Safety Risk Management in Large Diameter Modern Roundabout Applications

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ABSTRACT

Modern roundabouts are a relatively new intersection treatment in Canada, particularly in the highway context. However, their use is on the rise due to the increasingly recognized safety and operational benefits associated with them. Current roundabout design guidelines stipulate that the size of a modern roundabout should be minimized in order to reduce vehicle speeds within the circulatory roadway. However, in the highway context, a large-diameter roundabout may be required to safely transmit tractor-trailers.

This paper will discuss the safety benefits and disadvantages of large diameter modern roundabouts, using as an example the proposed roundabout at the intersection of Highway 8 and Highway 22 in the Province of Alberta where the co-authors conducted a Road Safety Audit. While large diameter roundabouts may be required to meet the needs of the design vehicle, the size of the roundabout may encourage smaller vehicles to travel at high speeds within the roundabout, hence limiting its effectiveness. The width of the apron can be increased to allow for truck off-tracking, but a wide apron may introduce other safety issues. This paper will discuss the trade-off between accommodating larger vehicles and keeping vehicle speeds to a minimum.

Finally, other issues related to large-diameter roundabouts, including the use of bypass ramps, driver comprehension and cyclist accommodation will be discussed, using the proposed Highway 8 and 22 installation as an example.

1.0 INTRODUCTION

The Federal Highway Administration's Roundabouts: An Informational Guide (2000) provides guidance regarding proper geometric design for modern roundabouts. The guidance is based primarily on roundabouts with an inscribed circle diameter of less than 40m, based on a WB-20 design vehicle.

With the increasing popularity of roundabouts due to their safety benefits, they are being considered as a traffic control device in a broader range of applications. In the highway context, modern roundabouts can be a viable alternative to stop-control or traffic signals, particularly at locations where delays are excessive. However, due to the high-speed environment and the need to accommodate larger vehicles, their application and design needs to be carefully considered.

The Highway 8 and Highway 22 intersection is located approximately 16 km west of the City of Calgary in the Province of Alberta. Increasing traffic volumes at the intersection have resulted in poor levels of service under two-way stop control operation, particularly for the westbound left-turn movement. The province has therefore recognized the need to upgrade the capacity of the intersection.

The proposed upgrade for the intersection is a large diameter, single-lane roundabout. A schematic drawing with the proposed inscribed diameter is shown in FIGURE 1. This would be the first highway-to-highway roundabout in Canada. Bypass ramps are proposed for the westbound to northbound and northbound to eastbound movements.

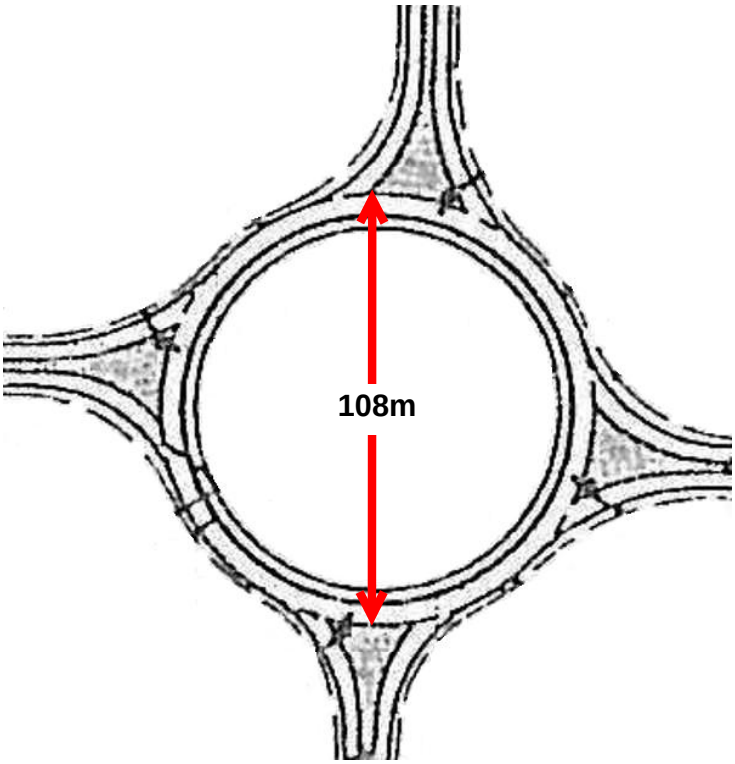


FIGURE 1 - INSCRIBED DIAMETER

The design for the intersection upgrade roundabout is currently being conducted by Earth Tech (Canada) Inc., as part of their detailed design of the twinning of Highway 8 between Highway 22 and the Calgary City Limits. The twinning of Highway 8 will take place in approximately 5 years and Highway 22 will be twinned in approximately 20 years. The proposed roundabout design has taken the future twinning of Highways 8 and 22 into account. Hamilton-Finn Road Safety Consultants, and specifically the co-authors of this paper, conducted a Road Safety Audit of the proposed design.

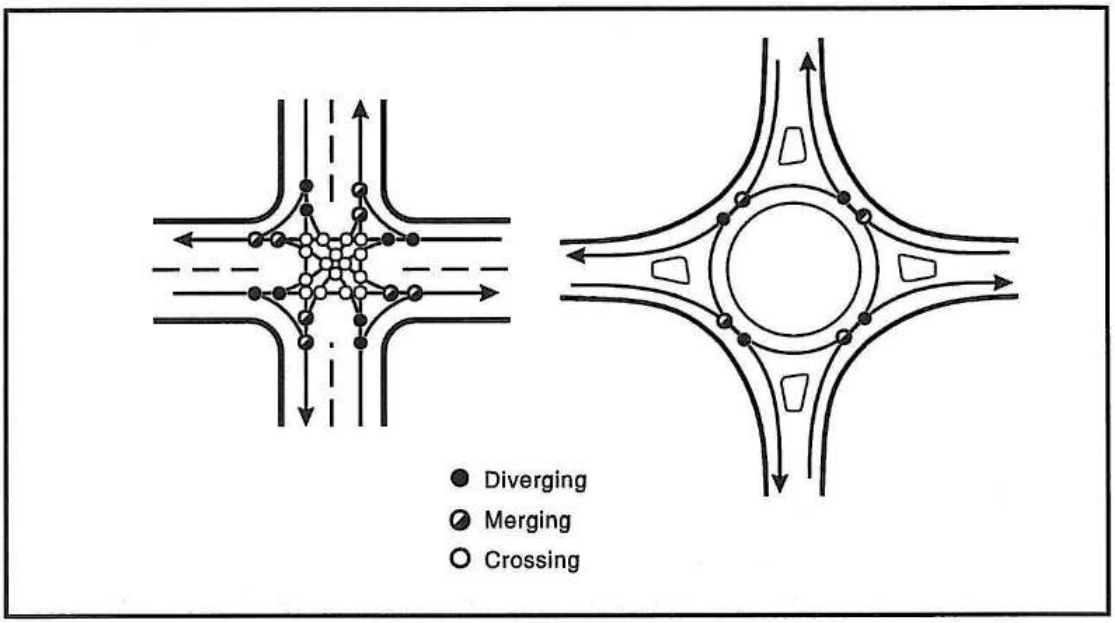
2.0 SAFETY BENEFITS

The reduction in collision frequency and severity in collisions after the installation of roundabouts in the United States are well documented. While large-diameter single-lane roundabouts contain some distinguishing features from the typical modern roundabout, they are still likely to offer several benefits.

Using the Highway 8 and 22 proposed roundabout as an example, several of the benefits that can be recognized with respect to large-diameter roundabouts are described here.

A. Reduction of Conflict Points

Upgrading the intersection to a roundabout will reduce the number of vehicle conflict points (FIGURE 2). A traditional intersection has 32 vehicle conflict points. In comparison, a single lane roundabout has only 8 vehicle conflict points. The proposed roundabout will have four additional conflict points due to the provision of bypass ramps, for a total of 12 conflict points. Each bypass ramp will have a conflict point at the entry and exit.



Note: The figure does not indicate the 4 conflict points associated with the bypass ramps

FIGURE 2 - VEHICLE CONFLICT POINTS
Source: FHWA's Roundabouts: An Informational Guide

B. Improved Intersection Capacity

At the Highway 8 and 22 intersection, increasing traffic volumes have resulted in poor levels of service, particularly for the westbound left-turn movement. The existing peak hour level of service (LOS) for westbound left turns is LOS C during the morning peak and LOS F during the afternoon peak. The projected 20-year (2023) level of service for the existing intersection is LOS F for both the morning and afternoon peaks.

It has been determined that in 2023 the proposed roundabout would have a LOS A during the morning peak and a LOS B during the afternoon peak. The LOS calculated for the roundabout did not include the bypass ramps in the northeast and southeast corners. These ramps are expected to remove a significant portion of traffic from the roundabout, resulting in higher levels of service.

Improved intersection capacity reduces congestion and delay. This results in a decreased risk of rear-end and other congestion-related collisions, and of risk-taking behaviour due to driver frustration.

C. Reduction of Vehicle Speeds

Many of the safety benefits associated with a roundabout are the result of reduced vehicle speeds. Collisions at roundabouts are typically not as severe as a traditional intersection, due to the slower speeds. The Transportation Association of Canada's (TAC) guide entitled The Canadian Guide to In-Service Road Safety Reviews (2003), reports that installing a roundabout has demonstrated the potential to reduce injury and fatal collisions by 30 to 75%. The reduction in speed provides motorists with more time to react to a potential conflict, which can assist in both the prevention and the impact reduction.

Speed differentials between vehicles are also typically reduced at roundabouts since traffic on each approach is required to slow to the same speed. Decreasing the speed differential between vehicles at the point of conflict typically reduces the crash rate and severity, particularly for rear end and sideswipe collisions.

D. Single Lane Roundabout

The level of service analysis conducted by Earth Tech revealed that the proposed single lane roundabout would provide sufficient capacity. Single lane roundabouts have fewer vehicle conflict points and are easier to navigate in comparison to a double-lane roundabout. With a double-lane roundabout, there are additional conflicts due to lane changing, passing, improper circulation and existing from the inner lane. These errors are likely to occur at the study location because roundabouts are still uncommon in the province. The single lane roundabout will be easier for unfamiliar drivers to understand initially, and would make the transition to a future possible double-lane roundabout smoother.

E. Approach Curves

The three highway approaches have consecutive reverse curves prior to the roundabout. These curves encourage motorists to reduce their speed prior to the roundabout. The change in the highway geometry will also provide a visual cue that can increase driver awareness. Lower approach speeds reduce the collision potential at the roundabout entry.

F. Landscaping

The Design Report mentioned that landscaping, such as evergreen trees and shrubs would be used to obscure the North/South and East/West sight lines. This provides a visual cue for motorists that through movements are not permitted at the intersection and draws their attention to the roundabout. This benefit can be realized as long as the landscaping does not impede the necessary circulatory sight distances.

The visual cue provided by landscaping will be particularly useful during conditions when snow cover makes it difficult to distinguish the roundabout.

G. Reduced Tractor Trailer Off-tracking

The large diameter of the roundabout limits the amount of off-tracking experienced by tractor trailers. The WB-36 design vehicle can navigate the circulatory roadway with limited off-tracking onto the apron. The limited off-tracking makes turning manoeuvres less complex.

H. Raised Splitter Islands

The raised splitter islands that are provided on each approach will help control speeds, guide traffic into the roundabout and deter wrong-way movements. The splitter islands are relatively long, which will encourage motorists to decelerate well in advance of the roundabout.

3.0 POTENTIAL SAFETY ISSUES

Due to the size and other characteristics of large, single-lane roundabouts, there are several particular items that need to be reviewed from a safety perspective. Four of these have been identified, and are described here. The risks can be assessed using an assessment tool based on collision *frequency* and collision *severity*. Collision frequency is predicted by considering both the *exposure* and *probability* measures. The exposure measure is a reflection the road user volumes encountering the identified issue. The probability measure is a reflection of the design and operational characteristics of the roadway faced by each road user. *Consequence* is a prediction of the collision severity or likelihood of injury associated with the identified issue, and is influenced by factors including the collision type, vehicle speeds, the vulnerability of the road users, the presence of trucks and roadside characteristics.

3.1 Issue 1: Large Diameter

INFTRA's Design Bulletin #31: Roundabouts: An Informational Guide, indicates that the inscribed circle diameter range for a rural single lane roundabout should be between 35m and 40m, based on a WB-20 design vehicle, which reflects the guidance provided in the Federal Highway Administration's Roundabouts: An Informational Guide (2000). Smaller diameter roundabouts are generally recommended because they can more effectively control vehicle speeds.

There are concerns that the large diameter will encourage motorists to accelerate to speeds above 40km/h within the roundabout, particularly if they are travelling half or ¾ of the roundabout. The tendency would be to treat the roundabout like a horizontal curve; the longer the curve and the larger the radius, the higher the speeds than can be expected.

However, the large inscribed diameter has been proposed in order to accommodate a WB-36 design vehicle, which is substantially larger than the WB-20 design vehicle on which the recommendations in INFTRA's Design Bulletin #31 and the FHWA guide are based. Therefore, the maximum diameter of 40m stipulated in the FHWA guide would not safely accommodate WB-36 design vehicles.

In order to accommodate a WB-36 design vehicle there are two options. The first option is to provide a larger inscribed diameter than what is stipulated in the FHWA guide. The second option is to provide a wider truck apron to accommodate the significant off-tracking of the rear wheels. The safety implications of each option are discussed here.

A. Option 1: Provide Large Inscribed Diameter

The large inscribed diameter has been proposed in order to accommodate the WB-36 design vehicle with limited off-tracking of the rear-end. The safety benefits of providing a larger diameter include the reduced risk of tractor-trailers encroaching upon the shoulders and clear zone and of having to reduce to nearly standstill speeds to safely complete a turning manoeuvre.

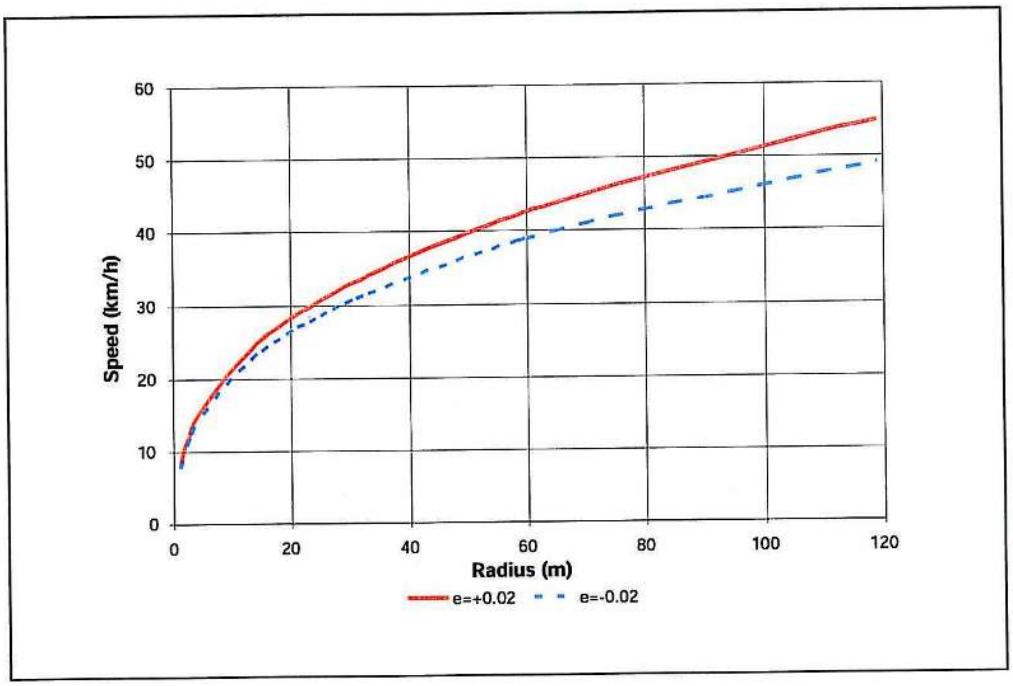
The concern with a large diameter is that it might encourage speeding within the roundabout. According to the FHWA guide, achieving appropriate vehicular speeds through the roundabout is the most critical design objective due to the impact on safety. The low vehicle speeds associated with roundabouts provide the following safety benefits:

- collision severity is reduced;
- motorists are provided with more time to react to potential conflicts; and,
- speed differentials are reduced.

Higher speeds within the roundabout would limit these benefits. In addition, higher speeds within the roundabout could also result in the loss of control, overturning or undesirable speed differentials.

The FHWA guide provides a chart illustrating the speed-radius relationship for curves as shown in FIGURE 3. According to Section 6.2.1.3 of the FHWA guide, the design speed is determined from the smallest radius along the fastest path. For the proposed roundabout the smallest radius is approximately 50m (FIGURE 4). According to FIGURE 3 a radius of 50m corresponds to a design speed of approximately 40 km/h, which is equal to the posted speed limit through the proposed roundabout.

The chart also indicates that to attain any reduction in speeds, the radius would need to be significantly reduced.



The different superelevations (e) correspond to the entry and exit curves (+0.02) and the circulatory roadway (-0.02).

FIGURE 3 - SPEED-RADIUS RELATIONSHIP
Source: FHWA's Roundabouts: An Informational Guide

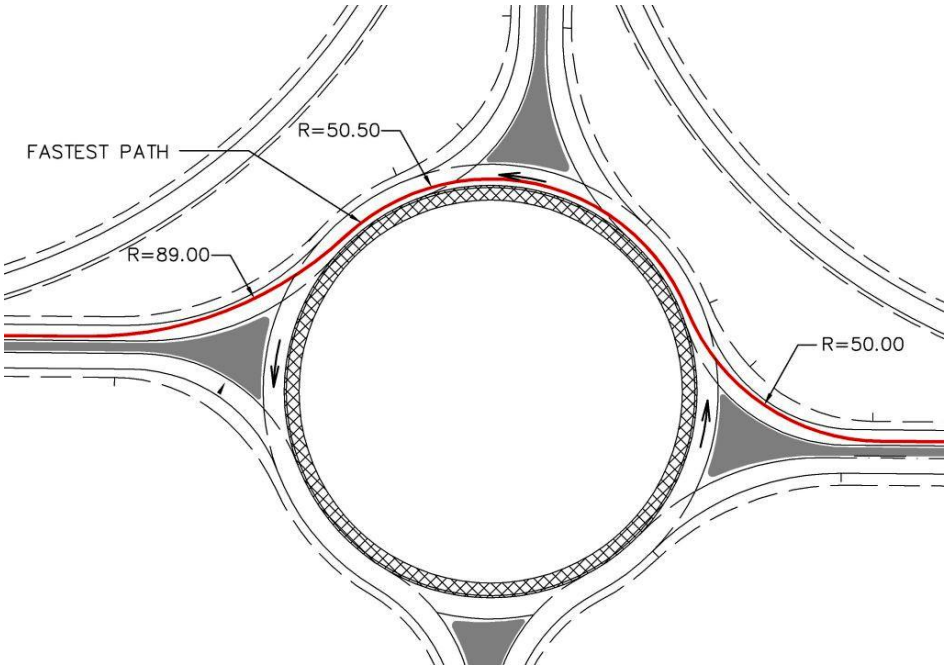
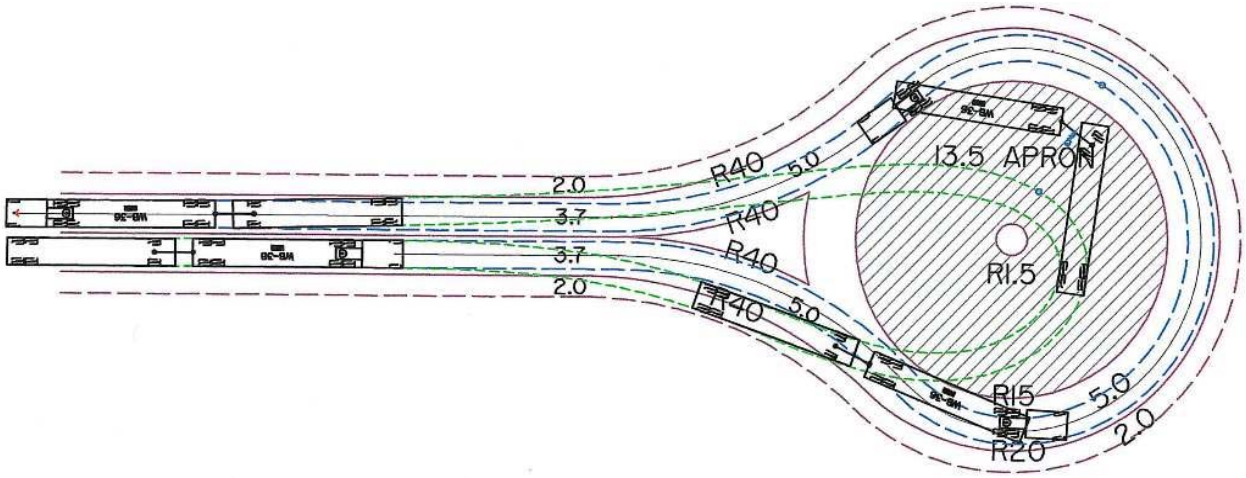


FIGURE 4 - PROPOSED ROUNDABOUT FASTEST PATH
Source: FHWA's Roundabouts: An Informational Guide

B. Option 2: Provide Smaller Diameter and Wider Apron

As the second option for accommodating the design vehicle, a wider truck mountable apron could be provided. A wider apron is required for a smaller diameter to accommodate the off-tracking at the rear-end of tractor trailers as they navigate the roundabout. A smaller diameter with a wider apron is likely to result in lower speeds. However, an increase in the off-tracking due to a wider apron makes navigating the roundabout more complex (see FIGURE 5).

According to Earth Tech's turning template analysis, a WB-36 design vehicle can be accommodated within a 40m inscribed diameter as illustrated in FIGURE 5. In order to accommodate the turning radius of a WB-36 a 13.5m wide apron is required.



Inscribed Diameter: 40m
Circulatory Roadway Width: 5.0m
Apron Width: 13.5m
Central Island Radius: 1.5m

FIGURE 5 - TURNING TEMPLATE FOR 40m INSCRIBED DIAMETER
Source: Earth Tech's Truck Turning Templates

There are several potential safety issues associated with wide aprons. First, the additional pavement surface might convey to drivers that they are permitted to traverse this area. Increasing the apron would reduce the size of the central island, which provides the visual cue that through movements are prohibited.

Second, the drivers of large trucks in particular might intentionally shortcut across the apron instead of following the circulatory road. These vehicles could come into conflict with motorists using the circulatory roadway as intended.

Third, the large paved section could lead motorists to believe that there is more than one travel lane in the roundabout. This could result in some motorists treating it as a double lane roundabout. This is of particular concern at the roundabout exits. Each exit has only one lane and the exit is aligned to accommodate traffic on the circulatory roadway only.

The review of the inscribed diameter compared the two options for accommodating the WB-36 design vehicle. Due to the safety issues associated with a wide apron, the safety audit team supports the large inscribed diameter to accommodate the selected design vehicle. Speeds are expected to be only marginally higher with the proposed diameter than with a substantially smaller diameter.

3.2 Bypass Ramps

Another characteristic that can be considered when implementing large-diameter roundabouts in the highway context is the use of bypass ramps. The purpose of bypass ramps is to reduce traffic volumes and improve capacity through the roundabout by separating selected movements further in advance of the roundabout. This is expected to reduce congestion and delay in the roundabout, and hence a decreased risk of rear-end collisions and risk-taking behaviour due to driver frustration. However, as this design feature is also relatively unconventional, it must be carefully applied. Two potential safety issues related to the use of bypass ramps are discussed here, using the Highway 8 and 22 roundabout as an example.

A. Issue 1: Speed Differential at Bypass Ramp Merges

The large radii of the bypass ramps, illustrated in FIGURE 6, might result in motorists exceeding the proposed 40km/h speed limit. This could create an undesirable speed differential between merging vehicles exiting the bypass ramp and vehicles exiting the roundabout.

The proposed bypass ramps have radii of 150m and 160m. According to Alberta Infrastructure and Transportation's Highway Geometric Design Guide (1999), these radii correspond to a design speed of 60km/h. The posted speed limit on the bypass ramps is 40km/h, which should correspond to a design speed of 50km/h. Due to the high speed rural highway context and the large radii of the bypass ramps, it is likely that motorists will exceed the posted 40km/h speed limit.

The FHWA guide indicates that the radius of the right-turn bypass lane should not be significantly larger than the radius of the fastest entry path provided at the roundabout, for reasons discussed below. The radius of the bypass ramp is 150 to 160 metres, whereas the radius of the fastest entry path is only 50 metres.

At the end of the each bypass ramp, motorists are required to merge with traffic exiting the roundabout. Through vehicles exiting the roundabout are more likely to be travelling at slower speeds than merging bypass traffic due to the design speed of the roundabout (50km/h, compared with 60km/h for the bypass ramps) and the limited acceleration distance between the roundabout and the merge.

Typically merging traffic is travelling at a slower speed than through traffic. Therefore, the proposed design might contradict the usual driver expectation that the through movement travels at higher speeds. Motorists exiting the bypass ramp might fail to yield and motorists from the roundabout might inappropriately yield to traffic on the bypass ramp. This could result in sideswipe and rear-end collisions. Possible right-of-way confusion is further increased by the alignment of the bypass merge, which is discussed in Issue 2.

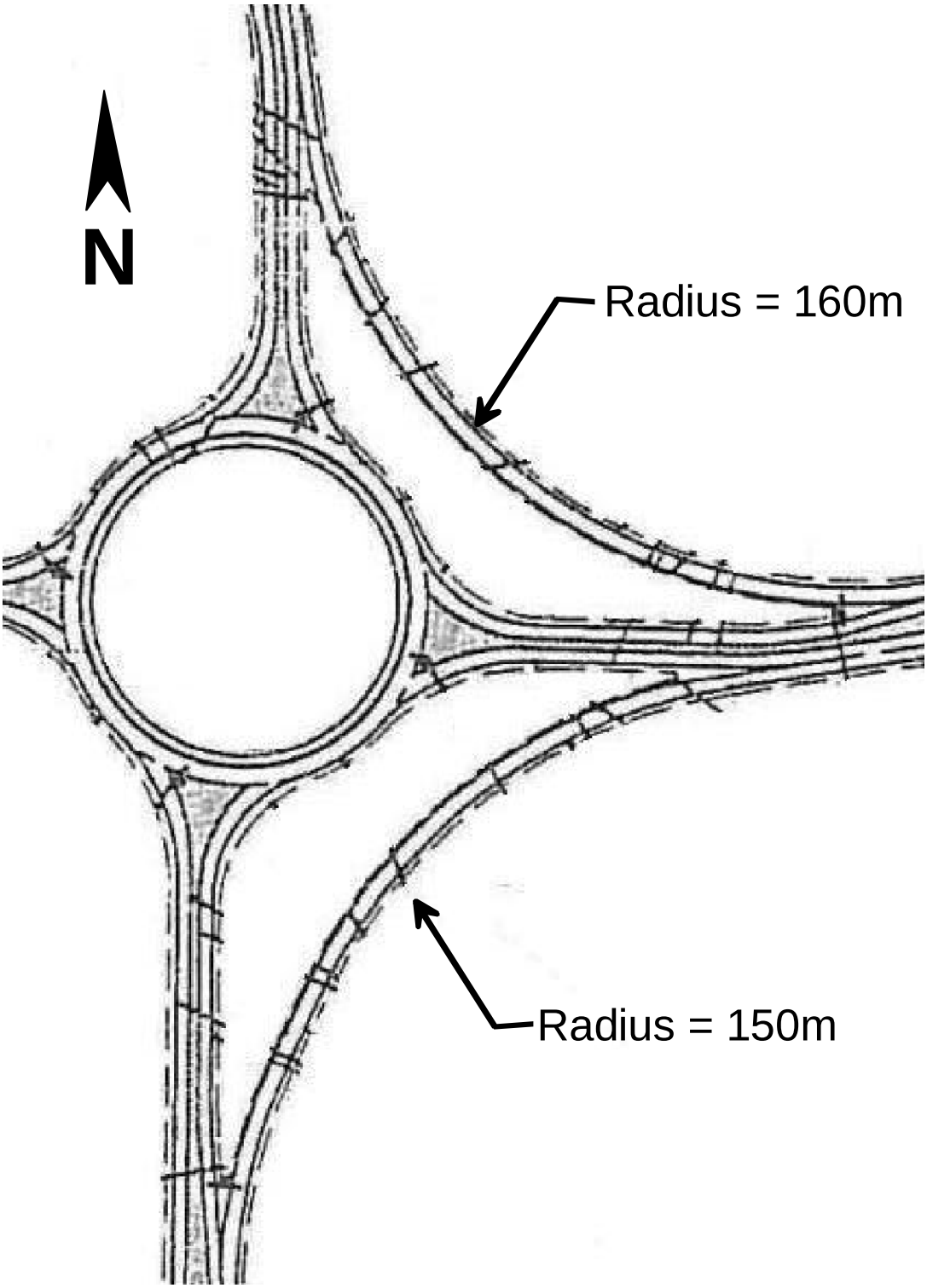


FIGURE 6 - LARGE RADIUS OF BYPASS RAMPS

B. Issue 2: Alignment of the Bypass Ramp Merges

The alignment at the bypass ramp exits could create right-of-way confusion for motorists departing the bypass ramp or the roundabout (FIGURE 7).

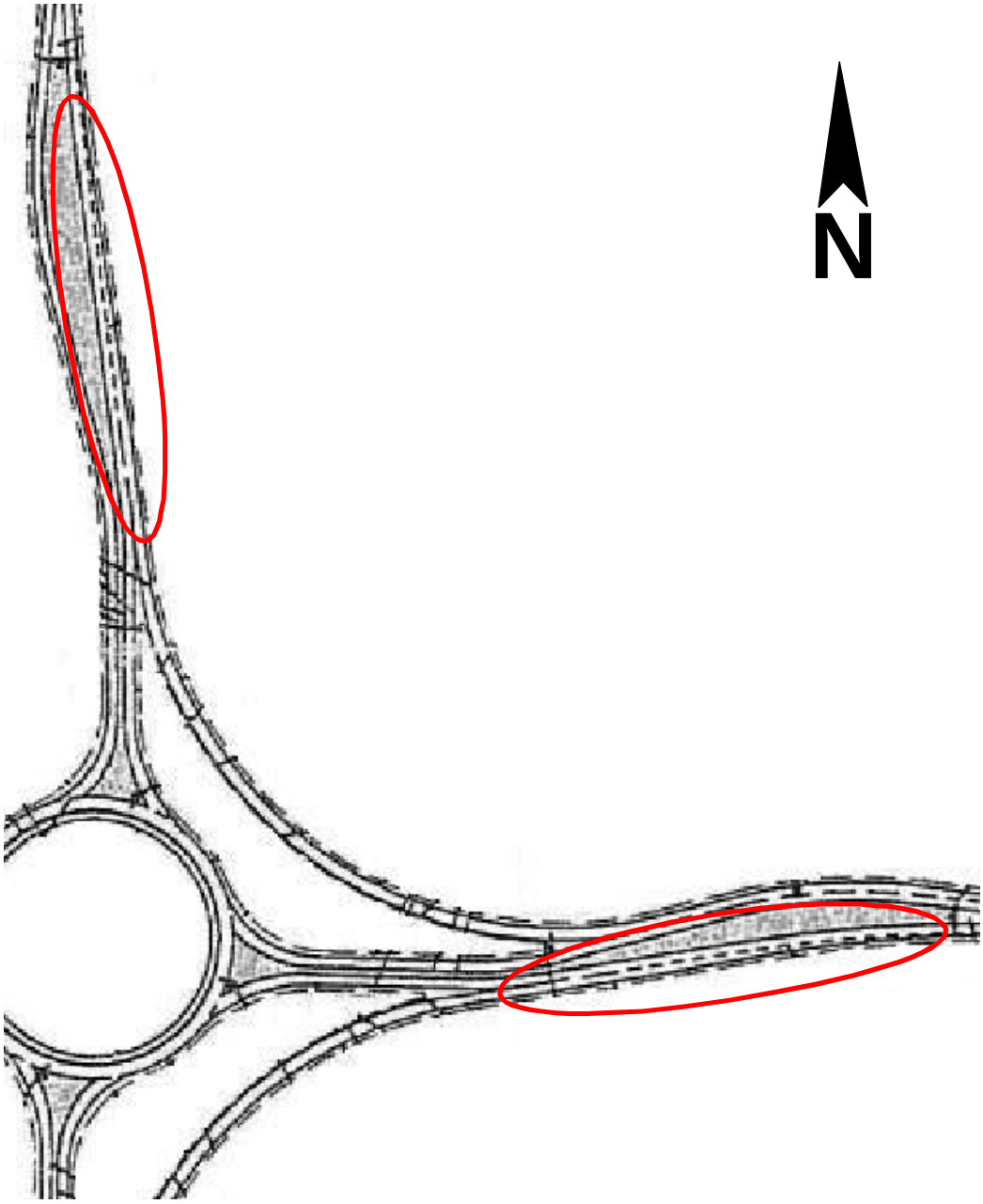


FIGURE 7 - BYPASS RAMP ALIGNMENT

The proposed alignment of the merging roadways at the end of the bypass ramps might mislead motorists, particularly during the winter months when snow and ice might cover the pavement markings. The combination of the horizontal curve on the through road and the straight alignment of the bypass ramp might cause bypass traffic to believe they can proceed straight through to the highway, because they think they have the right-of-way at the merge location. This could result in bypass traffic failing to yield the right-of-way to through traffic. The higher anticipated ramp speeds identified in Issue 1A would contribute to this misperception.

Similarly, motorists approaching the merge area on a horizontal curve from the roundabout might assume that traffic on the bypass ramp has the right-of-way. This could result in motorists slowing or stopping in the through lane, increasing the potential for a rear-end collision.

C. Improvement Suggestions:

The large radii of the bypass ramps could result in undesirable speed differentials at the merge and the alignment of the merge areas might create right-of-way confusion. Implementing one or both of the following geometric changes on each bypass ramp will improve merging operations:

Option 1: Reduce the Radius of the Bypass Ramp

Reducing the horizontal curve radius on the bypass ramp will encourage reduced speeds. According to the Alberta Highway Geometric Design Guide, the minimum radius that should be provided for a design speed of 50km/h is 90m (e=0.06). Therefore, the radius of each ramp could be reduced and still exceed the minimum radius required. The FHWA guide recommends that the right-turn bypass lane should not be significantly larger than the radius of the fastest entry path.

Option 2: Provide a Parallel Acceleration Lane

Providing a parallel acceleration lane at the merge locations would provide motorists with a greater opportunity to adjust their speed according to adjacent traffic. In addition, the acceleration lane might highlight that traffic exiting the roundabout has the right-of-way and that motorists exiting the bypass ramps are required to merge. This is illusrated in FIGURE 8.

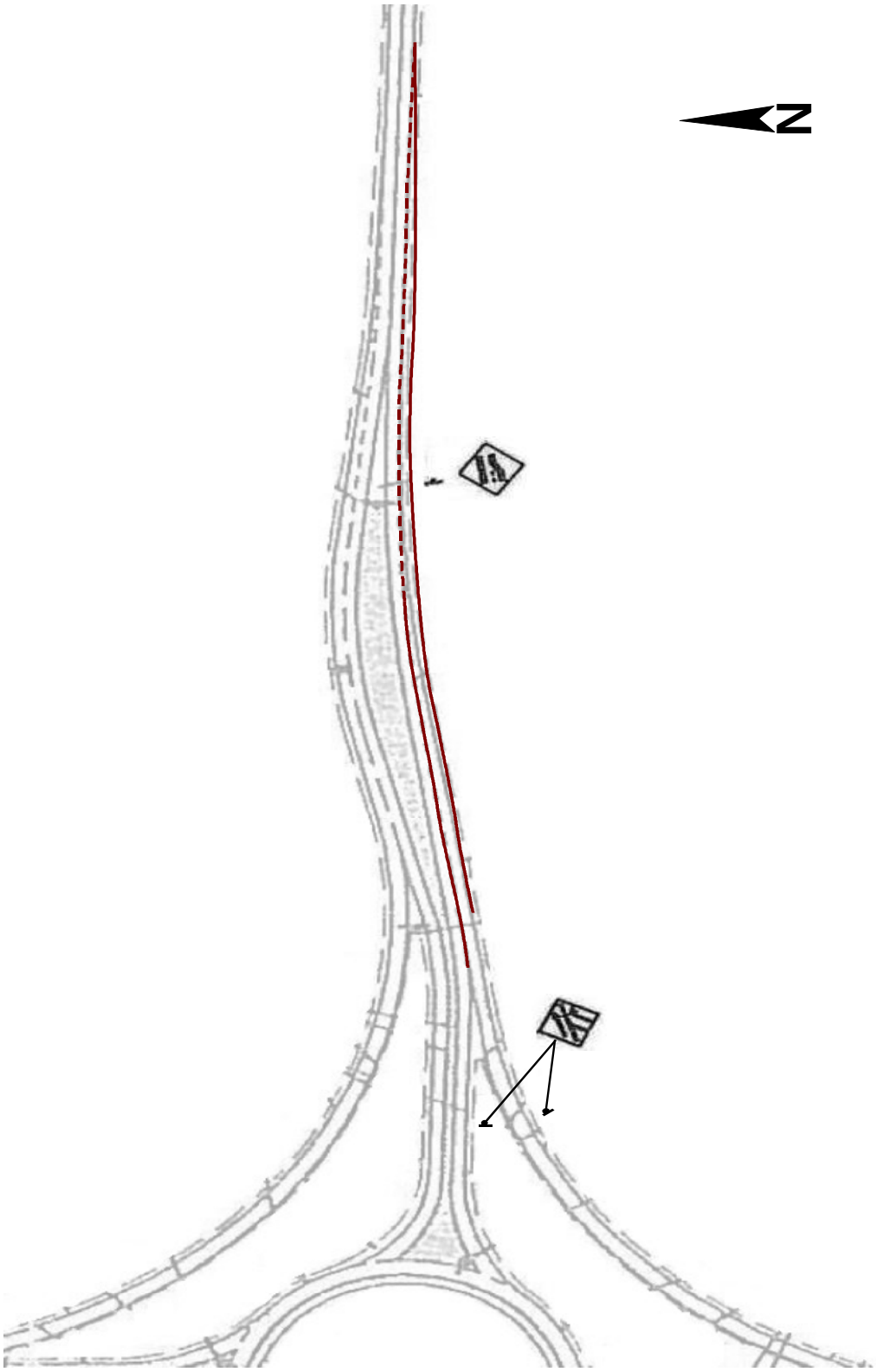


FIGURE 8 - PROVIDE PARALLEL ACCELERATION LANE

3.3 Other Risk Management Issues

A. Driver Awareness

Roundabouts are still uncommon in the province, particularly in the highway context. It is likely that some motorists will fail to yield the right-of-way, reduce to a safe speed, or mount the apron. There is also the possibility that unfamiliar drivers will brake or make an erratic manoeuvre if they are uncertain how to proceed and where to exit, in spite of instructional signing that is provided approaching the roundabout

In addition to the educational signing provided near the roundabout, information can be provided through the use of various education programs, such as:

- Media Coverage: Radio, television and newspaper ads could be used to inform motorists how to use a roundabout. The opening date of the roundabout should be announced to prepare motorists.

- Brochures: Pamphlets outlining the proper use of a roundabout could be distributed to the public, particularly those most likely to use the intersection.

- Website: Many jurisdictions have used websites to provide information on the proper use of a roundabout. In addition to text and pictures, several websites use animation to illustrate the proper navigation of a roundabout.

B. Cyclist Accommodation

Although bicycle volumes were not available and expected to be relatively low, but anecdotal information indicates that Highway 22 is a popular route for touring cyclists travelling between Banff and Calgary.

The FHWA guide indicates that the designer should strive to provide bicyclists the choice of proceeding through the roundabout as either a vehicle or a pedestrian. This is particularly true of touring cyclists, who may be unfamiliar with roundabouts. Guidance is given on how to accommodate cyclists in the FHWA guide.

At the Highway 8 and 22 intersection, it is expected that given the expected profile of the cyclists, the roadway context, the large circle size and the presence of the right-turn bypass lanes, cyclists will not be inclined to dismount and cross at a distance from the roundabout where crossing distances are shorter. Instead, they will share the pavement with vehicles. Therefore, it is important that vehicle speeds remain low enough and the paved cross-section is not excessively wide such that cyclists will travel at a lateral distance to vehicular traffic and become exposed to conflicts at the exit locations. Although cyclist safety is expected to be more favourable at lower design speeds, it needs to be balanced with the needs of the design vehicle. To assist bicyclists in the safe utilization of the facility, the following suggestions are made:

- Provide a pull-out with instructional signage informing cyclists how to navigate a roundabout;

- Develop a preferred route for cyclists to cross the bypass lanes and roundabout. The route would require adequate marking and signage.

- In the educational materials, there should be a special section on how cyclists should use roundabout.

4.0 CONCLUSION

With the increasing popularity of roundabouts, they are being considered for application in various contexts. This paper discusses the application of large-diameter roundabouts in a highway context that is characterized by high-speeds and large commercial vehicles. It describes the safety risks that may need to weighed and managed when considering a roundabout, including heavy vehicle accommodation, speed management, the use of bypass ramps, driver comprehension and cyclist accommodation. Using the example of the proposed large-diameter single-lane roundabout proposed at the intersection of Highway 8 and Highway 22 west of Calgary, Alberta, which was the subject of a Road Safety Audit by the co-authors, the paper concludes that with careful safety review and management of these risks, the application of modern roundabouts in the highway context can become a more viable intersection control option.