Design Consistency and Multi-modal Safety in Urban Areas

Mitchell Jacobson, M.Sc., PEng., Transportation Engineer, Boulevard Transportation
Tom Baumgartner, M.Sc., PEng., Transportation Engineer, Boulevard Transportation

Paper prepared for presentation at the Geometric Design - Lessons Learned: Linkages Between Design Standards and Road Safety Session

of the 2015 Conference of the
Transportation Association of Canada
Charlottetown, PEI

Abstract

An important component of road safety is the compatibility between intended operations of a facility and how drivers actually interpret and react to in-field geometric and traffic control characteristics. Individual design elements may meet or exceed minimum standards, but safety issues may still exist if the geometric characteristics are not fully consistent with signage and markings. At intersections in urban areas, safety issues can be compounded by impacting not only motor vehicle safety but also influencing the safety of pedestrians and cyclists.

Specific issues can arise when turning geometry is not fully compatible with the traffic control scheme. For example, a channelized right turn that has yield control, but is otherwise consistent in geometric design with an added merge lane (due to, for example, a large turning radius), can result in conflicts due to variable driver expectations, with some drivers braking (as per the yield control) while others accelerate to merge at speed, which can create speed differentials and an increase in rear end and merging collisions. Issues can also arise where the safe travel speed on an urban roadway alignment does not align with driver expectation.

This paper identifies common issues that can result in conflicts and collisions between motorists in urban areas due to compatibility issues with respect to turn movements as well as roadway approaches and alignments. Case study examples from Alberta and British Columbia are presented, where the safety issue is identified (for vehicular as well as non-motorized travel modes), the reasons (as possible) that the compatibility issue may exist in the first place, along with mitigation options that can be considered (while highlighting potential benefits of those improvements). Finally, conclusions and lessons learned are summarized.

Introduction

The compatibility between roadway geometry and traffic control elements is an important safety consideration, and one that can have impacts on safety for individual vehicles, conflicts between vehicles and safety implications for vulnerable road users (pedestrians and cyclists). A blanket application of design standards may, while meeting the “standard”, not automatically result in a facility that is as safe as it could be. This paper presents scenarios where design incompatibility contributes to one or more safety concerns, along with reasons for how these scenarios may have arisen in the first place, as well as possible mitigation strategies.

Safety at Right Turn Channelized Islands

Right turn channelization is frequently used at signalized intersections, particularly on higher volume and speed roadways such as arterials. One benefit is that they can increase capacity and otherwise minimize driver delay, and are particularly a consideration where the right turn is a major or dominant movement on arterial roads. They have either yield control or have merge or added lanes that allow for free right turns (and merging downstream).

The right turn geometry is typically designed in accordance to the design speed of the approach and intersecting roadways, where a larger radius can facilitate a higher navigating speed. Issues can arise, however, where the design speed and geometry of the channelized island does not match that of the in-field traffic control.

One area where this can result in safety issues is where there is a large right turn radius (one that is consistent with the design speed of a high-speed approach roadway) but where a yield condition is in effect. Yield control can have benefits in eliciting a slower entry speed, but if the geometry conveys a message of a high-speed turn (potentially a free right turn), then conflicts or collisions can occur between trailing vehicles and an abruptly-yielding vehicle, as well as between vehicles that enter the roadway at speed instead of properly yielding to traffic on the intersecting roadway. Also, because of the acute angle of entry onto the intersecting road, it can be difficult for some drivers to fully shoulder check for oncoming vehicles once they’ve slowed or stopped at the end of the curve.

This also has a negative impact on pedestrian safety; the large island is such that the sidewalk placement (as well as the inherent pedestrian desire line) is near the end of the right turn curve, where sight lines to/from pedestrians is at the minimum value, and where vehicles may be approaching at a rapid pace. Moving the sidewalk would likely only shift a portion of pedestrians, as it is a longer, indirect route.

An example of this situation is shown in Figure 1, from the intersection of Memorial Boulevard and 36 Street NE in Calgary.

Figure 1: Large Radius Right Turn Channelization with Yield Control

In this particular situation, the departure roadway has a posted speed limit of 80 km/h (although the intersection transitions to 50 km/h immediately past the intersection), and the turn radius of 49m equates to a design speed of 40 km/h. This is a relatively fast approach speed where abrupt braking for the yield condition may occur, which can result in rear end collisions. Note also that pedestrians on the outside corner of the intersection have only a minimum of visibility to approach vehicles, and even then, approach vehicles often are looking to their left for oncoming vehicles (to merge with or yield to) rather than to the right towards pedestrians.

A related, but effectively the opposite, situation is where the geometry appears to portray a yield-type design, but is in fact an added-lane scenario. Even if properly signed, this can result in yielding behaviour (particularly if the added lane signage is only on the right side of the road), which can result in conflicts from trailing vehicles that are not expecting the need to brake abruptly.

The example in Figure 2 shows the westbound right turn movement at 16 Avenue and 68 Street NE in Calgary. This location has a right turn lane with a small radius right turn, leading into an added lane (for a free right turn scenario). Despite this, numerous drivers were observed to brake and yield. It should be noted that there is in fact no Added Lane signage or Merge signage present, but nonetheless there is a long added lane downstream (and there is no immediate left turn opportunity downstream for which a turning driver might wait in order to make an immediate lane change). In this particular case there are utility constraints and a retaining wall that prevent the easy construction of a larger right turn radius. The inclusion of primary and secondary Added Lane signs would however help address this issue.

Figure 2: Small Radius Right Turn Island, with Added Lane

Figure 3 shows this situation at the intersection of Heritage Drive and Glendeer Circle in Calgary. In this example, there was a relatively recent change in traffic control (September 2013) from yield control to an added-lane (for a free right turn), which was done to accommodate the heavy right turn movement (the dominant movement at the intersection). This was done by eliminating one lane in the eastbound movement (left-to-right in the figure), as this is a comparatively low volume movement that does not need two lanes to meet capacity requirements. The geometry of the island, however, is still similar to a yield design, as it effectively just extends the existing yield-style island out further, without adding curvature that would indicate to drivers that they are protected from oncoming traffic. Approximately one in three drivers were observed to yield at the added lane approach, and frequent honking from trailing vehicles was noted. Although the paint markings do clearly show the intended path, and Added Lane signage is used on the outside corner, they do not in this case provide the physical and psychological reinforcement that it is truly a free right turn movement.

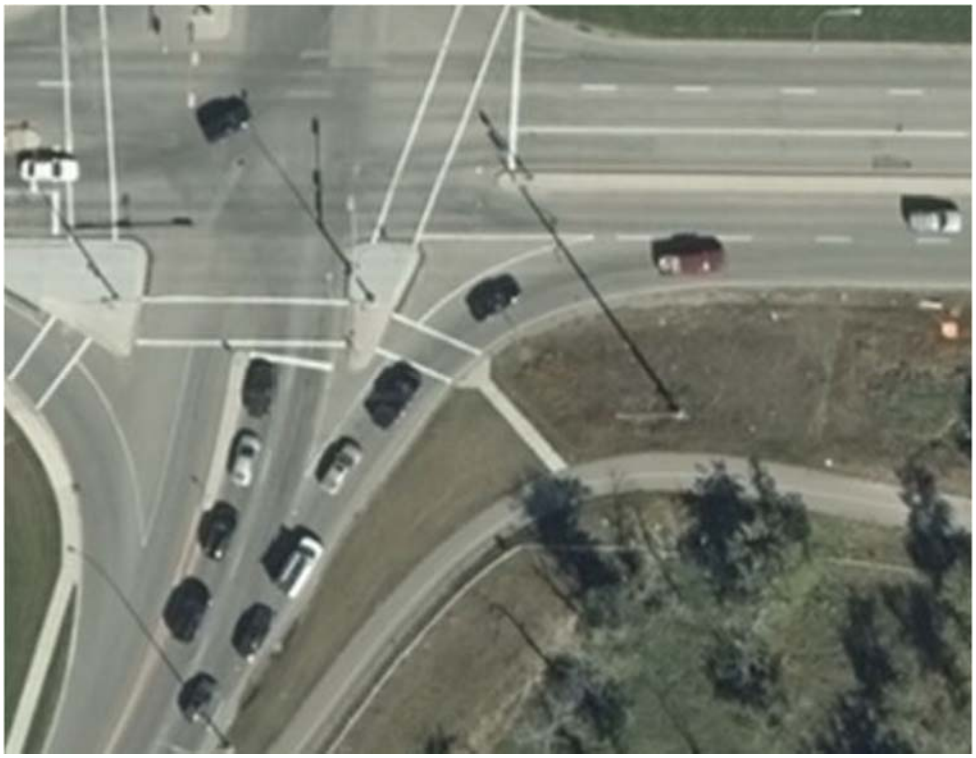

Figure 3: No Deflection on Right Turn Island (centre of photo), with Added Lane

A challenging scenario can be where there is a right turn island with yield control, but also a bus bay immediately upstream of the entry point onto the intersecting road. In this case, the bus bay may be misconstrued as a merge lane, and conflicts can arise since there is not sufficient acceleration length. This scenario can result in inconsistent driver behaviour, from drivers properly yielding (but with some trailing drivers being annoyed, as they perceive it to be an added lane or merge lane situation), drivers merging at speed (and conflicting with intersecting traffic), or drivers entering the bus lane, realizing there are not sufficient gaps, and stopping in the bus stop area (and potentially conflicting with buses, and even being overtaken by trailing right turn vehicles that drive straight into the main lane). See Figure 4 for an example, from the intersection of McKnight Boulevard and Edmonton Trail in Calgary.

Figure 4: Bus Bay at End of Right Turn Channelization with Yield Control

Mitigation Measures for Right Turn Channelization Design Consistency Issues

For situations where there is an incompatibility between right turn channelization geometry and intended operations, there are a number of options that can be considered.

At a basic level, improvements to signage can at times help clarify the situation; where yield control is in place, this may mean adding a secondary (left side) yield sign. In some cases, advance warning signage could also be employed (e.g. a Yield Ahead sign), particularly if it is clearly intended and interpreted for the right turn movement only (as might be the case for a large channelized island). Consideration for larger signs could also be appropriate as well if there is a significant collision history and/or if there are higher speeds.

In some cases marking improvements can have some benefits, and highlight the correct intent. For example, where a bus bay begins immediately past a right turn yield channelization island, the bus bay can be bounded by dashed bus bay lines, with a reserved diamond lane stencil added to the bus bay (see Figure 5, for a mitigation option for the situation in Figure 4). Additional emphasis of the bus bay can be given by colouring the bus bay red.

Figure 5: Mitigation Option (for Figure 4 scenario) - Guide Lines and Bus Bay Diamond

Signage and markings, however, are ultimately passive measures only that can be ignored or missed by drivers. Geometric changes are a stronger measure as they physically require driver action (lest the driver collide with the edge of the road). One geometric measure that can have a strong safety benefit for not only drivers but pedestrians as well is smart right turn channelization. This type of design results in a sharper angle approach, that allows for better driver visibility of pedestrians (either on the raised island or outside of the intersection) as well as yield signage, and more of a geometrically-inherent need to yield at the intersection, since the turning radius is greatly reduced. An example of how the situation depicted in Figure 1 could be mitigated with a smart right turn channel is shown in Figure 6, and an in-field example is shown in Figure 7.

Alternatively, in some cases it may be appropriate to construct right turn merge or added lanes onto the intersecting downstream leg. This would be most appropriate where there is a high volume of right turning vehicles (or even the dominant movement), and where access and intersection frequency is limited (e.g. arterial roads or expressways). If accesses are closely spaced to, or within, the merge / weave area, there can be additional conflicts which may just shift the safety issue. For downstream bus bays, if the bus bay can be relocated further downstream with a dedicated entry taper, it can bring the yield point up to the main lane, and better conform to the intended operation.

Figure 6: Mitigation Option (for Figure 1 scenario) – Smart Right Turn Channelization, and Separate Bus Bay

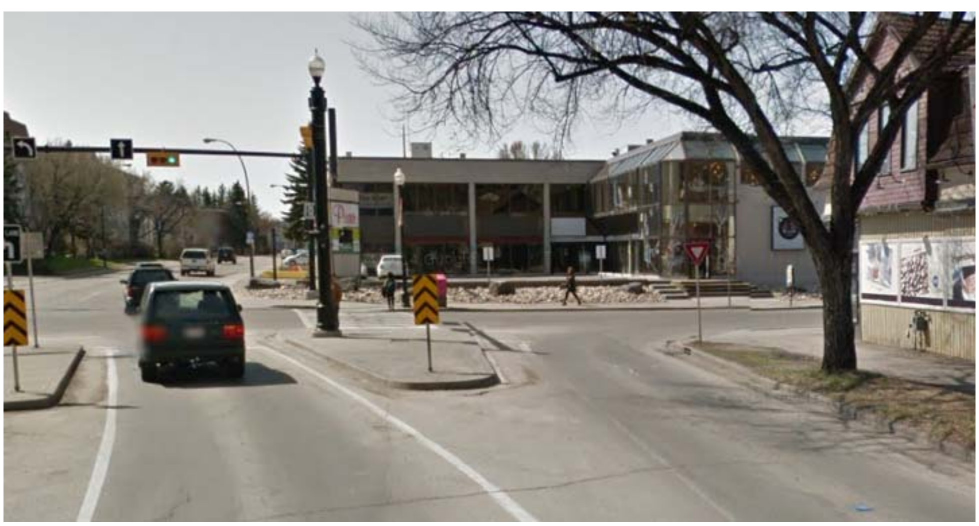
Figure 7: Example of Smart Right Turn Channelization (5 St and 17 Ave SW, Calgary)

Roadway Alignment for Hillside Developments

The incorporation of horizontal curvature in residential areas on collector roads can, in many cases, promote adherence to the design speed, or even serve a traffic calming role by requiring slower speeds on turns. In urban areas, a normal crown is typically maintained around these curves, particularly on collector and local roads (as opposed to developing a reverse crown or superelevation) since the driving discomfort felt by vehicles on the outside of the curve is generally minimal, and it can otherwise further promote slower navigation. This situation, however, is most applicable where approach grades are relatively flat. In hillside development areas, the additional challenge of grades can impact driving characteristics and also how drivers navigate the roadway. An example of where typical roadway standards resulted in a safety concern is for a portion of Bear Mountain Parkway, in Langford, BC.

This roadway was designed as a typical residential collector road (posted speed limit of 50 km/h), and is typical of other similar collector roads (constructed in the same era) within the municipality in terms of horizontal curve radii and cross section. However grades on this roadway can reach 9.0 percent or more. There are also numerous curves as the road wends up the mountain. The roadway has no on-street parking along a majority of its length, although some sections have houses and driveways along the road.

One particular stretch had a significant frequency of single-vehicle collisions from vehicles losing control in the downhill direction, and hitting the roadside barrier and either bouncing off (across the road into the oncoming lane or onto residential lots), or skidding beyond the end of the barrier onto a chip-trail below (approximately 5m below roadway elevation). The concern was not only the frequency of these incidents (up to one per month), but to potential for significant casualties should one of these vehicles drop onto a pedestrian using the trail.

The design characteristics were in general very consistent with residential collector roads for level / flat conditions, but that this generic design template likely contributed to the safety issues observed at the location. Based on As-Built drawings for Bear Mountain Parkway, the road and curve has the following design characteristics

- Grade – 8.9 percent uphill from the horizontal curve
- Curve Radius – 64m
- Normal Crown, at 2.5 percent slope
- Road width – 8.6m wide through the curve (4.3m wide lanes)

Based on TAC *Geometric Design Guide for Canadian Roads*, the recommended minimum horizontal radius for a normal crown in urban areas is, at 30 km/h, 420m (and 950m for 50 km/h). There is a significant effect, however, on the minimum recommended radius if the road is superelevated to even 2.0 percent (i.e. reverse crown). A horizontal curve with 2.0 percent superelevation with a radius of 64m would equate to a design speed of 40 km/h. Therefore superelevating this section to match the uphill cross-slope through the curve is a strong consideration that enhanced roadway friction alone likely cannot achieve.

The lane widths, at 4.3m wide, provide an appropriate road width for side-by-side bicycle / vehicle operation, however in the absence of on-street parking or frequent cyclists (of which there are few due to the long, steep grade), this width can promote faster vehicle speeds (exacerbated by the downhill approach grade).

Additional features that may contribute to the safety risk include median areas on curves demarcated by paint markings only, as many downhill drivers were observed to travel over the painted area in order to maintain as much speed as possible. Also, the existing Curve warning signage did not fully convey the extent of the safety risk (and the chevron signs were not as conspicuous as they could be due to inherent lighting and visual backdrop conditions), see Figures 8 and 9.

Figure 8: In-field Curve Warning Signage (left) vs. Preferred Option (right)

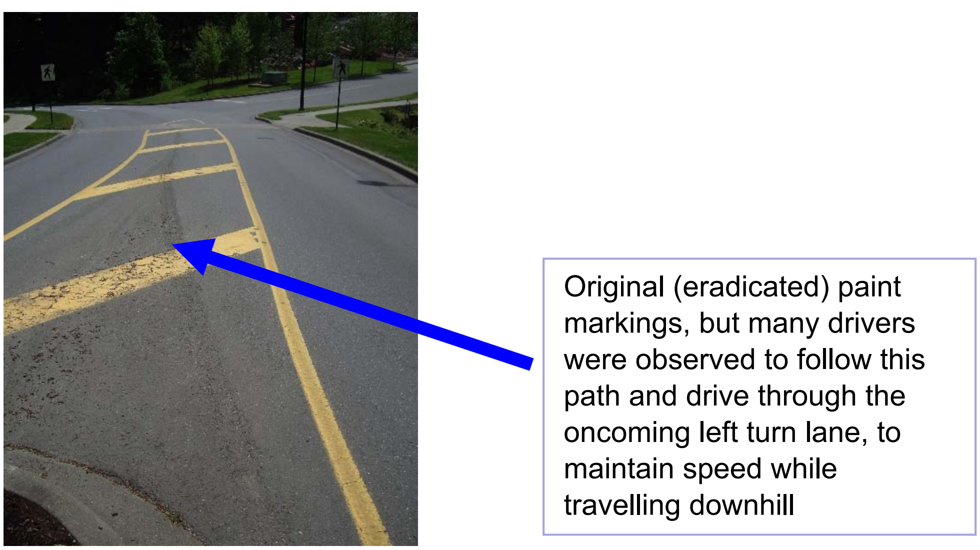

Figure 7: Upstream Median Markings

Mitigation Measures for Hillside Alignment Design Consistency Issues

A number of mitigation options were identified as part of the Bear Mountain Parkway safety review, but these could be considered for other similar situations as well. They include the following options:

- Roadway crossfall – convert to a reverse crown on curves with poor safety performance or at the bottom of long, steep downhill roadway approaches
- Install raised medians (with curbs) in lieu of painted medians, to force proper positioning in the lane and reinforce the appropriate drive speeds
- Improved signage (increased conspicuity, size, and emphasis)
- Lane narrowing; options include a mountable median (to allow for driveway access while still narrowing the roadway) or curb re-location
- Barrier improvements

Subsequent to the review of Bear Mountain Parkway, the City installed centre line pickets, improved signage, and raised medians (that force proper positioning in the lane) in advance of the area of concern. The measures have thus far had a positive impact, with no reported collisions in the area by Langford staff in the first year.

Conclusions

Road standards and typical designs can be beneficial for maintaining consistency between locations, and thereby meet driver expectation. There are, however, situations where deviations from typical design standards is a strong consideration to ensure that a facility operates in a safe manner. At right turn channelized islands, issues can arise where there is an incompatibility between the geometry and the traffic control. Roadway alignments can also contribute to safety issues if a typical alignment and design approach is used but where other site-specific factors are not fully accounted for, such as approach road grades and sharp horizontal curvature. Improvement measures may include enhanced signage and marking measures. Geometry improvements can be even more beneficial when they physically require drivers to adjust their behaviour to match the actual conditions, although this are not always possible in constrained areas. It is therefore important, when designing a roadway alignment or intersection, to consider potential safety influencers at the outset, so that any geometric requirements are incorporated at the outset as opposed to difficult, or prohibitive, retrofit situations.