_c$ are the entering and circulating AADT;
E = entry width of each approach (feet);
θ = angle to next leg;
ICD = inscribed circle diameter (feet);
Cw = circulatory width (feet); and
V = approach half-width (feet).

It is possible that both collision prediction methods may be incorporated into the two-lane and multi-lane highways sections of the US Highway Safety Manual (HSM) currently under development.

Collisions can also be predicted on the basis of collision modification factors (CMF's) using the results of before/after studies of intersections converted to modern roundabouts. This is discussed in the next section.

MOTOR VEHICLE COLLISIONS

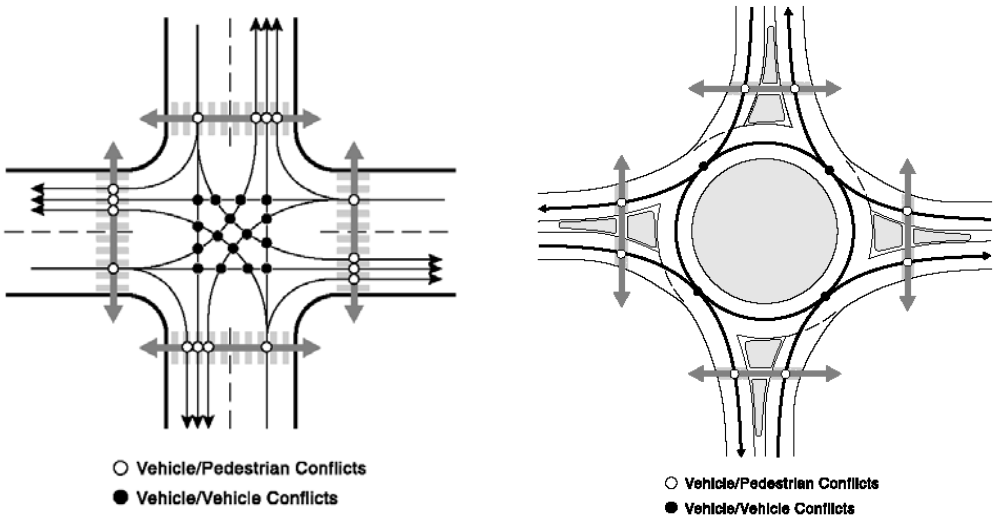
Compared to other intersections, modern roundabouts have fewer potential vehicle-vehicle conflict points. For a four-leg intersection, the reduction is significant – from 32 to 8 conflict points (see Figure 5.1). For a three-leg intersection the reduction is from 9 to 6 conflict points. Normally not all conflicts occur at the same time at other intersections, as certain movements are separated in time by a Stop sign or traffic signal. However, serious collisions can result when this separation in time does not occur (the case with red light running, for example).

The most severe right angle and opposing left turn collisions are therefore eliminated at modern roundabouts. The remaining vehicle collisions that are common can be classified as:

- Failure to yield at entry (entry-circulating).
- Single-vehicle runoff the circulatory road.
- Single-vehicle loss of control at entry.
- Rear-end at entry.
- Exit-circulating.
- Single-vehicle loss of control at exit.
- Pedestrian involvement.
- Bicyclist involvement.

Entry-circulating crashes because of failure to yield at the entry are usually the most common type at modern roundabouts, as evidenced by crash experience in France, Australia and the United Kingdom.

Figure 5.1
Comparison of Vehicle and Pedestrian Conflicts at a 4-Leg Intersection



Source: FHWA Roundabouts: An Informational Guide

Experience has shown that entry geometry plays an important role in determining what crash types are most probable. For example, an entry that is tangential to the circulating vehicle path will make entry-circulating collisions more likely because these drivers will be less inclined to yield. Conversely, an entry that is almost perpendicular to the circulating vehicle path will generate rear end and loss of control collisions more likely because abrupt braking may be necessary. The differences in entry geometry are illustrated in Figure 5.2. An entry geometry somewhere in between the two extremes is most appropriate.

Perhaps the most well known study of collision experience at modern roundabouts in North America is from a March 2000 report by the Insurance Institute for Highway Safety (IIHS) entitled *A Study of Crash Reductions Following Installation of Roundabouts in the United States*. The study looked at changes in motor vehicle crashes after the conversion of 24 intersections from stop sign or traffic signal control to roundabouts. The before and after data was collected from a mix of urban and rural locations in eight states, and involved 15 single-lane and 9 multi-lane modern roundabouts.

The study used an empirical Bayes approach, which accounts for regression-to-the-mean effects. It found the following highly significant relationships:

- Reduction in collisions of all types of 39%.
- Reduction in injury collisions of 76%.
- Reduction in fatal and incapacitating collisions of about 90%.

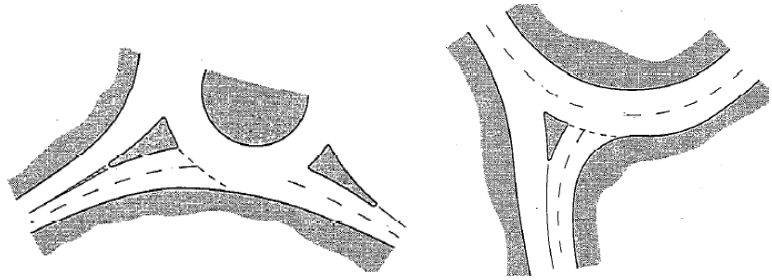
These CMF's are "consistent with numerous international studies and suggest roundabout installation should be strongly promoted as an effective safety treatment for intersections". This is given the large numbers of injury (700,000) and property damage (1,300,000) crashes that occur each year at Stop signs and traffic signals in the US.

The IIHS study also noted that while concerns had been expressed with older drivers having difficulties adjusting to roundabouts, the average age of crash-involved drivers did not increase, suggesting that roundabouts do not pose a problem for older drivers.

The study was expanded in 2003 by the New York State Department of Transportation (NYSDOT) to 33 roundabouts, representing a more extensive database in terms of number of locations, years of data and diversity of conditions. The results are presented in Table 5.1, and show that roundabouts continue to have excellent safety records. Total collisions of all types were reduced by 47%, and injury collisions were reduced by 72%.

Comparing single-lane roundabouts to multi-lane roundabouts, the NYSDOT study shows that multi-lane roundabouts are more prone to property damage only (PDO) collisions. This is likely due to additional entry-circulating, exit-circulating and sideswipe conflicts and increased visibility obstructions. In this study, multi-lane roundabouts were not shown to be more prone to injury collisions when higher traffic volumes were accounted for. This was somewhat countered by a 2004 study of 11 modern roundabouts in the US that showed greater reductions in collisions at single-lane roundabouts than at multi-lane roundabouts (73% versus 31%).

Figure 5.2
Tangential and Straight Entry Geometry



Source: Ourston Roundabout Design Guidelines

Table 5.1
Safety Impacts at US Roundabouts

Condition Before Conversion to Roundabout	Sites	Change in Collision Frequency		
		PDO	Injury	Total
Single-Lane, Urban Stop Controlled	12	67%	80%	69%
Single-Lane, Rural Stop Controlled	9	63%	68%	65%
Multi-Lane, Urban Stop Controlled	7	0%	73%	8%
Urban Signalized	5	31%	75%	37%
All Sites	33	41%	72%	47%

Source: ITE 2004, Designing and Operating Safer Roundabouts

Additional before/after analysis for multi-lane roundabouts has come out of the draft results from NCHRP 572:

- Conversion from a signalized intersection to a multi-lane roundabout (four sites, suburban settings) yielded a 67% reduction in all crashes. In terms of injury crashes the sample size was too small to calculate a percentage, but of the 98 crashes in the after period, only two involved injury.
- Conversion from a two-way stop to a multi-lane roundabout (11 sites, urban/suburban settings) yielded an 18% reduction in all crashes and a 72% reduction in injury crashes. Of the 272 crashes in the after period, 13 involved injuries.

NCHRP 572 has also verified the collision reduction findings of the IIHS and NSYDOT studies, with a composite CMF for injury crashes of 75.8%. NCHRP 572 further disaggregates the CMF's by previous intersection control (two-way stop, all-way stop or signalized), study area (urban, suburban, rural) and number of entry lanes, although for the most part these sample sizes are small.

A number of other studies have been conducted in North America, most using limited sample sizes and not accounting for regression-to-the-mean effects. Some involved roundabouts installed at problem locations. All concluded that roundabouts reduced crashes. A report entitled *Roundabout - Providing an Excellent Service to the Road User* stated: "Even if there are variations in the accident rates observed in different countries, it is indisputable that the rates are much lower… and the accident severity is equally reduced."

PEDESTRIAN-VEHICLE COLLISIONS

Roundabouts result in fewer potential vehicle-pedestrian conflict points, when compared to other intersections. A pedestrian crossing at a typical signalized intersection faces four potential vehicular conflicts, each coming from a different direction (see Figure 5.1):

- Right turns on green (legal).
- Left turns on green (legal for protected-permitted or permitted left turn phasing).
- Right turns on red (typically legal).
- Crossing movements on red (typically high-speed, illegal).

For a four-leg intersection with single-lane entries and exits, this represents 16 vehicle-pedestrian conflicts. While the illegal movements are less likely to occur, they are potentially the most severe for a pedestrian and often occur without warning. Pedestrians at single-lane roundabouts face two conflicting vehicular movements on each approach: with entering vehicles, and with exiting vehicles. It should be noted that at both types of intersections, an additional conflict is added for each additional lane that a pedestrian must cross.

There are other advantages for pedestrians at roundabouts:

- Crossing distances are usually shorter.
- Crossings are less complex, requiring looking in only one direction at a time.
- Conflicting traffic speeds are generally lower, meaning less chance of injury in a collision.
- Drivers are more likely to see pedestrians in the crosswalk.

- Their actual level of safety is more related to their feeling of security. At signalized crossings, pedestrians can experience an exaggerated feeling of safety because of the walk indication that does not match their actual level of safety.

A potential disadvantage at roundabouts is the accommodation of visually impaired pedestrians. There is more discussion of this issue in Part 8.

Research on pedestrian safety at modern roundabouts in North America has been limited to only a few before/after studies. The IIHS study mentions that although the sample was too small to estimate effects on pedestrian crashes, none of the multi-lane roundabouts have had a single pedestrian crash so far, even though there were two crashes during the before period at these sites.

Elsewhere:

- A 1993 study in the Netherlands examined collision experience at 181 intersections converted to roundabouts. Pedestrian collisions (all injury severities) dropped 73% and pedestrian casualties dropped 89%.
- Evaluations in Sweden concluded that single-lane roundabouts are very safe for pedestrians, at about a 78% reduction in injuries, and that multi-lane roundabouts are about as safe as other intersections.
- A 2002 study of collision experience at the roundabouts in Park City, Vail, West Vail and Avon, Colorado, showed 2 pedestrian crashes prior to the roundabouts operating with over 164 million vehicle movements, compared to 1 pedestrian crash with roundabouts experiencing over 282 million vehicle movements.

BICYCLIST-VEHICLE COLLISIONS

At most roundabouts bicyclists have the option of travelling through a roundabout as would a motor vehicle, or dismounting and traversing as a pedestrian. Bicyclists therefore face about the same number of conflicts as drivers or pedestrians. However, because bicyclists typically ride on the right side of the road between intersections, they can face additional conflicts due to overlapping paths with motor vehicles when travelling through or exiting a roundabout as a vehicle. This is particularly the case at multi-lane roundabouts.
Bicyclists are often considered to be the most vulnerable users of roundabouts. Almost half of the collisions involving cyclists occur between an entering vehicle and a bicyclist who is already on the circulatory road. In many cases, these crashes occur when a driver does not yield on entry.

There has been even less research on bicyclist safety at roundabouts in North America than pedestrian safety. The most comprehensive study overseas was undertaken in western France at 1,238 signalized intersections and 179 roundabouts. The study found that in proportion to the total number of crashes, two-wheeled vehicles were involved in crashes more often at roundabouts (+16%), but were involved in injury crashes more often at signalized intersections (+77%).

A study in Sweden at 72 locations concluded that at single-lane roundabouts bicyclists were involved in 20% fewer injury collisions than at other intersections. However, at multi-lane roundabouts they were twice as likely to be involved in injury crashes (although these were classified as “light” injury crashes).

Studies in the Netherlands showed that roundabouts decreased bicyclist injuries by 44 to 73%. Separate bicycle paths were found to be the safest, while a bicycle lane within the circulatory road was found to be the least safe.

In general, it seems that collisions involving bicyclists are reduced somewhat with roundabouts, particularly in severity, but not to the same extent as for collisions involving vehicles or pedestrians.

RESULTS OF SURVEY

Part 5 of the survey addressed modern roundabout safety experience of North American agencies. Agencies were asked if they had conducted any formal studies to measure roundabout safety performance compared to the previous intersection control. They were also asked about types of crashes at their roundabouts and what mitigative measures have been used to prevent them.

1. Formal studies to measure roundabout safety performance were not reported by any of the agencies in the survey. Some had undertaken informal before/after comparisons with no regression-to-the-mean analysis. A few of the roundabouts in this survey were part of the IIHS *A Study of Crash Reductions Following Installation of Roundabouts in the United States*.

2. Compared to the previous intersection control, overall 29% of the agencies responding indicated that property damage only collisions were lower, and 29% indicated that injury and fatal collisions were lower. Only 3% overall reported these collisions as being higher. The results with pedestrians and cyclists were generally inconclusive, likely due to low involvement rates, although no agencies reported that bicyclist crashes were higher.

   About a quarter of the agencies did not know about the collision experience at their roundabouts, and approximately the same number had not collected data because the roundabouts were new intersections.

3. The results were fairly evenly split among crash types. Most reported were Approach crashes – Rear-End and Loss of Control (total of 47% of all responses and 33% of the "high" group). Entry-Circulating and Exit-Circulating crashes were also reported at about 20% each. There were very few pedestrian and bicyclist collisions reported. About a quarter of the agencies did not know what types of collisions had been occurring at their roundabouts.

4. Several measures have been implemented after construction by the various agencies to improve safety performance. The most commonly used were related to Signs and Pavement Markings at over 50% of the agencies each. This is not surprising, as these types of measures can be implemented quickly and inexpensively. The next most common measure is more Central Island Landscaping, again likely because of the low cost compared to other measures. Less common are measures to Increase Entry Deflection and Make Larger to Accommodate Trucks.

INTERPRETATION AND CONCLUSIONS

Similar to experience elsewhere, most agencies surveyed reported that the installation of roundabouts had lowered property damage only and injury collisions (including fatalities). No formal studies seem to have been undertaken to measure roundabout safety performance in North America apart from participation in the IIHS, NYSDOT or NCHRP 572 before/after studies.

Approach crashes were the most common type of collision according to the agencies surveyed, even though entry-circulating crashes are the most common type according to experience in other countries. This suggests that either too much entry deflection is being applied at these roundabouts (contrary to the survey results in Part 4 stating that insufficient deflection is the most common design deficiency), or that insufficient design treatments are present at roundabouts on high-speed roads.

Pedestrian safety is an issue of perceived versus real risks. Even though pedestrian safety at roundabouts is generally high based on international experience and limited experience in North America, many do not perceive roundabouts to be safe for pedestrians due to the absence of a positive exchange of the right-of-way priority by a traffic signal. The general public takes these signals to mean it is safe to cross, when in fact they are still in conflict with drivers turning left or right across the crosswalk during a walk signal. More education of the public is needed in this regard.

Because collisions are not reduced to the same extent for bicyclists as for those involving vehicles or pedestrians, the relative benefits of roundabouts can be less for bicyclists. General international experience is that bicyclists are safer at roundabouts, particularly single-lane roundabouts, than at other intersections because of lower vehicle speeds and fewer conflicts.

More research is needed on pedestrian and bicyclist safety at modern roundabouts in North America, and for developing collision prediction models for these users. This research should use the largest sample size possible and account for regression-to-the-mean effects.

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6.0 OPERATIONS EXPERIENCE

This chapter addresses issues related to modern roundabout operations such as traffic studies, truck accommodation, signs, and markings. The recent trend in developing the traffic information system for roundabouts has involved an attempt to transfer what has been applied at other types of intersections. Not all components of the information system have been transferable.

MODERN ROUNDABOUT SIGNS

Regulatory and Warning Signs

According to the principles of positive guidance, the process of navigating a roundabout involves acquiring and processing information from the geometry of the road, from pavement markings, and from signs. All three elements should be designed and located in order to minimize detection, reading and processing time, and maximize comprehension and ability for drivers to perform the tasks of navigation, guidance and vehicle control. Signs at all roundabouts should aid in detecting the presence of the roundabout ahead, deciding on a destination or exit leg, and slowing to an appropriate speed. Signs at multi-lane roundabouts should also aid in deciding on the correct entry lane.

In the United States, sign use is regulated through the *Manual on Uniform Traffic Control Devices* (MUTCD) and local state supplements. In Canada, TAC's *Manual of Uniform Traffic Control Devices for Canada* (MUTCDC) and additional provincial guides regulate sign use. These documents can be used to provide direction on the application of regulatory and warning signs at modern roundabouts.

Regulatory signs at roundabouts usually consist of Yield signs, Keep Right signs, One-Way signs, and Lane Designation signs (at multi-lane roundabouts). Warning signs can include Roundabout Ahead signs, Yield Ahead signs, and warning chevrons.

A Yield sign is mandatory on the right side of the entry at roundabouts in North America. Many agencies install a second Yield sign on the left side at larger roundabouts. Because drivers look to the left to enter a roundabout, it is usually this sign that is more visible. A modified Yield sign for use at roundabouts, as shown in Figure 6.1, has been endorsed in the latest edition of the TAC MUTCDC.

Most agencies install One-Way signs in the central islands of their roundabouts to indicate counter-clockwise circulation. By themselves they are not sufficiently visible to approaching drivers except at small roundabouts, and they imply not only that the circulatory road is one-way but also that the crossroad is one-way. The use of warning chevrons or chevron alignment signs instead of One-Way signs may be an improvement. In Quebec, a wider version of their red and white chevron is used without a One-Way sign. A few agencies report that roundabouts on high-speed roads could benefit from having more than one warning chevron per approach. In the United Kingdom several chevrons are often linked to increase conspicuity of the central island and reinforce direction of travel. Examples of central island signs in Canada and the UK are shown in Figure 6.2.

Figure 6.1
TAC Modified Yield Sign, RA-3

Source: TAC MUTCDC, 2002 Edition

Figure 6.2
Central Island Signs in Canada and the UK

Photos: Ourston Roundabouts Canada

Like other intersection approaches, Lane Designation signs are needed to present entry lane choice at multi-lane roundabouts. Standard or "fishhook" Lane Designation signs are both in use in North America (see Figure 6.3).

Many in the engineering community believe fishhook signs may be appropriate to mitigate the tendency of some drivers wishing to turn left at a modern roundabout to do so in front of the central island. Others think this is a potential issue better addressed through good central island signing and the geometry of the approach. Fishhook lane signs are in draft form in the US MUTCD. If they result in a better understanding of how to make left turns at roundabouts, then perhaps they may be appropriate as a temporary sign in areas where roundabouts are new. More research is needed in this area.

A Roundabout Ahead sign is an Intersection Warning sign common at roundabouts (see Figure 6.4). Generally Intersection Warning signs are used at other intersections only under certain conditions, but the Quebec Traffic Control Devices manual, TAC MUTCDC and US MUTCD note that Roundabout Ahead signs should be installed on all approaches to roundabouts.

Figure 6.3
Standard and "Fishhook" Lane Designation Signs

Source: TAC MUTCDC, 2002 Edition and Ourston Roundabouts Canada

Figure 6.4
Roundabout Ahead Sign

Source: US MUTCD, 2003 Edition

Yield Ahead signs are another warning sign common at roundabouts. A Yield Ahead sign is normally required on an approach to a Yield condition that is not visible for a sufficient upstream distance for a driver to respond. They could be considered redundant at roundabouts if there are no sightline issues. Some jurisdictions such as the Region of Waterloo, Ontario, do not use them unless warranted. Others use them on a temporary basis, for 30 to 60 days after a roundabout has opened.

Guide Signs

Unlike the case for regulatory and warning signs, there is little guidance in North America on the use of guide signs at roundabouts. A paper entitled "Internationally Recognized Roundabout Signs" presents the principles used in designing and locating guide signs in countries where roundabouts are more widespread than in North America, and seeks to assimilate proven practice with North American standards. In particular, guide sign practice in the United Kingdom is referenced including practice on complex multi-lane roundabouts on high-speed approaches.

Most guide signs in North America that are located in advance of intersections are "stack type" signs. An example is shown in Figure 6.5. They are useful when the intersection configuration is simple or the number of destinations is small. They can be used at roundabouts as well, but many jurisdictions are installing diagrammatic or "map-type" signs, especially in rural locations where boulevard space is available.

Map-type guide signs are common at intersections internationally because of the number of destinations that often need to be conveyed to drivers, and have been shown to create faster reading times in these cases compared to stack-type guide signs common in North America. Map-type signs at roundabouts also display the configuration of an upcoming intersection. This is an advantage where roundabouts have skewed angles, by-pass lanes or more than four approaches. Map-type signs need to be well designed to convey the necessary information from a sufficient distance upstream without making the signs too large for the boulevard space available. A good example is shown in Figure 6.6.

Figure 6.5
Example of "Stack-Type" Sign

Source: Ontario Traffic Manual (OTM) Book 1A

Figure 6.6
Example of "Map-Type" Sign at Complex Roundabout

Graphic: Ourston Roundabouts Canada

Guide signs at roundabout exits are useful to confirm exit leg choice. They are usually street name blades or signs on the splitter islands that point to the appropriate exit. The splitter island signs may have an arrow in the sign, or the right edge of the sign may form a point. Examples of both are in Figure 6.7. Recent research in the US has shown that "flag-type" signs that point in the direction of travel give more advance recognition of a destination than rectangular signs, an advantage at roundabouts where circulating drivers have limited reading time.

There are instances where other signs not related directly to a roundabout may need to be installed on certain approaches to roundabouts. Examples include tourism signs (TODS), signs to denote municipal facilities such as hospitals and police stations, signs for parking areas, etc. Again, there is little related guidance in North America. These signs may be installed in advance of a roundabout by adjusting the spacing between other advance signs as appropriate. Another method is to incorporate them directly into the map-type guide signs. In the UK sometimes two sets of map-type signs are used: a primary sign to convey street names or destinations, and a secondary sign to convey more local information. Figure 6.8 shows an example of such a secondary map-type sign that shows nearby parking lots.

ROUNDABOUT MARKINGS

Markings at All Roundabouts

Approach and entry pavement markings at all modern roundabouts consist of yield lines and channelization markings. Yield lines are used to demarcate the entry from the circulatory road, and are located along the edge of the inscribed circle. The most common yield line pavement marking is a broken line treatment. Alternatively, several European countries use yield line markings consisting of a series of white triangles (known as "shark's teeth"). These markings tend to be more visible to approaching drivers, but are more difficult to install and may be unfamiliar to North American drivers. Examples of both, from the state of Maryland, are shown in Figure 6.9.

Figure 6.7
Examples of Exit Signs at Roundabouts

Graphics: FHWA Roundabouts: An Informational Guide and Ourston Roundabouts Canada

Figure 6.8
Example of Secondary Map-Type Sign

Photo: Ourston Roundabouts Canada

Figure 6.9
Broken Line and "Sharks Teeth" Yield Line Markings

Source: FHWA Roundabouts: An Informational Guide

The word YIELD is painted prior to the yield line in many US jurisdictions to supplement the signing and yield line marking. Some countries paint a symbolic yield sign upstream of the yield line. This treatment has the advantage of being symbolic, but again may be unfamiliar to North American drivers. Outside of Quebec, this practice is rarely used in Canada.

Channelization markings can consist of edge line markings, and approach lane markings and arrows at multi-lane roundabouts. As in standard intersection treatments, channelization markings must be yellow on the left side and white on the right side. For a roundabout splitter island, pavement markings must be yellow adjacent to the entry and exit and white adjacent to the circulatory road. Optionally, edge lines may end at the points of the splitter islands, allowing the curbs themselves to provide edge delineation. A yellow line around the central island or truck apron is usually optional as well, although one agency reported that truck drivers are discouraged from crossing onto the truck apron due to the yellow line. Supplemental raised pavement markers or "cats-eyes" are common in many US jurisdictions.

The majority of agencies use approach lane markings on multi-lane roundabouts. As at signalized intersections, approach lane markings are critical at multi-lane roundabouts to get drivers into the correct lane before they enter the intersection. This ensures no lane changing is necessary once they are in the circulatory road. Correct lane markings also encourage proper lane utilization.

There is some debate about the use of left turn arrows on the approaches. British Columbia and New York State, for example, do not use left turn arrows because of the concern they may cause drivers to turn left in advance of the central island. This presents a dilemma for conditions where on a multi-lane approach a vehicle in the left lane cannot proceed to a single-lane exit without cutting off a vehicle exiting in the right lane. A related concern is that not using left turn arrows at all may lead drivers into thinking they can turn left from the right lane. A response has been the use of "fishhook" lane arrows in some jurisdictions, as shown in Figure 6.10, in conjunction with "fishhook" Lane Designation signs.

Mini-roundabouts require pavement marking arrows in the circulatory road in front of each entry to indicate the direction of travel, since no signs can be placed in the fully mountable central island.

Circulatory Road Markings at Multi-Lane Roundabouts

Circulatory road markings at multi-lane roundabouts is a complex topic, of which there are currently two schools of thought in North America. The first is that lane lines should not be marked within the circulatory road unless required to designate dual left turns or other special configurations. This is common practice where drivers are familiar with roundabouts such as in the UK. The second is that lane lines should always be marked within the circulatory road to provide positive guidance for drivers, especially in North America where those unfamiliar with roundabouts may be tempted to make a left turn at a roundabout by entering from the right lane.

Figure 6.10
"Fishhook" Lane Arrows

Photo: Ourston Roundabouts Canada

Some sources suggest that not marking the circulatory road allows entering and circulating drivers to better recognize the space needs of trucks. This may reduce the overall width required for the circulatory road and truck apron. Additional sources suggest that circulatory road markings are unnecessary for a width less than 9 metres or fewer than three-lane entries.

As mentioned, circulatory road markings are essential in complex designs. However, they do result in lane consciousness, or a tendency for drivers to stay in their own lane regardless of the consequences. This is generally not a problem except when a large truck and a passenger car enter a roundabout simultaneously. As a consequence of this, truck aprons have started to appear on multi-lane designs as well as single-lane designs.

If circulatory road markings are used, they must be accompanied by adequate lane designation to ensure drivers are in the correct lane at entry, and are not misled into thinking they can exit only from the outer lane or right lane of the roundabout.

In the United States, the Markings Technical Committee has developed a draft chapter for a future edition of the US MUTCD that includes numerous examples of pavement markings for single-lane and multi-lane roundabouts. The examples illustrate recommended pavement markings for a variety of roundabout configurations, such as multi-lane roundabouts having double left turns and associated spiral circulatory road striping.

ILLUMINATION

Reasons for illuminating an intersection include the presence of existing lighting nearby or on one or more of the intersecting roads, and to light objects and conflict areas where pedestrians and bicyclists may be present at night. For these reasons, and because drivers are often unfamiliar with roundabouts, they are usually illuminated.

Chapter 11 of the 2006 TAC *Guide for the Design of Roadway Lighting* has provisions for roundabout illumination. This is a newly released guide for which there was no experience with its use at the time of the agency survey. The TAC lighting guide emphasizes horizontal and vertical illuminance recognizing that with circulating traffic at roundabouts the headlight contact time with signs and objects is minimal, especially for high conflict areas at entries, exits and pedestrian crosswalks. It also specifies the need to calculate vertical luminance for crosswalk areas.

Although other guides are relatively new as well, the lighting chapter of the Kansas guide is in use by agencies having roundabouts on both sides of the border.

Roundabouts can be illuminated by one or more luminaires in the central island, by luminaires around the outside, or both. Table 6.1 summarizes the advantages and disadvantages of central and peripheral illumination.

Table 6.1
Central and Peripheral Illumination at Roundabouts

Illumination Type	Advantages	Disadvantages
Central	▪ Assists in perception at a distance by illuminating the central island. ▪ Requires fewer poles to achieve the same illumination. ▪ Pole in central island is clear of critical conflict areas for all but the smallest of roundabouts. ▪ Exit guide signs on the periphery appear in positive contrast (front lit) and are clearly visible.	▪ Illumination is weakest in critical pedestrian and bicycle areas. ▪ Signs on the approach are in negative contrast (back lit). ▪ A path is needed to the base of the central pole for maintenance. ▪ There is a greater risk of glare. ▪ The central pole affects central island landscaping plan. ▪ High mast lighting may be inappropriate in urban areas, especially residential areas.
Peripheral	▪ Illumination can be strongest around critical bicycle and pedestrian areas. ▪ Maintains a continuity of poles and luminaires for the illumination of the lanes, as well as good visual guidance on the circulatory road. ▪ Approach signs appear in positive contrast and are clearly visible. ▪ Maintenance of luminaires is easier due to curbside location.	▪ Illumination is weakest in central island, which may limit visibility of a roundabout from a distance. ▪ Requires more poles to achieve same level of illumination. ▪ Poles may need to be located in critical conflict areas to achieve illumination levels and uniformity.

Source: Kansas Guide

Generally the preferred practice is to illuminate roundabouts from the perimeter in, and place luminaires to light conflict areas, pedestrian crosswalks and important signs from the front. The luminaires should depart from a straight line along the edge of the road at the roundabout to identify it to drivers from a distance at night.

As at other types of intersections, a photometric analysis is usually required to determine luminaire wattage, mounting height, arm length, and pole placement at a roundabout. The position of luminaire poles relative to the curbs at a roundabout is governed by site context and the potential speeds of any vehicles that may run off the road.

LANDSCAPING

Landscaping at a roundabout can be used to structure sightlines, direct pedestrians and bicyclists, and improve aesthetics. Most agencies agree that landscaping should:

- Make the central island more conspicuous by creating a terminal vista to clearly indicate to drivers they cannot pass straight through the intersection.
- Maintain appropriate sight distances.
- Minimize introducing hazards to the roundabout, such as trees, statues, etc.
- Avoid obscuring the roundabout or associated signage.
- Discourage pedestrian traffic through the central island.
- Help visually impaired pedestrians locate sidewalks and crosswalks, and discourage pedestrians from crossing where not appropriate.
- Improve the aesthetics of the area.

The roundabout in Figure 6.11 could have benefited from a more conspicuous central island to prevent a “see-through” problem that may have contributed to several single vehicle collisions.

Agencies are finding that roundabouts in rural areas need more prominent central islands as compared to urban roundabouts. Landscaping on the right and left side of the approaches and within the splitter islands (where appropriate) can also help to create a funnelling effect and induce a decrease in speeds approaching the roundabout.

Figure 6.11
Example of "See-Through" Problem

Photo: City of Hamilton

MAINTENANCE

Traffic control is necessary for maintenance operations performed in the circulatory road or central island of a roundabout. As with other intersections, the traffic control can be complex where traffic volumes are high and multiple legs are affected. Some operations such as line painting require the closure of a roundabout for short durations. With single-lane roundabouts it can be difficult to accommodate large vehicles in the circulatory road when part of it is taken up by maintenance operations. This is not as much of a problem with the wider circulatory roads of multi-lane roundabouts, particularly where truck aprons can be used for maintenance vehicle parking.

Experience in Quebec and elsewhere has shown that during snow clearing operations, snow is pushed towards the outside of the circulatory road, but is not thrown very far because the snow removal equipment is moving at low speed. Therefore snow can pile up along the outside of a roundabout and eventually encroach upon the entries, exits and circulatory road, blocking sightlines and potentially reducing capacity. Further, roundabouts can take longer to dry after winter salting operations because traffic is moving at lower speeds than along other sections of the road network.

RESULTS OF SURVEY

Part 6 of the agency survey dealt with various issues related to roundabout operations, such as traffic studies, truck accommodation, signs, and markings.

1. Most agencies have not undertaken traffic counts at their roundabouts yet. For those who did undertake counts, the most commonly cited method was to count entering flows only.

2. Most agencies have not planned speed studies. For those who did undertake speed studies, the most common method was to record upstream and downstream speeds.

3. In terms of accommodating trucks, most agencies use truck aprons for single-lane designs and some use aprons for multi-lane designs. With multi-lane roundabouts, most agencies have designs that allow trucks to track into adjacent lanes. Some agencies have roundabout designs where trucks stay in their lane when the entry lanes are striped. No agencies have roundabout designs where trucks would stay in their lane, even when not striped in the circulatory road.

4. The most common sign required was the Roundabout Ahead sign (84% of the responses and 78% of the "high" group), most with a speed or speed reduction tab.
   Other common signs were:

   - Pedestrian Crossing signs (58% of all responses and 50% of the "high" group). Pedestrian priority at roundabout crosswalks is discussed in Part 8.
   - Yield Ahead signs (51% of the responses and 50% of the "high" group).
   - Lane Use signs on multi-lane roundabouts (49% of the responses and 61% of the "high" group).
   - Map-Type diagrammatic guide signs (47% of the responses and 44% of the "high" group).

5. With regard to Lane Use signs, there was no clear indication among agencies as to which is preferred – standard or "fishhook" signs. Standard lane use arrows for pavement markings are currently preferred over "fishhook" lane arrows.

6. With regard to pavement markings in the circulatory road of multi-lane roundabouts, most responses were that they are always installed.

7. Agencies were also asked an open-ended question about whether they have experienced or are experiencing any issues related to maintenance inside the roundabout, snow clearing or emergency response. None responded.

INTERPRETATION AND RECOMMENDATIONS

As mentioned in Part 4, good visibility of the intersection is important especially on high-speed approaches, and can be accomplished through the geometry of the approach and entry. It can be aided through approach signs and pavement markings, and conspicuous central island landscaping. In the UK special warning signs and transverse pavement markings (with decreasing separation as one approaches the roundabout) are standard treatments on high-speed approaches. Both are shown in Figure 6.12. These treatments could be applied in North America as well.

With respect to signs, it would seem from the survey responses there is a tendency for the more experienced agencies to require fewer signs, in particular Roundabout Ahead, Pedestrian Crossing, and Yield Ahead signs. Although map-type diagrammatic signs are perhaps the most important approach signs at roundabouts, they were used less frequently by the more experienced agencies.

Figure 6.12
High-Speed Approach Treatments in the UK

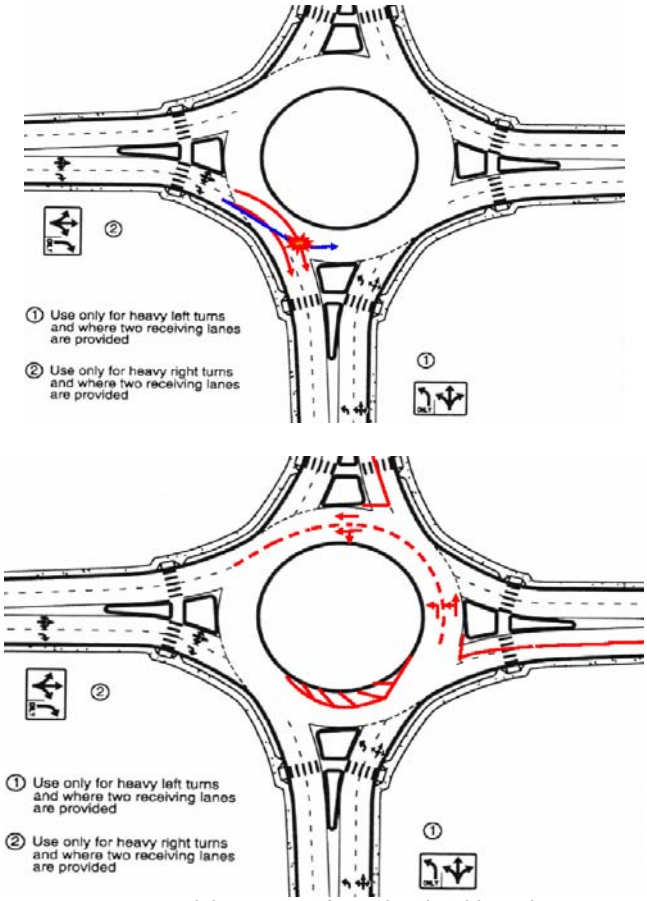
Photo: Roundabouts and Traffic Engineering

Circulatory road markings may or may not be necessary at all multi-lane roundabouts depending on the lane configuration that is dictated by traffic demands. They are necessary for dual left turns, other exclusive lanes, and roundabouts having more than four legs. An example of this need is in Exhibit 7-5 of the FHWA guide, as shown in Figure 6.13 for a roundabout with dual left and right turn lanes.

The top diagram illustrates incorrect geometry where the two-lane circulatory road gives drivers in the eastbound right turn lane the opportunity to make through movements, with the possibility of an exit-circulating crash. In this case, the circulatory road must not be wide enough to allow two-lane operation past the next downstream splitter island.

The bottom diagram shows the addition of circulatory road markings based on the lane use signage. The markings lessen the possibility of an exit-circulating crash at the south leg of the roundabout because of the dual right turn. The markings also lessen the possibility of an exit-circulating crash at the north leg of the roundabout because of the dual left turn. In this case, because of the unusual lane designation, the circulatory road markings increase positive guidance for drivers and greatly lessen the potential for crashes in the roundabout. Note that on the lower diagram, markings indicating the single lane exits on the east and north legs reinforce that the geometry should not allow for a two-lane exit. In the foregoing examples a failure to understand the lane configuration would lead to incorrect geometry for the anticipated traffic patterns.

Figure 6.13
A Case for Circulatory Road Markings



Source: FHWA Roundabouts: An Informational Guide and Barry Crown

Most of the agencies surveyed reported they always used circulatory road markings at multi-lane roundabouts, regardless of the lane configurations.

The Markings Technical Committee draft chapter for a future edition of the US MUTCD, which shows examples of pavement markings for single-lane and multi-lane roundabouts, presents good information on how to designate lane use for various lane configurations. However, there is no supplementary guidance governing the conditions when each configuration should be applied. Designers need to be aware that traffic volumes (peak and off-peak) dictate the use of alternative lane designation configurations, and that the geometry of the roundabout will be affected by the choice of lane designation.

More research is needed about conditions under which the circulatory road of a multi-lane roundabout should be marked, and in quantifying the advantages and disadvantages of circulatory road marking in terms of lane consciousness and the space needs of trucks. This research should employ case studies and human factors testing.

Human factors testing should be undertaken on the use and recognition of special signs and markings for roundabouts. These include various guide signs, navigation signs (to nearby regional/provincial/national parks, municipal facilities, tourist attractions, parking areas, etc.) broken line versus “shark’s teeth” yield line markings, and standard versus “fishhook” lane designation signs and pavement arrows for multi-lane roundabouts.

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7.0 RULES OF THE ROAD

LITERATURE REVIEW

Roundabouts are relatively new to North American drivers, and any new traffic device requires widespread education. Unfortunately, only a relatively small number of road authorities are in the process of developing provincial or state vehicle codes, local ordinances or regulations for roundabouts. Slowly, driver education guidelines and statutory operating procedures for driving roundabouts are being disseminated.

Some of the methods by which drivers can be educated on roundabout use include:

- Adding roundabout information in driver education manuals.
- Including roundabout general operating principles in driving license tests.
- Using videos that demonstrate how to navigate a roundabout.

Many agencies are seeking a model for rules of the road at roundabouts. The model that has been in existence the longest is the UK model contained in their driver handbook. In the interests of providing Canadian road agencies with assistance in developing their highway codes to include roundabouts, the following is an excerpt from the UK Highway Code (transposed for North American driving):

- When entering a roundabout, give way to any traffic on your immediate left unless road markings indicate otherwise; but keep moving if the way is clear. At some junctions there may be more than one roundabout. At each, apply the normal rules for roundabouts. Keep a special lookout for the give way lines.
- Where there are two lanes at the entrance to a roundabout, unless signs or road markings indicate otherwise:
  When turning right:
  Approach in the right hand lane; keep to that lane in the roundabout.
  When going forward:
  Approach in the right hand lane; keep to that lane in the roundabout. If conditions dictate (for example, if the right hand lane is blocked), approach in the left hand lane; keep to that lane in the roundabout. If the roundabout itself is clear of other traffic, take the most convenient route through the roundabout.
  When turning left:
  Approach in the left hand lane; keep to that lane in the roundabout.
- When there are more than two lanes at the entrance to a roundabout, unless signs or road markings indicate otherwise, use the clearest, most convenient lane on approach and through the roundabout suitable for the exit you intend to take.
- When in a roundabout, look out for and show consideration to other vehicles crossing in front of you, especially those intending to leave by the next exit.
- Turn signals at roundabouts:
  When turning right:
  Use the right turn indicator on approach and through the roundabout.
  When going forward:
  Use the right turn indicator when passing the exit before the one to be taken.
  When turning left:
  Use the left turn indicator on approach, and maintain this signal until passing the exit before the one to be taken. Then change to the right turn indicator.
- Watch out for cyclists and for long vehicles, which have to take a different course, both on the approach to and in the roundabout.

A second example, in North America, is the Vermont code:

- A roundabout is a circular intersection designed to slow traffic while lowering delays and handling higher traffic volumes. Roundabouts have proved to more safely accommodate vehicles, pedestrians and bicyclists than Stop signs or traffic signals. U-turns are also permitted at roundabouts.
- The most common signs you will see when approaching a roundabout are as follows: “Roundabout Ahead” and “Reduced Speed Ahead” signs which inform that you are approaching a roundabout.
- The advisory speed limit sign tells the driver the maximum safe operating speed for

approaching the roundabout and operating through the roundabout. When approaching a roundabout, slow down to advisory speed. Also be prepared to stop for pedestrians, if a crosswalk is in the vicinity.

- You will also find Yield signs in a roundabout. When a Yield sign is present, slow down or stop at the entry line to the circular roadway when there are other vehicles present. The vehicles already in the roundabout have the right of way over vehicles entering the roundabout. Enter the roundabout only when there is an adequate and safe gap in traffic.
- Signalling at roundabouts is important and is courteous to others to let them know your intentions, and it is the law. When approaching a roundabout, use a right signal for right hand turns, no signal for through travel, and a left signal for left hand turns.

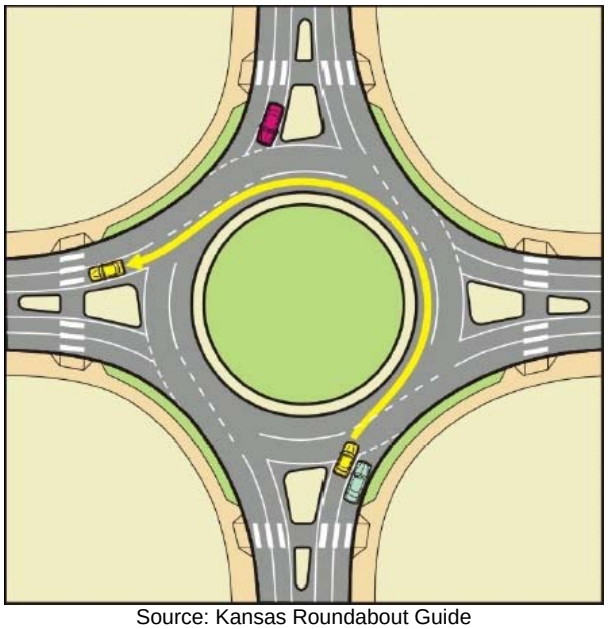
The main emphasis with driver education for roundabouts is to ensure that circulating traffic has priority over entering traffic and that drivers travel in a counter-clockwise direction in the circulatory road. In theory, the yield at entry rule should be relatively easy to mandate and enforce, requiring only regulatory Yield signs. Some jurisdictions have enforced this with tabs under the Yield sign reading “To Traffic in Circle” or similar. Additional measures such as this may be useful where an approach was previously not subjected to any traffic control. Counter-clockwise travel should be relatively easy to mandate and enforce, although several Canadian jurisdictions have reported the installation of regulatory One-Way signs in the central island to reinforce the rule.

The concept of maintaining correct lane use at multi-lane roundabouts is more difficult to convey. Some drivers tend to stay in the outside lane at all times when navigating a roundabout, feeling safer and thinking they do not have to change lanes when exiting. Roundabouts should be treated the same as other intersections in regards to lane choice. As Figure 7.1 shows, the correct lane to enter a roundabout when making a left turn is the left lane. If a northbound driver makes a left turn from the outside lane, a driver making a northbound through movement from the inside lane (typically permitted) will be cut off at the north leg exit.

Additional rules of the road for multi-lane roundabouts include:

- Do not overtake in the circulatory road.

Figure 7.1
Turning Left at a Multi-Lane Roundabout



Source: Kansas Roundabout Guide

- Keep a safe distance from large vehicles. Most roundabouts are designed to allow two cars to circulate side by side, but only one truck. Turning trucks tend to sweep wide and over-track to the inside. Just as at other intersections, do not pass trucks that are turning right on the inside, or overtake trucks that are turning left.
- Do not change lanes once inside the roundabout. Rather, choose the correct lane at entry, and stay in that lane through to the exit.

Collisions between exiting vehicles are possible at multi-lane roundabouts when drivers choose a lane incorrectly, as shown in Figure 7.2. Driver education guidelines need to ensure the public understands proper lane use at multi-lane roundabouts. Education for enforcement personnel is also needed. For the case of the left turn from the outer lane, one agency reported that an officer incorrectly cited the driver in the inner lane for not allowing the driver in the outer lane to continue turning left, although the exit lane lines and the vehicle positions suggested the driver in the outer lane was in error.

A typical set of instructions from the Region of Waterloo on navigating a roundabout is included in Appendix B. The instructions include driving instructions such as signalling at roundabouts, and guidance for pedestrians and bicyclists.

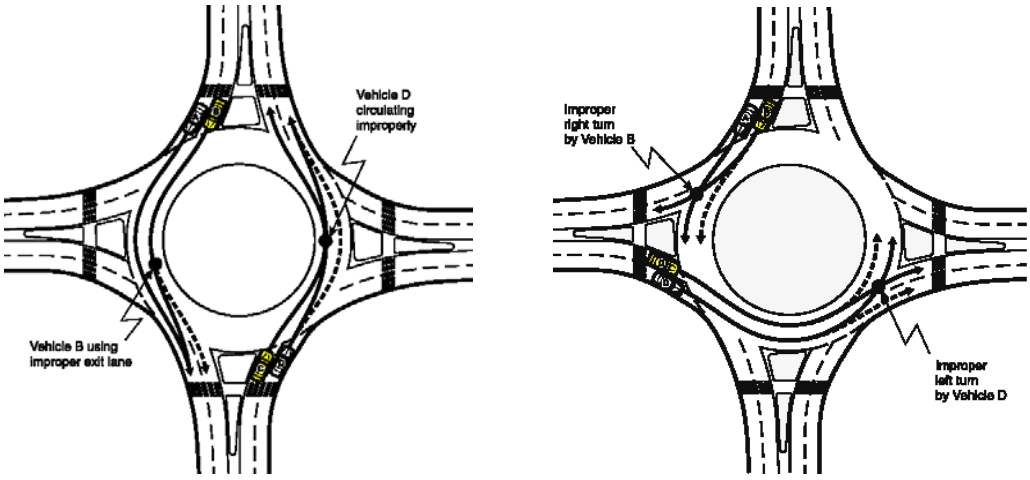
Pedestrians and drivers should be aware of regulatory priority at roundabout crosswalks. In Ontario, for example, pedestrians do not have priority at marked crosswalks unless accompanied by a traffic control device. Bicyclists should follow the same rules of the road as drivers when they navigate a roundabout as a vehicle. Pedestrian and bicyclist issues at roundabouts are discussed in Part 8.

RESULTS OF SURVEY

Part 7 of the survey of agencies sought information on practices regarding rules of the road.

1. Agencies were asked an open-ended question about whether they had any state/provincial vehicle codes, or local ordinances or regulations, in place for roundabouts. The City of Hamilton stated that a Road Alteration By-Law was required. Collier County, Florida, reported they use State laws for operating a vehicle within a roundabout. A few other US agencies stated they have adopted local or state ordinances. Dublin, Ohio mentioned they are revising their traffic code to allow U-turns at roundabouts.

Figure 7.2
Improper Lane Use and Turn Conflicts at Multi-Lane Roundabouts



Source: FHWA Roundabouts: An Informational Guide

2. Agencies were also asked an open-ended question about whether changes had been made to driver education guidelines and statutory operating procedures to include roundabouts. Some states, notably Colorado, New York, Vermont and Washington, have provisions for how to drive roundabouts in their driver education handbooks. Some have created brochures to distribute at schools and to new homeowners, or videos for the general public.

INTERPRETATION AND CONCLUSIONS

Knowing how to navigate a roundabout is important for all users – drivers, pedestrians and bicyclists. This is particularly the case for rules of the road at multi-lane roundabouts. There have been some efforts to develop regulations and guidelines for roundabout use, but a more concerted effort is needed by more road agencies. This should happen over time as more roundabouts become operational, but efforts are still required if widespread acceptance is to accompany the proliferation of roundabouts in Canada.

The general issue of public education is discussed in Part 9. Specific driver education must ensure yield at entry and counter-clockwise circulation are enforceable through existing regulatory signage and good design. Experience has shown that even the best geometric speed reduction does not ensure yield compliance without education and enforcement.

Ensuring correct lane use at multi-lane roundabouts not only requires education, but also correct signs and pavement markings to direct drivers into the appropriate lane before they enter the roundabout. The concept of correct lane use, particularly when making a left turn, seems to be more of an issue in North America than the engineering community had first realized.

REFERENCES

1. Federal Highway Administration (FHWA) *Roundabouts: An Informational Guide*, 2000.

2. The Highway Code, Her Majesty's Stationery Office, United Kingdom, Undated.

8.0 VULNERABLE ROAD USERS

As roundabouts began to appear in growing numbers across North America, the engineering community reacted with concern over the safety of vulnerable road users. The concerns stem from general unfamiliarity of drivers with roundabouts along with the problem of right-of-way priority at pedestrian crossings. Despite the safety evidence, agencies continue to remain cautious of their use and benefits. Pedestrians that use roundabout crosswalks acknowledge the need for vigilance, but are generally comfortable because of the conditions afforded by a shorter two-stage crossing in a low speed environment.

This section highlights the experiences of road agencies in attempting to educate vulnerable road users and provide optimal information to all users.

PROVISIONS FOR PEDESTRIANS

Pedestrian Facilities

Any roundabout where there is a reasonable possibility of pedestrian activity should be designed to accommodate pedestrians. This includes having sidewalk connections to the pedestrian crossings, curb depressions, and refuge areas on the splitter islands. These refuge areas should be wide enough, at least 1.8 metres, to accommodate a person pushing a stroller or walking a bicycle.

Pedestrian crossings at roundabouts should be located one vehicle length, or a multiple thereof, back from the yield line. This length is given in the FHWA guide as 7.5 metres, although many jurisdictions are now using a shorter 6.0 metre distance to better reflect the length of most passenger cars.

Many agencies install Pedestrian Crosswalk signs in advance of pedestrian crossings on both the entry and exit of a roundabout where pedestrians are expected. In Ontario, where the closest equivalent is the Pedestrian Ahead warning sign, the Region of Waterloo installs signs facing drivers indicating "Yield Here to Pedestrian", as shown in Figure 8.1. This indicates that a driver must yield to a pedestrian within a crosswalk at a roundabout.

Pedestrian Crosswalk Markings

Most jurisdictions in North America install crosswalk markings at all pedestrian crossings at roundabouts. According to the FHWA guide, the intent of crosswalk markings is to channel pedestrians to an appropriate crossing location, since it is located away from the yield line, and to provide a visual cue to drivers of where pedestrians may be within the road. Marked crosswalks are generally not needed at locations where the crosswalk is distinguished from the road by visually contrasting pavement colours and textures.

Figure 8.1
"Yield Here to Pedestrian" Sign at Pedestrian Crossing

Photo: Region of Waterloo

These markings should not be construed as a safety device, as data from other countries suggest that the presence of markings has no appreciable effect on pedestrian safety. A study done in 2005 by the FWHA entitled "Safety Effects of Marked Versus Unmarked Crosswalks at Uncontrolled Locations" concluded that under no condition was the presence of marked crosswalk alone at an uncontrolled location (not necessarily a roundabout) associated with significantly lower pedestrian crash rate compared to unmarked crosswalk. Furthermore, on multi-lane roads with traffic volumes greater than 12,000 vehicles per day, having a marked crosswalk was associated with a higher pedestrian crash rate compared to an unmarked crosswalk. Therefore, just adding marked crosswalks (with no engineering, enforcement, or education) is not expected to reduce pedestrian crashes.

If crosswalks are to be marked, a marking pattern using a series of lines parallel to the flow of traffic is generally recommended. Most jurisdictions use "zebra" markings with lines approximately 0.3 to 0.6 metres wide, spaced 0.3 to 1.0 metres apart, spanning the width of the crosswalk, or "ladder" type markings that add transverse lines to the zebra markings. These crosswalks are more visible than standard transverse crosswalks and less likely to be confused with the yield line of a roundabout. Regardless of type, when crosswalk markings are installed agencies agree they should cross both the entrance and exit of each leg and any by-pass lanes.

In addition to pavement markings, a few US jurisdictions are experimenting with in-pavement flashing warning lights activated by push button to enhance pedestrian visibility.

In rural areas where pedestrian activity is minimal, the FHWA guide recommends that pedestrian crosswalk markings be optional, and that they not be used at roundabouts without illumination because vehicle headlights may not be sufficient to illuminate a pedestrian in time to avoid a collision.

Pedestrian Signals

If pedestrian volumes are sufficiently high, it may be necessary to signalize one or more of the crossings. This can impact motor vehicle operations, mainly because exiting vehicles can queue back into the roundabout and block adjacent entries. Fortunately, minimum pedestrian walk times can be kept short since the crossing can be split into two stages with the presence of splitter islands and modern signal technology.

Figure 8.2 shows one of the only signalized pedestrian crossings of a roundabout in North America, in Gatineau, Quebec. This roundabout and one immediately to the west have signalized pedestrian crossings on all legs. Observations of the level of pedestrian activity suggest that the signals were not warranted. Nevertheless, each signalized crossing has the following characteristics:

Figure 8.2
Signalized Pedestrian Crossing at Roundabout, Gatineau, Quebec

Photo: Ourston Roundabouts Canada

- The crossing is staggered through each splitter island.
- The signal is push button actuated for each stage of the crossing. This is ideal because the pedestrian can decide whether the signal is needed to cross one or both legs.
- A 10 second countdown timer for each crossing leg with minimal clearance time.
- Audible signals for the visually impaired.

One issue that has been raised in conjunction with the signalization is whether the presence of a green signal indication upstream of the roundabout entry, which is under yield control, would give a conflicting message to drivers and pedestrians. In this case, the signals at the smaller of the two roundabouts are closer to the exits and can be confused with the yield control upstream. At the larger roundabout (photo) the signal is far enough from the upstream entry to not cause this confusion.

Pedestrian signals are common at roundabouts in the UK, but because they are usually located well away from the roundabout entries and exits the possibility of a conflicting indication between the signal and the roundabout entry is relatively low.

PROVISIONS FOR VISUALLY IMPAIRED PEDESTRIANS

At roundabouts and other intersections, visually impaired pedestrians are presented with travel challenges that are not experienced by sighted pedestrians. These challenges can be broken down into two categories: way-finding and gap detection. According to the Kansas guide, the crossing of a leg of a roundabout for a visually impaired pedestrian consists of the following tasks:

1. Finding the beginning of the crosswalk.
2. Establishing directional alignment for the crossing.
3. Deciding when to initiate the crossing.
4. Maintaining proper direction and monitoring traffic movements while crossing.
5. Finding the beginning of the splitter island.
6. Finding the end of the splitter island.
7. Finding the end of the crosswalk.

With the exception of task 3, each of the above tasks can be aided through design treatments at the roundabout. Some of the more common treatments include low-growth landscaping to direct visually impaired pedestrians to crosswalk locations, truncated domes of a contrasting colour that provides a distinctive surface detectable by cane or underfoot, and audible pedestrian signals on one or more legs of the roundabout. Figure 8.3 shows an example of low-growth landscaping in Clearwater, Florida. Figure 8.4 shows a crosswalk in Madison, Wisconsin, with truncated domes at the curb and placed transversely across the sidewalk to locate the crossing for visually impaired pedestrians.

Task 3, deciding when to initiate the crossing, is much more complex, as it requires a visually impaired pedestrian to distinguish between circulating vehicles and entering or exiting vehicles.

Figure 8.3
Example of Low-Growth Landscaping to Direct Pedestrians

Photo: Ourston Roundabouts Canada

Figure 8.4
Pedestrian Crossing with Tactile Treatments

Photo: Ourston Roundabouts Canada

In the United States, as of November 2005 the US Access Board is recommending that all multi-lane crossings at roundabouts be equipped with pedestrian signals to assist the visually impaired, regardless of location or pedestrian volumes.

PROVISIONS FOR BICYCLISTS

Bicyclists should have the option of travelling through a roundabout as would a motor vehicle, or dismounting and traversing as a pedestrian. If bicycle lanes are in place on one or more of the legs of a roundabout, then they should terminate at the roundabout to present bicyclists with the option (see Figure 8.5). Standard Bike Lane Begins and Bike Lane Ends signs are usually used when terminating bike lanes at roundabouts.

Almost all North American sources agree that under no circumstances should bicycle lanes be continued through a roundabout. The additional width of a bike lane within the circulatory road increases vehicle speeds, and the lane keeps bicyclists in the outside of the circulatory road and vulnerable to exiting vehicles, whose drivers are seldom expecting bicyclists.

Figure 8.5
Bicycle Re-Entry at a Roundabout Exit

Photo: Region of Waterloo

RESULTS OF SURVEY

Part 8 of the survey was about accommodating pedestrians, visually or mobility impaired pedestrians, and bicyclists.

1. Regarding pedestrian provisions at single-lane roundabouts, almost all agencies responded they provided marked crossings (86% of all responses and 83% of the "high" group). Fewer reported they had no provisions (7% of all responses and 17% of the "high" group).

2. Regarding pedestrian provisions at multi-lane roundabouts, the majority of agencies responded they provided marked crossings (57% of all responses and 67% of the "high" group). A higher number of agencies reported they had no provisions than was the case for single-lane roundabouts (26% of all responses and 17% of the "high" group).

3. As for criteria for marking crosswalks, most agencies always marked them (55% of all responses and 50% of the "high" group). Few marked crosswalks only under certain conditions.

4. Concerning priority at crosswalks, most agencies stated that pedestrians had priority at marked crosswalks (71% of all responses and 67% of the "high" group). Some stated that pedestrians had priority at unmarked crosswalks (31% responses received, 22% of the "high" group). Few indicated that pedestrians did not have priority.

5. Various treatments are in use to specifically protect pedestrians at crosswalks. The most common response was Pedestrian Warning Signs for vehicles, followed by None and Pedestrian Warning Signs for pedestrians.

6. Several treatments were identified for accommodating visually or mobility impaired pedestrians at roundabouts. The most common was Curb Ramps (79% of all responses and 83% of the "high" group). The next most common was tactile Sidewalk Ramps (45% of all responses and 44% of the "high" group).

7. When accommodating bicyclists, most agencies responded they either provided Bike Lane Terminations (48% of all responses and 50% of the "high" group), or None (36% of all responses and 33% of the "high" group). Unfortunately, due to the wording of the question we are not sure whether the "None" response means the agency has bike lanes and does not provide terminations, or that the agency does not have any roundabouts with bike lanes. We note very few (2% of all responses and 6% of the "high" group) have Dedicated Bike Lanes Through Roundabout, a potentially hazardous treatment for bicyclists.

INTERPRETATION AND CONCLUSIONS

According to the literature review and survey, most agencies in North America mark all pedestrian crosswalks at single-lane and multi-lane roundabouts, regardless of pedestrian volumes. Pedestrians have priority at marked crosswalks in most jurisdictions, and in some they have priority at unmarked crosswalks as well. Studies at other types of intersections have shown pedestrian safety is not necessarily enhanced by the presence of markings.

In the UK, the decision whether to mark a crosswalk is based on the formula:

PV^2

where P = number of pedestrians crossing within 50 m either side of the proposed crossing site; and
V = number of vehicles both directions passing the site.

The criterion is applied on a scale beginning with no crossing or refuge, then a crossing without markings, then a crossing with markings and so on, until a pedestrian signal is warranted. Pedestrian crosswalks are normally not marked unless the degree of conflict is greater than a certain minimum. A similar method of warrants could be considered for North American locations.

The US Access Board recommendation that all multi-lane crossings at roundabouts be equipped

with pedestrian signals has potentially far-reaching consequences. Initially they sought to require that all roundabouts have pedestrian signals to assist the visually impaired. The need to provide access for all users is reasonable but there are concerns about costs of providing pedestrian signals at all multi-lane roundabouts, and this could limit the number that are installed. It is recommended the merits of pedestrian signals at roundabouts be evaluated on a case-by-case basis.

REFERENCES

1. Federal Highway Administration (FHWA) *Roundabouts: An Informational Guide*, 2000.

2. Zegeer, C. et al, *Safety Effects of Marked Versus Unmarked Crosswalks at Uncontrolled Locations*, US Department of Transportation, FHWA, 2005.

3. California Department of Transportation (CalTrans), *Design Information Bulletin Number 80-01 Roundabouts*, 2003.

4. Kansas Department of Transportation, *Kansas Roundabout Guide*, 2003.

9.0 PUBLIC EDUCATION AND ACCEPTANCE

LITERATURE REVIEW

Public acceptance is often one of the biggest challenges facing a jurisdiction planning its first roundabout. Without the benefit of explanation or first-hand experience and observation, the public is likely to incorrectly associate roundabouts with older traffic circles or rotaries they have experienced or heard about. The public, and many road agencies, can resist such changes in driving behaviour and environment as roundabouts.

To lessen public opposition, most successful projects start with education on the differences between traffic circles or rotaries and roundabouts. Brochures, videos, and mass media can be used when a roundabout is under consideration, or during the initial stages of a project.

Often the public expresses a high degree of opposition to roundabouts, particularly the first roundabout in an area, prior to construction, then a more positive attitude after experiencing them firsthand. A survey conducted through NCHRP Synthesis 264 on public attitudes towards roundabouts is summarized in Table 9.1.

A more recent survey of public opinion before and after roundabout installations, undertaken by The Insurance Institute for Highway Safety, found that 41% of those surveyed "strongly opposed" and 31% were "in favour" of roundabouts before they opened, versus 15% strongly opposed and 63% in favour after they opened.

The most successful efforts, whether to educate on roundabouts or otherwise, seem to have these elements in common:

- Foresight and careful planning.
- Meetings with the public on their "own turf".
- Visual aids during presentations.
- Partnering with the press for education and awareness.

An example of a public education program from the City of Lacey, Washington, is provided in Appendix C.

RESULTS OF SURVEY

In Part 9, agencies were asked about public acceptance levels before and after roundabouts, concerns and misconceptions, and public education and attitudes.

1. Before construction of the first roundabout in a jurisdiction, agencies overall reported that public opinion on roundabouts was about 43% Negative or Very Negative compared with 13% Positive or Very Positive.

2. After construction of the first roundabout, agencies overall reported that public opinion on roundabouts was about 40% Positive or Very Positive compared with 15% Negative or Very Negative. The public opinion information is summarized in Table 9.2. It should be noted, however, that this information is not based on any actual surveys undertaken by the responding agencies.

Table 9.1
Typical Public Attitudes Towards Roundabouts

Attitude	Percent	
	Before Construction	After Construction
Very Negative	23	0
Negative	45	0
Neutral	18	27
Positive	14	41
Very Positive	0	32

Source: NCHRP Synthesis 264

Table 9.2
Summary of Public Opinion of Roundabouts (All Jurisdictions Surveyed)

Public Opinion	Before First Roundabout	Currently
Very Negative	17%	4%
Negative	26%	11%
Neutral	17%	11%
Positive	7%	31%
Very Positive	6%	9%
Unknown	17%	34%

3. The most common misconception that agencies had to overcome about roundabouts was Drivers Will Not Get Used to Them (56% responses received, 89% of the "high" group). Other misconceptions were:

   - They are Traffic Circles or Rotaries (52% of all responses and 67% of the "high" group).
   - They are Unsafe for Pedestrians and Bicyclists (46% of all responses and 78% of the "high" group).
   - They are Unsafe for All Users (41% of all responses and 61% of the "high" group).
   - They Need to be Larger to Accommodate Large Trucks (30% of all responses and 56% of the "high" group).
   - They are Only Applicable on Low-Volume Roads (30% of all responses and 56% of the "high" group).

4. The main concern agencies had with opening the first roundabout in their jurisdiction was Public Education (57% of all responses and 83% of the "high" group). Secondary concerns were Pedestrian and Bicyclist Safety, Driver Safety, and Correct Lane Use for multi-lane roundabouts.

5. A variety of public education programs were undertaken by the various agencies. The most common were Informational Brochures (57% of all responses and 94% of the "high" group), Public Meetings (44% of all responses and 61% of the "high" group), and TV or Radio Spots (30% of all responses and 44% of the "high" group). Few agencies stated they did no public education (7% of all responses and 6% of the "high" group). It would seem the more experienced agencies also undertook more public education.

6. In terms of undesirable driver behaviour noted at roundabouts in the jurisdiction, agencies reported Low Rate of Yielding (30% of all responses and 44% of the "high" group), Illegal Left Turn in Front of Central Island (28% responses received and 33% of the "high" group), and Poor Lane Discipline on multi-lane roundabouts (26% of all responses and 50% of the "high" group) as the most common. Interestingly, agencies with a higher number of roundabouts had a higher rate of drivers making a left turn from the outer lane (39% versus 17% of all responses).

7. The survey then asked an open-ended question about what steps had been taken to resolve these concerns. Twenty-one (21) agencies responded, generally stating they had enforcement increased, and modified or added signs and pavement markings. Of the latter, adding a tab to Yield signs with the message "To Traffic in Roundabout" or similar was the most common. Several agencies said that with regard to multi-lane roundabouts, revised lane assignment signs and pavement markings aided correct lane use, as did maintaining the striping in the circulatory road of the roundabout.

8. Another open-ended question was asked about policies in place or challenges with roundabout implementation. Responses included the consideration of roundabouts whenever traffic signals were being planned, and mention of political pressure and public opinion. A few agencies said the state opposes roundabouts or has not

been supportive of local roundabout programs. Some agencies also mentioned that they:

- Recommend that roundabouts be considered whenever an intersection is being evaluated for safety or capacity concerns.
- Require a roundabout evaluation with new or poorly operating signals or all-way stops.
- Allow them on any classification of road, but not with more than 2 approach lanes, or if grades exceed 4%, or if volumes exceed LOS 'B' in RODEL.
- Favour single lane roundabouts, but not necessarily multi-lane roundabouts on high-speed roads.

Although not included in the survey responses, three jurisdictions have policies on roundabout implementation. Policies for the Region of Waterloo, Ontario, the Province of BC and the New York State DOT are discussed in Part 2. Also, the State of Wisconsin requires that studies routinely be undertaken to compare alternative types of intersection control.

9. A third open-ended question was about additional thoughts on public education. Most responses had to do with the need for more and better education on roundabout use, and how it is seldom given the attention or budget it deserves. One response summed it up: "Can never have enough. Please visit the City of Lacey Website for the video we created for driving in modern multi-lane roundabouts."

INTERPRETATION AND CONCLUSIONS

The results of the survey in terms of public opinion of roundabouts is similar to that conducted through NCHRP Synthesis 264 and elsewhere, and shows that generally they are better received once they are in operation. Experience in North America is also demonstrating that drivers can get used to roundabouts, that they are safe for all users, and that they are not just applicable on low-volume or low-speed roads. If an agency is able to implement a roundabout that solves a specific congestion or safety problem, then future such projects will be easier for the public to accept.

As mentioned in Part 7 with driver behaviour and rules of the road at roundabouts, public education is essential for getting the public to accept roundabouts, particularly multi-lane roundabouts, and understand how they operate.

REFERENCES

1. Taekratok, T. *Modern Roundabouts for Oregon*, Oregon Department of Transportation, 1998.

2. Insurance Institute for Highway Safety (IIHS), *A Review of Evidence-based Traffic Engineering Measures to Reduce Pedestrian-Motor Vehicle Crashes*, 2003.

3. Jacquemart, G. *Modern Roundabout Practice in the United States*, National Cooperative Research Program (NCHRP) Synthesis 264, 1998.

10.0 SYSTEM CONSIDERATIONS

The final chapter of this synthesis addresses general comments and concerns over the implementation of roundabouts. Roundabouts can be viewed as a transportation planning tool for system-wide consideration, such as corridors and grid networks. Thus as an extension of the planning section, Part 2, this section documents further experiences and North American practice in planning for roundabouts throughout a road network.

ROUNDABOUTS AND ACCESS MANAGEMENT

Access management with roundabouts is applied using the same design speed criteria as at other intersections. But because operating speeds are lower near roundabouts at all times and for all approaches, access management restrictions are less onerous. In many countries where they are common, commercial developers seek corner properties at roundabouts for these reasons.

The location of access points near a roundabout is usually evaluated on the basis of vehicle queuing along the approach in question, and queuing based on the traffic demand for left turn movements into the access point. In addition to queue requirements, the splitter islands of a roundabout may limit the location of nearby access points, although long splitter islands can be interrupted for access, or access points can be made right turns only.

Most guides agree that access points should not be located between pedestrian crosswalks and the yield line of a roundabout. They also agree that access points along the circulatory road of a roundabout is generally not desirable. They introduce conflicts into the circulatory road, including acceleration and deceleration, and a typical driveway does not discourage wrong way movements into and out of a roundabout like a splitter island. Nonetheless, due to site constraints some agencies have had to provide direct access into a roundabout. Ideally, traffic volumes should be low, and the design of the site should be such that vehicles can be turned around internally and not have to back out into the roundabout.

PROXIMITY TO OTHER TRAFFIC CONTROL DEVICES

Roundabouts are seldom built in isolation in urban areas. They are usually installed near other types of traffic control, and sometimes they are installed in corridors or at interchanges. The spacing between the roundabout and other types of traffic control or other roundabouts is determined through an estimate of queuing between intersections. Usually a roundabout will result in less queuing, so the queues expected at the signalized or unsignalized intersection will govern. The 95th-percentile queue should be completely accommodated between the two intersections and not impact any pedestrian crossings.

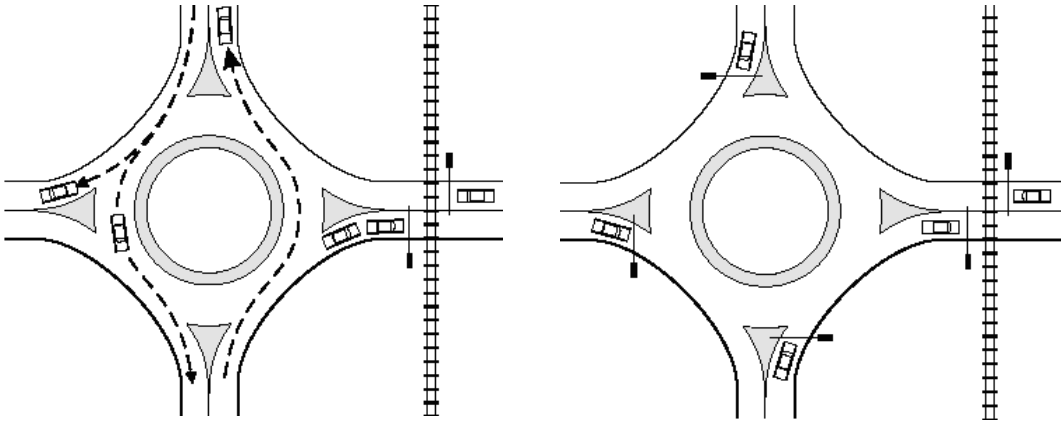
A downstream vehicle queue that extends back into a roundabout impedes circulating flow. As circulating flow is impeded, exits in the roundabout upstream of the impeded exit become blocked, further increasing the queuing within the circulatory road. In theory, an entire roundabout could lock up if an exit is blocked for long enough. Thus downstream queues should not back up into a roundabout for any significant period of time.

ROUNDABOUTS AND RAILWAYS

There are two cases where railway crossings can interact with roundabouts: through the centre of the roundabout, or across one of the legs. In either case queuing from a roundabout must not be allowed to back up into the track right-of-way. This can be achieved by preventing all vehicles from crossing the tracks while still allowing some movements to occur, or by installing gates to prevent all vehicles from entering the roundabout. Both are illustrated in Figure 10.1. The former could be considered if the 95th-percentile queue between the rail crossing and roundabout can be adequately accommodated between the two. Otherwise, the FHWA guide states that gates should be installed on all legs of the roundabout.

An example of a rail crossing through the middle of a roundabout in Salt Lake City, Utah, is shown in Figure 10.2.

Figure 10.1
Rail Crossings Adjacent to a Roundabout



Source: FHWA Roundabouts: An Informational Guide

Figure 10.2
Example of Rail Crossing in Middle of Roundabout

Photo: RoundaboutsUSA

In this case gates were installed on all legs of the roundabout and in the central island. The gates drop in succession to allow most vehicles already in the circle to exit before the train arrives. After the train leaves the circle, the two gates next to the tracks raise first, allowing vehicles coming from the traffic signal to get a head start into the roundabout.

If the 95th-percentile queue from the rail crossing backs up into the roundabout, full gating of the roundabout may not be necessary. This type of queue spillback occurs frequently at other types of intersections near rail crossings and may be more tolerated by the public.

ROUNDABOUTS IN CORRIDORS

Intersections usually determine the capacity of a corridor, not the sections in between. Signalized intersections often require exclusive turn lanes, with sufficient storage to avoid queue spillback. By contrast, roundabouts may require more right-of-way at the intersection, but not as much on the approaches.

Roundabouts in road corridors can:

- Result in less congestion.
- Slow traffic.
- Be more pedestrian friendly, both at the intersection because it is a roundabout, and between intersections because the road can be narrowed.
- Allow close intersection spacing.
- Facilitate U-turns.
- Result in less overall right-of-way impact.
- Create capacity at the intersection where it is needed, minimizing costs for pavement and right-of-way.

In Avon, Colorado, three signalized intersections along Avon Road and two unsignalized intersections at the I-70 ramp terminals were replaced with five consecutive roundabouts (see Figure 10.3). The roundabouts eliminated the need for costly road widenings, and the need to widen the I-70 overpass to accommodate left turn lanes for drivers to turn from Avon Road onto I-70.

In Golden, Colorado, four roundabouts were introduced in a commercial redevelopment along South Golden Road that generates 20,000 ADT. The other alternative looked at was traffic signals with centre medians and restricted left turns. With traffic signals there would be problems providing access to all businesses, and the resulting large intersections would be difficult for pedestrians. With roundabouts, drivers could make U-turns and not require full access at all the driveways (some could be made right turns only), and the driveways could be located closer together.

The following was reported after the roundabout alternative was implemented in Golden:

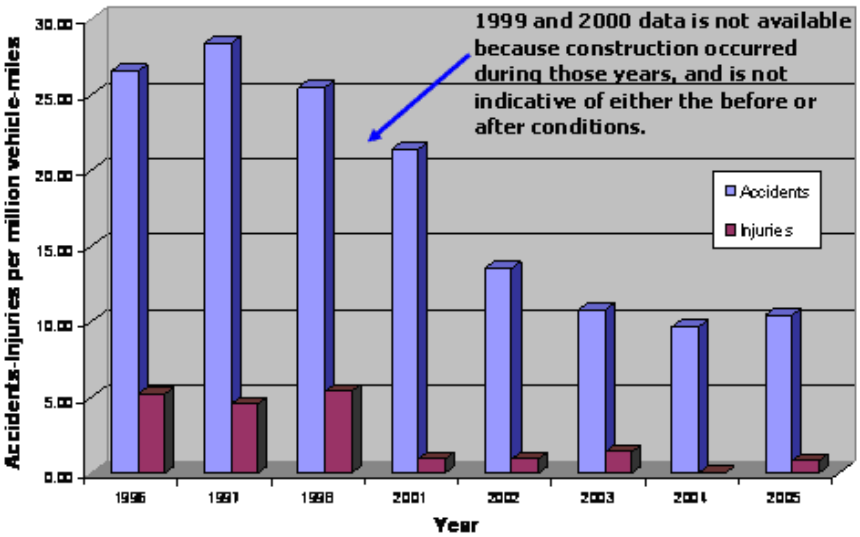
- A 60% reduction in collisions, and a 94% reduction in injury collisions (from 31 in three years). Refer to Figure 10.4.
- No pedestrian crashes.
- A reduction of 95th-percentile speeds from 48 mph to 33 mph.
- A reduction in average delay (the time needed to drive the half-mile of the corridor was reduced even with a 15 mph speed reduction).
- Elimination of large queues from parking lots.

Corridors with roundabouts, and relatively narrow road sections in between, are common in the UK. This “wide nodes” and “narrow roads” approach makes for efficient use of land along road corridors by maximizing capacity where it’s needed – at the intersections.

Figure 10.3
Five-Roundabout Corridor, Avon, Colorado

Photo: Ed Waddell

Figure 10.4
Collision Reductions Along South Golden Road



Source: City of Golden, Colorado

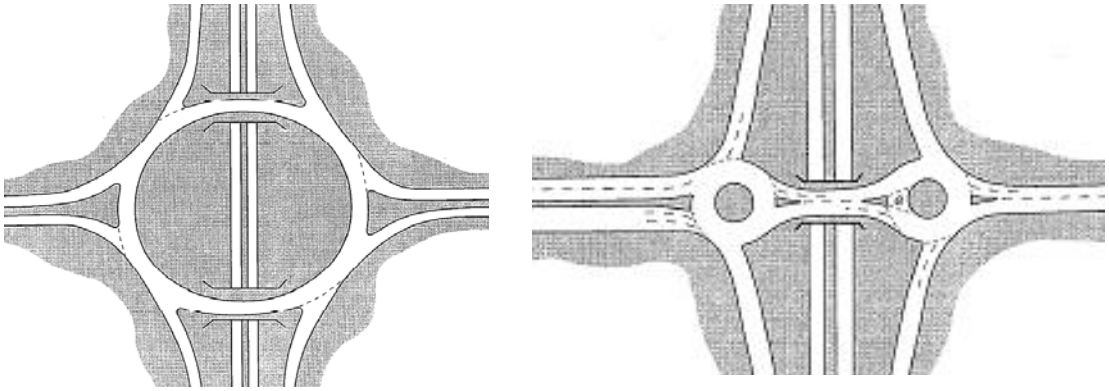
ROUNDABOUTS AT INTERCHANGES

The use of roundabouts in the US at highway interchanges is increasing. There are two configurations for roundabout interchanges: one large diameter roundabout centred over or under a highway, or two more compact roundabouts – one on either side of the highway. Both types are illustrated in Figure 10.5.

The one-roundabout interchange was historically favoured in the UK, but in more recent installations a pair of roundabouts in a diamond interchange configuration has become preferred. Only one bridge is required unless the highway is widely divided. Two compact roundabouts operate with lower circulating speeds which, combined with improved sight distances in and around the circle, generally results in better safety performance. They also tend to cost less because only one overpass or underpass structure is required instead of two.

One-roundabout interchanges tend to have slightly higher capacities. Two roundabouts in close spacing require well-implemented signs and pavement markings to ensure proper navigation.

Figure 10.5
Roundabout Interchanges



Source: Ourston Roundabout Design Guidelines

Elsewhere in the world, including recently in North America, the compact two-roundabout interchange is preferred. Examples of roundabout interchanges in North America include:

- I-70 at Vail Road, Vail, Colorado.
- I-70 at Chamonix Road, West Vail, Colorado.
- I-70 at Avon Road, Avon, Colorado.
- I-70 at Post Road, Avon, Colorado.
- I-135 at 1st Street, Newton, Kansas (one-roundabout interchange).
- I-91 at US5/VT9, Battleboro, Vermont.
- I-87 t the Northway, Saratoga Springs, New York.
- M-53/Van Dyke Avenue/18½ Mile Road, Stirling Heights, Michigan.

Additional considerations for roundabouts at interchanges compared to other locations include maintaining low approach grades, and ensuring vehicles queues do not block back to an adjacent closely spaced intersection or back to the highway. In the case of two-roundabout interchanges, they must be treated as a system in terms of lane continuity and balancing of lane use. This becomes especially important where frontage or service roads are closely spaced with the ramp terminal intersections, as shown in Figure 10.6.

The diamond ramp configuration is a more cost-effective and efficient interchange concept with roundabouts than with traffic signals. A pair of signalized intersections at the ramp terminals usually requires two dedicated lanes across the overpass or underpass to accommodate back-to-back turn lanes for opposing left turn queues. These extra lanes are not needed for roundabouts at the ramp terminals. This reduces the width of the overpass or underpass and the overall cost of the interchange.

The alternative to closely-spaced service roads is to consolidate the services road and ramp terminal into one roundabout. This has been done successfully at Vail and Avon, Colorado (see Figure 10.7).

Figure 10.6
Roundabout Interchange with Closely-Spaced Service Road, Lee Road, Michigan

Source: Mark Johnson, MTJ Engineering

Figure 10.7
Roundabout Interchange with Integrated Service Roads, Vail, Colorado

Photo: Ourston Roundabout Engineering, Inc.

Incorporating service roads into a roundabout is feasible when the service road volumes are low in proportion to the ramp terminal. That way, heavy left turn flows from the ramp terminals do not overly constrain capacity at the service road entries due to high opposing circulating flows. It is also feasible when the roundabouts are single-lane, as complex lane use signage is not required. Finally, this configuration takes up less space.

When service road volumes are proportionately high, separate roundabouts for the service road and ramp terminal are needed. With two roundabouts, for example, the off-ramp left turns do not need to pass each entry from the service road. Otherwise, the same left turn passes each service road, creating a greater constraint on capacity. Separate roundabouts are also advisable with multi-lane designs, as the circulatory road markings and navigation demands would be overly complex and demanding for drivers with a five-leg or six-leg roundabout that incorporates service roads. The accommodation of vehicle queues between the closely-spaced roundabouts is a critical design check.

ROUNDABOUTS IN A ROADWAY HIERARCHY

Safe and efficient vehicle travel on modern road networks is supplied using principles of a hierarchical system of streets. The streets are arranged according to classification, usually in a grid, where mobility and land access are exchanged according to desired function and expected travel demand. Where intersection volume and road function becomes a priority, roundabouts can serve an important role in promoting efficiency without the safety trade-offs that other large intersections can suffer from.

Figure 10.8 illustrates a well-developed grid road network in the UK including roundabouts at highway interchanges. In the photo there are approximately 28 roundabouts that have varying function according to the hierarchy of the road network. The minor intersections, where commercial development is located, are controlled by traffic signals, whereas the high mobility arterial intersections are controlled by roundabouts. The local intersections are low speed, accommodate higher pedestrian traffic and are compact, while the higher function roads with roundabouts are access controlled and accommodate pedestrian crossings at mid-block overpasses.

Figure 10.8
Modern Grid Road Network Using Roundabouts

Photo: Town of Milton Keynes

This post-war community is an example of how vehicle mobility can be optimized without sacrificing safety, efficiency and the needs of pedestrians and bicyclists. There are numerous examples of this type of road network in North America without roundabouts. The potential exists for new communities to be built on traditional grid networks, but with more efficient transportation infrastructure using roundabouts.

RESULTS OF SURVEY

Part 10 of the survey asked two open-ended questions about opinions of roundabouts as a traffic control device and other comments about roundabouts.

1. Respondents were asked for opinions on whether roundabouts were viewed as an alternative intersection control, or a unique solution with limited applications. Almost all the responses indicated roundabouts were an alternative intersection control to traffic signals and Stop signs.

2. The last survey question invited further comments. A wide variety of responses were received. Some of the more candid comments were:

   - Many still need to be convinced of their benefits.
   - There are still concerns about them from the public and among transportation professionals.
   - We are receiving more requests to install them.
   - They should be tied into the Kyoto Accord because of their environmental benefits. The federal government should be providing financial support for promoting and integrating roundabouts. (This is sometimes done in the US through the Congestion Management Air Quality (CMAQ) funding program).

- They need to be designed by experts, as minor variances in design parameters can yield big differences in operations.
- It is important to get all departments within an agency (local and state) to understand/accept the concept of roundabouts and include guidance in their department manuals.
- I predict the number of roundabouts will increase dramatically over the next 10 years.

INTERPRETATION AND CONCLUSIONS

At a system level roundabouts can have a wide variety of applications, from arterial corridors and highway interchanges to locations near signalized and unsignalized intersections, railway crossings, and access points. Survey experience in North America reveals most agencies are considering roundabouts not just as a unique solution with limited applications, but also fully as an alternative intersection control to traffic signals and Stop signs.

Where federal funding of surface transportation is widespread, as in the US, many states are considering strings of roundabouts in corridors to replace traffic signals. This is being done as in retrofit cases or to accommodate intensification of land uses where decreased access spacing is desirable but not feasible with traffic signals.

In the United Kingdom roundabouts are the default control at four-way intersections and three-way intersections with sufficient side street traffic volumes. The engineering community there considers traffic signals, at least in rural areas, to be inherently dangerous, as they allow for the possibility of right angle collisions at high-speed. Stop signs are rare (and require Department of Transport approval). The widespread use of Yield signs and roundabouts has resulted in a road network where, at least during off-peak periods, it is possible to travel long distances without ever having to stop. Despite this high level of mobility, the UK has the lowest rate of traffic fatalities among industrialized countries, with a collision rate significantly lower than in Canada.

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APPENDIX A

SURVEY OF ROUNDABOUT PRACTICE
RESULTS OF SURVEY REPORT
LIST OF AGENCIES RESPONDING TO SURVEY

For the E-Mailed Instructions…

Hi _____,

We are hoping you can take the time to help complete a survey for us….

The Transportation Association of Canada (TAC) has hired us to conduct a survey of roundabout practice in North America. The survey will form the basis of a Canadian Roundabout Synthesis of Practice, similar to NCHRP Synthesis 264.

We are interested in learning of your experience with roundabouts. We just need one survey per organization, to be representative of roundabout practice in your jurisdiction. More than one person can fill out the same survey so you may want to collaborate by filling out certain pages, and have your colleagues fill in the rest. We estimate it will take about 15 minutes to complete. We would like the surveys back before January 27th.

To start filling out the survey, please click on the link below:

http://www.roundabouts.ca/tac_survey/userlogin.asp
User name: _____
Password: _____

For an explanation of the differences between roundabouts and traffic circles, please go to www.roundabouts.ca/orc_introduction.htm.

If we have not sent this e-mail to the correct person in your organization, could you please forward this message and copy us so we know who received it? Thank you.

For the Survey Introduction Page…

Welcome to our survey!

Our firm has been retained by the Transportation Association of Canada (TAC) to conduct a survey of roundabout practice in North America. The survey will form the basis of a Canadian Roundabout Synthesis of Practice, similar to NCHRP Synthesis 264.

We're interested in learning of your agency's experience with roundabouts, and hope you can take the time to complete this valuable survey of practice. We just need one survey per organization, to be representative of roundabout practice by your agency.

The survey is a web-based design where you to go forward and backward using your internet browser, or click on the tabs at the top of each page. This allows for more than one person to contribute to filling it out without having to save multiple copies. For instance, you may want to collaborate by filling out certain pages, and have your colleagues fill in the rest. Information will be automatically saved when you exit the survey. However, once you click on the "Submit" button at the bottom of each page, the information on that page is sent to our database.

Please contact us, below, if you have questions or would like further information on the Canadian Roundabout Synthesis of Practice.

Ourston Roundabouts Canada:

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Finally, we would appreciate it if we can get a copy of any policy or design guidelines you have produced related to roundabouts.

Thank you for your time!

Part 1: Background Information

1	What agency is responding to this survey?	Box
2	Who are the individuals responding to this survey? - Name and position - Name and position - Name and position - Name and position	Boxes
3	What influence do you have over the use of roundabouts? - Technical advisor - Decision maker - Other (please specify) (For an explanation of the differences between roundabouts and traffic circles, please go to our website.)	Checks plus box
4	How many roundabouts are currently in your jurisdiction, classified by number of lanes on the widest entry and fastest approach speed? - One lane, low speed - One lane, high speed (over 70 km/h or 45 mph) - Two lanes, low speed - Two lanes, high speed (over 70 km/h or 45 mph) - Three or more lanes, low speed - Three or more lanes, high speed (over 70 km/h or 45 mph)	Boxes
5	At what type of locations have most of them been constructed? - Local or collector road intersections - Arterial road intersections - Highway intersections - Freeway ramp terminals - Other (please specify)	Checks plus box
6	What type of control were the locations under previously? - New intersection - Stop control - Traffic signal - Other (please specify)	Checks plus box
7	How many roundabouts are planned in your jurisdiction over the next 5 years, classified by number of lanes on the widest entry and fastest approach speed? - One lane, low speed - One lane, high speed (over 70 km/h or 45 mph) - Two lanes, low speed - Two lanes, high speed (over 70 km/h or 45 mph) - Three or more lanes, low speed - Three or more lanes, high speed (over 70 km/h or 45 mph)	Boxes
8	At what type of locations are most of them planned? - Local or collector road intersections - Arterial road intersections - Highway intersections - Freeway ramp terminals - Other (please specify)	Checks plus box

Part 2: Planning and Site Selection

1 What is generally the main reason for constructing or planning roundabouts? Checks plus box

- Greater safety
- Delay or queue reduction
- Lower costs
- Unusual intersection layout
- Speed reduction/traffic calming
- Aesthetics/urban design
- Environmental reasons
- Requests from public or other
- Other (please specify)

2 What has determined the need for roundabouts? Checks plus box

- Traffic volumes or capacity analyses
- Collision history
- Anecdotal evidence
- New intersection
- Requests from the public
- Other (please specify)

3 Why have some sites been rejected as candidates for roundabouts? Checks plus box

- Insufficient space or right-of-way
- Costs too high
- Traffic volumes too high
- Uneven distribution of traffic
- Too many pedestrians or cyclists
- Approach speeds too high
- Road profile too steep
- Insufficient stopping sight distance
- Too close to nearby signal or rail crossing
- Public opposition
- Other (please specify)

Part 3: Design Methods and Guidance

1 What capacity analysis procedure do you use or require? — Checks plus box

- FHWA guide analysis procedure
- aaSidra software
- Arcady software
- Rodel software
- SimTraffic
- Vissim
- Paramix
- Other (please specify)

2 If you use a local or state guide, on what is it based? — Checks plus box

- NA
- FHWA guide
- United Kingdom guidelines
- Australian guidelines
- French guidelines
- Local practice
- Other (please specify)

3 If a successor to the FHWA guide is created, what type of information would you want added or expanded upon? — Checks plus box

- Policy information
- Planning advice
- Operations information
- Safety information
- Detailed design guidance
- Multi-lane design guidance
- Traffic guidance (signs, markings, etc.)
- Systems advice
- Other (please specify)

4 What design checks do you look for or require? — Checks plus box

- None
- Design vehicle turning space
- Entry speed
- Circulating speed
- Exit speed
- Speed consistency
- Entry path overlap (multi-lane roundabouts)
- Exit path overlap (multi-lane roundabouts)
- Minimum pedestrian refuge size
- Sight distances
- Grading
- Other (please specify)

5 What other capacity analysis or design guidance would be helpful for upcoming projects? — Box

Part 4: Design and Construction

1 What design features apply to the roundabouts in your jurisdiction? — Checks with box

- Standardized entry and exit widths
- Tight entry and exit radii to control speeds
- Right turn by-pass lanes
- Entries and exits have similar deflection
- Entries have more deflection than exits
- Pedestrians cross perpendicular to traffic
- Pedestrians cross in straight line
- Mountable central island (mini-roundabout)
- Mountable curb and no signs on splitter islands
- Other (please specify)

2 What design deficiencies, if any, have been noted with existing roundabouts in your jurisdiction? — Checks with box

- Not enough entry deflection (high entry speeds)
- Too much entry deflection (approach conflicts)
- Small vehicles tend to use truck apron
- Some load shifting in trucks
- Does not accommodate design vehicle
- Pedestrian refuges on splitter islands too small
- Entry path overlap (multi-lane roundabouts)
- Exit path overlap (multi-lane roundabouts)
- Other (please specify)

3 What vertical design treatments are applicable to existing roundabouts in your jurisdiction? — Checks with box

- Roundabout grade matches approaches
- Roundabout is “benched” on steep grades
- Circulatory road slopes outwards
- Circulatory road is crowned
- Truck apron slope is 3 percent or less
- Truck apron slope is more than 3 percent
- Truck apron uses mountable curb
- Truck apron uses bevelled curb
- Other (please specify)

4 What special design treatments do you use or require for roundabouts on high-speed approaches? — Checks with box

- NA/none
- Extra long splitter islands
- Reverse curves on approaches
- Enhanced approach signing
- Enhanced central island signing
- Enhanced central island landscaping
- Extra illumination
- Other (please specify)

5 What range of construction costs have been realized for your single-lane and multi-lane roundabouts? — Box

6 What are some of the issues or challenges you have experienced with construction and construction staging? — Box

Part 5: Safety Experience

1	Have you conducted any formal studies to measure roundabout safety performance compared to the previous intersection control? (If formal studies have been conducted, we would appreciate a copy. Please attach a file or contact us through our website.)	Box plus "Attach File" button
2	What roundabout safety performance have you found compared to the previous intersection control (use percentages if available)? - NA (new intersection) - Unknown - Injury or fatal crashes higher - Injury or fatal crashes lower - Property damage only crashes higher - Property damage only crashes lower - Pedestrian crashes higher - Pedestrian crashes lower - Cyclist crashes higher - Cyclist crashes lower	Checks plus boxes
3	What types of crashes have been occurring most at your roundabouts (use percentages if available)? - Unknown - Approach (rear-end) - Approach (loss of control) - Entry-circulating - Exit-circulating - Pedestrian or cyclist - Other (please specify)	Checks plus boxes
4	What measures have you identified or implemented after construction to improve safety performance? - None - Make larger to accommodate trucks - Increase entry deflection - Decrease entry deflection - Correct entry path overlap (multi-lane roundabouts) - Correct exit path overlap (multi-lane roundabouts) - Better sightlines - More central island landscaping - Relocate objects to outside of clear zones - Signage-related - Pavement marking or re-striping - Other (please specify)	Checks plus box

Part 6: Operations Experience

1	What best describes your agency's approach to recording traffic volumes at roundabouts? - No traffic counts undertaken - None yet, but plan to - Count entering flows only - Count all movements using video camera - Other (please specify)	Checks plus box
2	What best describes your agency's approach regarding speed studies at roundabouts? - No speed studies undertaken - None yet, but plan to - Record entry and through speeds - Record upstream and downstream speeds - Other (please specify)	Checks plus box
3	What has been observed in terms of accommodating large trucks? - Aprons used for single-lane designs - Aprons used for multi-lane designs - Trucks track into adjacent lanes (multi-lane roundabouts) - Trucks stay in lane when striped (multi-lane roundabouts) - Trucks stay in lane when not striped (multi-lane roundabouts) - Other (please specify)	Checks plus box
4	What advance signs do you use or require on approaches to roundabouts? - Roundabout Ahead - Yield Ahead - Speed reduction/speed tab - Stack-type guide signs - Map-type (diagrammatic) guide signs - Lane use signs (multi-lane roundabouts) - Pedestrian crossing signs - Other (please specify)	Checks plus box
5	What type of lane use signs and markings do you use or require at multi-lane roundabouts? - NA/none - Lane use signs - standard - Lane use signs - "fishhook" (curved arrow) - Lane arrows - standard - Lane arrows - "fishhook" (curved arrow) - Other (please specify)	Checks plus box
6	What pavement markings do you use or require in the circulatory road of multi-lane roundabouts? - NA/none - Stripe only if unbalanced lane use (i.e. dual lefts) - Always stripe - Other (please specify)	Checks plus box
7	What specific issues, if any, have been experienced related to maintenance inside the roundabout, snow clearing, or emergency response?	Box

Part 7: Rules of the Road

1	What state/provincial vehicle codes, local ordinances or regulations, if any, do you have in place for roundabouts? (If you have any examples, we would appreciate a copy. Please attach a file or contact us through our website.)	Box plus "Attach File" button
2	What changes, if any, have been made to your jurisdiction's driver education guidelines and statutory operating procedures for driving roundabouts? (If you have such provisions, we would appreciate a copy. Please attach a file or contact us through our website.)	Box plus "Attach File" button

Part 8: Vulnerable Road Users

1 What provisions are there for pedestrians at single-lane roundabouts? Checks plus box
- NA/no provisions
- Unmarked crossings
- Marked crosswalks
- Pedestrian signals
- Other (please specify)

2 What provisions are there for pedestrians at multi-lane roundabouts? Checks plus box
- NA/no provisions
- Unmarked crossings
- Marked crosswalks
- Pedestrian signals
- Other (please specify)

3 Do you have any criteria for marking crosswalks at roundabouts (use numbers if available)? Checks plus boxes
- No, always mark crosswalks
- Mark if pedestrian generators are nearby
- Mark with minimum pedestrian volumes
- Other (please specify)

4 What priority do pedestrians have at your roundabouts? Checks plus box
- Have priority at marked crosswalks
- Have priority at unmarked crossings
- Do not have priority at marked crosswalks
- Do not have priority at unmarked crossings
- Other (please specify)

5 What treatments, if any, are used to specifically protect pedestrians at roundabouts? Checks plus box
- NA/none
- Small roundabout size
- Speed humps/tables or rumble strips
- In-pavement crosswalk flashers
- Warning signs for vehicles
- Warning signs for pedestrians
- Other (please specify)

6 What treatments are used to accommodate visually or mobility impaired pedestrians? Checks plus box
- NA/none
- Curb ramps
- Tactile sidewalk ramps
- Tactile crosswalks or crosswalk edges
- Contrasting surfaces
- Low-growth landscaping
- Audible pedestrian signals
- Other (please specify)

7 What treatments are used to accommodate cyclists? Checks plus box
- NA/none
- Bike lane terminations
- Paths around outside of roundabout
- Dedicated bike lanes through roundabout
- Other (please specify)

Part 9: Public Education and Acceptance

1	What would you say the public acceptance level was before your first roundabout was built? - Unknown - Very negative - Negative - Neutral - Positive - Very positive	Checks plus boxes
2	What would you say the public acceptance level is now? - Unknown - Very negative - Negative - Neutral - Positive - Very positive	Checks plus boxes
3	What misconceptions about roundabouts did you have to overcome? - They are traffic circles or rotaries - Drivers will not get used to them - They are unsafe for all users - They are unsafe for pedestrians and cyclists - They need to be larger for large trucks - They are only applicable on low-volume roads - Other (please specify)	Checks plus box
4	What were your main concerns when opening the first roundabout in your jurisdiction? - Pedestrian and cyclist safety - Motorist safety - Public education - Correct lane use (multi-lane roundabouts) - Other (please specify)	Checks plus box
5	What specific public education programs have you undertaken? - None - Public meetings - Informational brochures - TV or radio spots - Special/variable message signs - Other (please specify)	Checks plus box
6	What instances of undesirable driver behaviour have been noted at your roundabouts? - Low rate of yielding - Passing trucks in circulatory road - Illegal left turn in front of central island - Left turn from outside lane (multi-lane roundabouts) - Poor lane discipline (multi-lane roundabouts) - Other (please specify)	Checks plus box
7	What steps have you taken to resolve these concerns?	Box
8	What policy, if any, do you have in place regarding roundabouts (i.e. where or when to use), or what challenges have you faced regarding their implementation?	Box

9	What additional thoughts do you have on public education?	Box

Part 10: Conclusion

1	Do you view roundabouts as an alternative intersection control to traffic signals and Stop signs, or only as a unique solution with limited applications?	Box
2	Any other comments you wish to add?	Box

Thank you for taking the time to complete this survey!

Agency	Location		Last Name	First Name	Telephone	E-Mail
City of Edmonton - Traffic Operations	Edmonton	AB	Cebryk	Gord	780-496-2678	gord.cebryk@edmonton.ca
Alberta Ministry of Transportation	Edmonton	AB	Chow	Richard		Richard.Chow@gov.ab.ca
BC Ministry of Transportation	Victoria	BC	Froese	Gerald	250-387-7583	jerry.froese@gov.bc.ca
BC Ministry of Transportation	Burnaby	BC	Braacx	Andy	604-660-8273	andy.braacx@gov.bc.ca
Manitoba Transportation & Gov Serv	Winnipeg	MB	Rogers	Ben	204-945-1447	brogers@gov.mb.ca
City of Brandon	Brandon	MB	Snure	Ted	204-729-2214	t.snure@brandon.ca
Nova Scotia Dept. of Highways	Halifax	NS	Boddy	Keith		boddyke@gov.ns.ca
Town of Aurora	Aurora	ON	Atkins	David	905-727-3123	datkins@town.aurora.on.ca
City of Guelph	Guelph	ON	McMillan	Dean	519-837-5604	dean.mcmillan@guelph.ca
City of Hamilton - Traffic Eng & Operations	Hamilton	ON	Gallo	Ron	905-546-2424, x6160	rgallo@hamilton.ca
City of Ottawa - Mobility & Traffic	Ottawa	ON	Orchin	Rob	613-580-2424, x13662	rob.orchin@ottawa.ca
Regional Municipality of Waterloo	Kitchener	ON	van De Keere	Steve	519-575-4792	vsteve@region.waterloo.on.ca
Ville de Gatineau	Gatineau	QC	Robert	Jean-François		robert.jean-francois@ville.gatineau.qc
Ministere des Transports - Quebec	Montreal	QC	Masse	Michel		mmasse@mtq.gouv.qc.ca
Ministere des Transports - Quebec	Montreal	QC	Lacasse	Pascal	514-873-1656	placasse@mtq.gouv.qc.ca
Ministere des Transports - Quebec	Quebec	QC	Berthod	Catherine	418-643-4100	cberthod@mtq.gouv.qc.ca
Ministere des Transports - Quebec	Quebec	QC	Marquis	Bruno	418-643-3981	bmarquis@mtq.gouv.qc.ca
City of Yorkton	Regina	SK	Zasada	Max	306-786-1730	mzasada@yorkton.ca
City of Whitehorse	Whitehourse	YK	Crist	Brian	867-668-8351	brian.crist@city.whitehorse.yk.ca

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Arizona DOT - Traffic Group	Phoenix	AZ	Riley	Annette	602-712-7643	ariley@azdot.gov
City of Phoenix - Engineering	Phoenix	AZ	Young	Heide	602-262-7580	heide.young@phoenix.gov
City of Agoura Hills	Agoura Hills	CA	Thorsen	Jim	818-597-7314	jthorsen@ci.agoura-hills.ca.us
City of Chico	Chico	CA	Murray	Craig	530-879-6900	cmurray@ci.chico.ca.us
City of Chico	Chico	CA	Green	Lane	530-879-6933	lgreen@ci.chico.ca.us
Caltrans District 1	Eureka	CA	Martinelli	Ralph	707-445-6376	ralph_martinelli@dot.ca.gov
Caltrans District 7	Los Angeles	CA	Hatai	Kenneth K.	213-897-4655	ken_hatai@dot.ca.gov
Los Angeles County - Public Works		CA	Witler	Barry		bwitler@ladpw.org
City of Sacramento Engineering	Sacramento	CA	Binning	Katherine	916-808-8365	kbinning@cityofsacramento.org
City of Santa Barbara	Santa Barbara	CA	Qi	Jinsong	805-897-2615	jqi@santabarbaraca.gov
Town of Avon	Avon	CO	Wood	Norman	970-748-4045	nwood@avon.org
City of Colorado Springs	Colorado Springs	CO	Kenny	Robert		bkenny@springsgov.com
City of Fort Collins	Fort Collins	CO	Bracke	Eric L.	970-988-7551	ebracke@fcgov.com
City of Loveland	Loveland	CO	Knostman	Tom		knostt@ci.loveland.co.us
City of Loveland	Loveland	CO	Hange	William		hangeb@ci.loveland.co.us
Town of Vail	Vail	CO	Hall	Greg	970-390-4676	GHall@vailgov.com
Connecticut DOT		CT	Britnell	William		William.Britnell@po.state.ct.us
City of Clearwater	Clearwater	FL	Sides	Ken	757-562-4792	ken.sides@myclearwater.com
City of Naples	Naples	FL	Archibald	George	239-213-5003	garchibald@naplesgov.com
City of Gainesville	Gainesville	FL	Kanely	Brian	352-334-5070	kanelybd@ci.gainesville.fl.us
Kansas DOT	Topeka	KS	King	Steve	785-296-0255	stevenk@ksdot.org
Kansas DOT	Topeka	KS	Bass	Stephen	785-296-2386	sbass@ksdot.org
Kentucky Transportation Cabinet		KY	Sweger	Brent	502-564-7183, x3297	Brent.Sweger@KY.GOV
Harford County	Bel Air	MD	Banigan	Cheryl	410-638-3545	clbanigan@co.ha.md.us

Agency	Location		Last Name	First Name	Telephone	E-Mail
Harford County	Bel Air	MD	Stratmeyer	Jeffrey	410-638-3509	jmstratmeyer@co.ha.md.us
Maine Department of Transportation	Augusta	ME	Mousseau	Atlee	207-624-3384	atlee.mousseau@maine.gov
City of South Portland	South Portland	ME	Haeuser	Tex	207-767-7602	chaeuser@southportland.org
Oakland County Road Commission	Beverly Hills	MI	O'Brien	Jeffery	248-645-0618	jobrien@rcoc.org
Mississippi DOT		MI	Altman	Jeff	601-359-7675	jaltman@mdot.state.ms.us
NC DOT - Congestion management	Raleigh	NC	Dunlop	Jim	919-250-4151	jdunlop@dot.state.nc.us
Nebraska Dept. of Roads	Lincoln	NE	Neemann	Matthew	402-479-3844	mneemann@dor.state.ne.us
City of Farmington	Farmington	NM	Krest	Stephen	505-599-8201	skrest@fmtn.org
New Mexico DOT	Albuquerque	NM	Abbo	Tony S.	505-841-2761	tony.abbo@nmshtd.state.nm.us
New Mexico DOT	Santa Fe	NM	Garcia	Kathleen	505-827-5521	kathleen.garcia@nmshtd.state.nm.us
Franklin County	Columbus	OH	Meeks	Mike		mmeeks@fceo.co.franklin.oh.us
Franklin County	Columbus	OH	Robertson	Cornell		croberston@fceo.co.franklin.oh.us
NY DOT	Albany	NY	McCulloch	Howard	518-783-2124	hmcculloch@dot.state.ny.us
City of Hilliard	Hilliard	OH	Schamp	Letty	614-334-2456	lschamp@cityofhilliard.com
City of Hilliard	Hilliard	OH	Sweder	Michael		msweder@cityofhilliard.com
City of Dublin	Dublin	OH	Willis	Jeannie	614-410-4633	jwillis@dublin.oh.us
Ohio DOT	Columbus	OH	Young	James	614-387-1622	james.young@dot.state.oh.us
PennDOT	Harrisburg	PA	Stewart	Daniel	717-787-0456	danistewar@state.pa.us
PennDOT	Harrisburg	PA	Grey	Gavin	717-783-5542	gagray@state.pa.us
City of Portland	Portland	OR	Batson	Scott		Scott.Batson@PDXTRANS.ORG
City of West Jordan	West Jordan	UT	Baranowski	Bill	801-569-5047	billba@wjordan.com
Virginia DOT	Richmond	VA	Gould	Robert	804-786-4197	Robert.Gould@VDOT.virginia.gov
Vermont DOT	Montpelier	VT	Redington	Tony	802-828-4039	TonyRVT@ISPWEST.COM
King County DOT	Seattle	WA	Dovey	Dan	206-263-6144	Dan.Dovey@MEtroKC.gov

Agency	Location		Last Name	First Name	Telephone	E-Mail
City of Lacey	Lacey	WA	Schoessel	Roger		rschoess@ci.lacey.wa.us
City of Lacey	Lacey	WA	Diekmann	Josh		jdiekman@ci.lacey.wa.us
City of Olympia	Olympia	WA	Wesselman	Randy	360-753-8477	rwesselm@ci.olympia.wa.us
Washington State DOT	Seattle	WA	Rilling	Matt	206-440-4335	rillinm@wsdot.wa.gov
Washington State DOT	Seattle	WA	Walsh	Brian		walshb@wsdot.wa.gov
Wisconsin DOT	Madison	WI	Fleming	Patrick	608-266-8486	patrick.fleming@dot.state.wi.us

APPENDIX B

EXAMPLE INSTRUCTIONS ON USING A ROUNDABOUT (REGION OF WATERLOO, ONTARIO)

WHAT DO THESE SIGNS MEAN?

There is a roundabout ahead – slow down.

There are three exits from the roundabout ahead – choose one. Do you want to turn right, go straight through, or turn left?

There are two entry lanes to the roundabout – choose the correct one. If you are turning left, get in the left lane.

Yield to all traffic in the roundabout.

Drive counterclockwise only in the roundabout.

June 2006

IMPORTANT ROUNDABOUT RULES

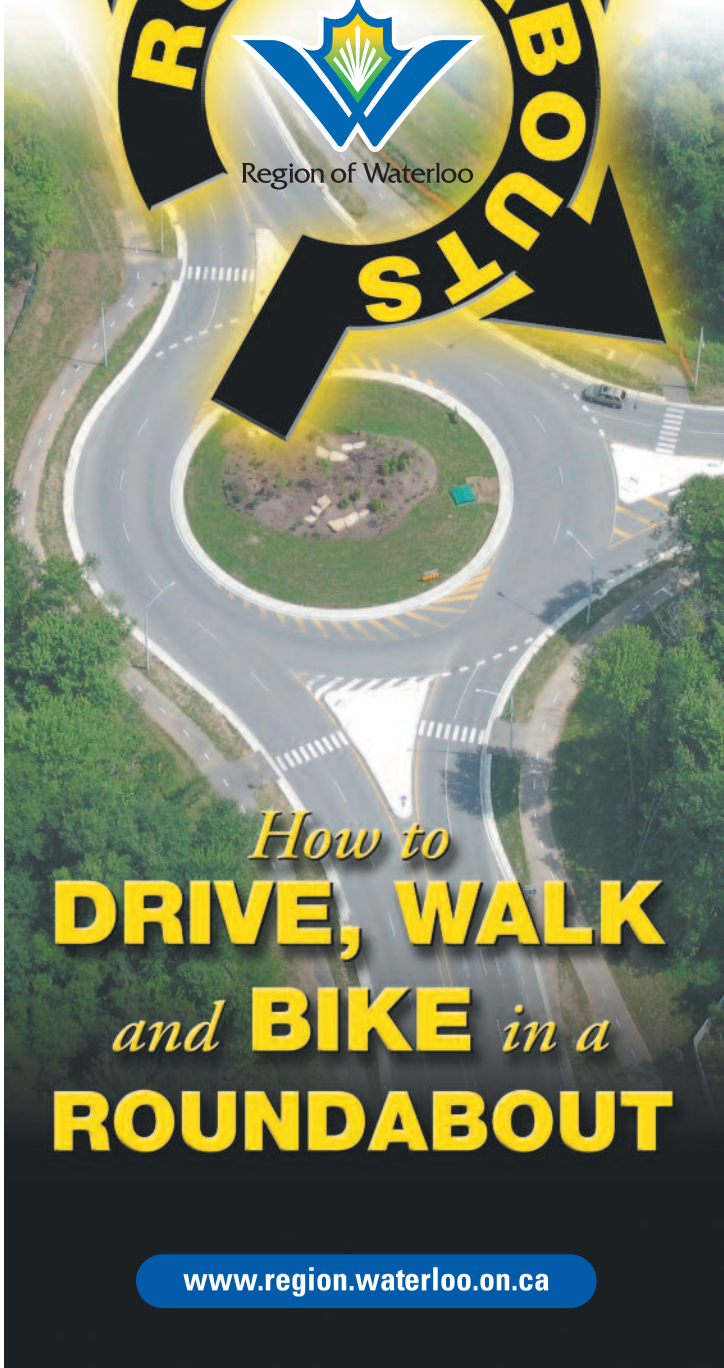
- ✔ Slow down
- ✔ Choose the correct entry lane
- ✔ Yield to pedestrians at the crosswalk
- ✔ Yield to ALL traffic in the roundabout, including cyclists
- ✔ Give large vehicles extra space
- ✔ Never pass another vehicle in the roundabout

Region of Waterloo

For more information, call 519-575-4558 or visit the roundabouts page on the Region's website

All about ROUNDABOUTS

Region of Waterloo

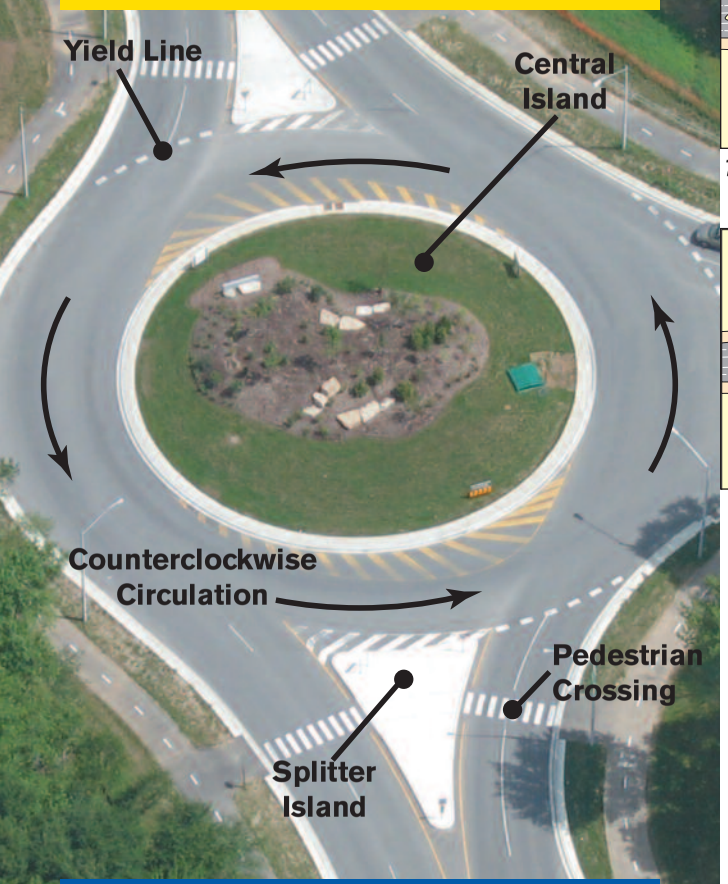


How to DRIVE, WALK *and* BIKE *in a* ROUNDABOUT

www.region.waterloo.on.ca

WHAT IS A ROUNDABOUT?

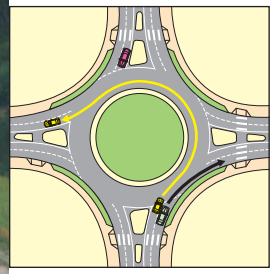
A roundabout is an intersection at which all traffic circulates counterclockwise, to the right of a central island. Entering vehicles must yield to all traffic already in the roundabout.



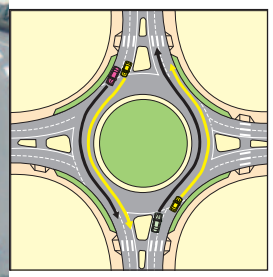
ROUNDABOUTS:

- Reduce injury collisions
- Keep traffic moving
- Reduce unnecessary stops
- Reduce unnecessary idling and air pollution
- Improve intersection appearance

HOW TO DRIVE IN A ROUNDABOUT



Turning right and turning left



Driving straight through a roundabout

1. Slow down when approaching a roundabout.
2. Keep to the right of the "splitter island".
3. Choose the correct entry lane. To turn right, get in the right lane. To turn left, get in the left lane. To go straight, get in the left or right lane.
4. Observe the crosswalk and yield to pedestrians.
5. Move to the yield line and wait for a gap in traffic before entering the roundabout. Yield to all traffic to your left (including cyclists), regardless of their position.
6. Do not enter beside someone already in the roundabout because they may be exiting. Drivers in the roundabout always have the right-of-way.
7. Within the roundabout always travel counterclockwise and do not stop; you have the right-of-way over entering traffic.
8. Do not pass other vehicles in the roundabout. Give large vehicles extra space because they may use both lanes.
9. As you approach your desired exit, use your right turn signal and take the exit while maintaining a slow speed. Do not change lanes before exiting.

TIPS FOR DRIVERS OF LARGE VEHICLES

When getting into the roundabout, straddle the entry lanes. Within the roundabout, use both lanes. Don't try to leave space for another vehicle to pass you.

TIPS FOR PEDESTRIANS

1. Use the sidewalks and crosswalks around the outside of the roundabout. Do not cut across the middle of the roundabout.
2. Use the "splitter island". This will let you cross one direction of traffic at a time.
3. Watch for gaps in approaching traffic. Choose a safe time to cross.

TIPS FOR CYCLISTS

For experienced cyclists, ride as if you were driving a car. Vehicles in roundabouts travel slowly, close to the speed you ride your bicycle. When getting into a roundabout, merge into the travel lane before the bike lane or shoulder ends. Within the roundabout, ride in the middle of your lane; don't hug the curb. Watch out for drivers' blind spots.

For less confident cyclists, dismount and walk your bicycle. Follow the tips for pedestrians.

WHAT ABOUT EMERGENCY VEHICLES?

If you have not yet entered the roundabout, let the emergency vehicle pass you. If you are in the roundabout, continue on and exit as normal, then pull to the right where there is room for the emergency vehicle to pass. Do not stop inside the roundabout.

APPENDIX C

EXAMPLE ROUNDABOUT PUBLIC EDUCATION CAMPAIGN
(CITY OF LACEY, WASHINGTON)

City of Lacey Roundabout Education Efforts

The City of Lacey has devoted considerable resources to providing information about modern roundabouts to the public. Since our community was one of the first to utilize roundabouts, we understood the necessity to provide as much information to the public as possible, and went to great lengths to ensure that the driving public was informed. The bullets provide a general overview of the City of Lacey's efforts to inform the public:

1) Hosted several public open houses explaining the design, function, and utility of modern roundabouts.
2) Discussed modern roundabout use with the Lacey City Council and Planning Commission at numerous meetings open to the public.
3) Published no less than 10 articles about roundabouts in the city newsletter, "Lacey Life," which is mailed directly to each household in the City, and some households in the City's Urban Growth Area.
4) Developed two informational brochures: One jointly created with the Washington State Department of Transportation and the City of Olympia addressing modern roundabouts in the state of Washington; and one specifically addressing roundabouts in the City of Lacey. These brochures have been distributed around the City, are provided to citizens by Lacey Police, and are available at City Hall.
5) Made an instructional video in partnership with the WSDOT and the City of Olympia visually showing drivers how to correctly use roundabouts. The video, entitled "Driving Modern Roundabouts," was nominated for, and won, a Telly Award in 2003. This video is available at Lacey City Hall, through the City of Olympia and WSDOT.
6) Distributed the roundabout video to all Timberland Regional Libraries.
7) Arranged, through Washington State's Office of the Superintendent of Public Instruction, for distribution of the video to all Washington State high schools for use in driver training programs.
8) Provided the video to Thurston Community Television (TCTV), channel 3, which has played the video during the course of the past year.
9) Encouraged, with help from WSDOT, updates to Washington State Department of Licensing's Driver's Guide—the *Rules of the Road* section now addresses roundabouts: http://www.dol.wa.gov/ds/guide/guide3.htm.
10) Developed a Web Page devoted to roundabout education: http://www.ci.lacey.wa.us/roundabouts/roundabout_main_page.html.
11) Hosted members of the press to an informal tour of the first roundabout constructed in the City. This generated press coverage by the Tacoma News Tribune, The Olympian, KAYO Radio, and KGY Radio.
12) Contributed to extensive coverage, by the Olympian Newspaper, on construction and use of modern roundabouts in our region for the last two years.
13) Conducted "emphasis patrols" wherein the Lacey Police Department issues warning to drivers making minor violations within the roundabouts, and gives the drivers brochures describing safe and proper use of roundabouts.

Please contact the City of Lacey Department of Public Works with any questions: (360) 491-5600.

May 2004