Modern Roundabout or Signalized and Stop-Controlled Intersections?

– Case Studies of At-Grade Intersections on Alberta and Saskatchewan Rural Highways

by

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Abstract

In order to demonstrate the analysis procedures for feasibility study of roundabouts, five case studies on Alberta and Saskatchewan rural arterial highways, including signalized and stop-controlled intersections as well as an interchange ramp terminal were analyzed. They all have either long delays or operational and safety concerns that improvements are required. In the case studies, future intersection turning volumes were predicted to evaluate traffic operations and capacity of each alternative. Cross comparison of traffic operations was made between stop-controlled intersections, signal controls, single-lane and two-lane roundabouts. Detailed traffic analysis was carried out for different alternatives using several software packages, including Synchro, SIDRA and VISSIM. Economic analysis and rating matrix methods were used in alternative evaluation. These case studies demonstrated intersections where roundabout is a good solution and locations where roundabout is not the best choice. Based on the study, it is concluded that in order for a roundabout to be feasible for an intersection, it should have adequate capacity, expected safety performance and superior economic value than other competing alternatives. The capacity of single-lane roundabouts is higher than all-way-stop controlled intersections but lower than signalized intersections with properly designed through and turning lanes. The capacity of two-lane roundabouts is usually lower than channelized intersections with two through lanes in each direction and exclusive left-turn lanes. Innovative use of roundabouts at some interchange terminals can not only provide safety benefits, but also offer operational advantages that were otherwise unavailable with conventional stop-controlled intersections.

1. Introduction

Major application of roundabouts can be found in four areas: to improve traffic safety at intersections, as a control measure to improve traffic operations under certain traffic conditions, to suit for complex geometry, such as intersections with more than four legs, and to slow down traffic through neighborhoods for traffic calming.

Alberta Transportation has adopted a proactive policy of implementing modern roundabouts on rural highways. With this policy, when intersection improvement is warranted, modern roundabouts should be considered as the first option unless it is proven not feasible. The Ministry of Transportation and Infrastructure of British Columbia and some states in the United States have also similar policy. This will result in more modern roundabouts on rural highway intersections, including at interchange ramp terminals. Even though there is strong policy endorsement from highway agencies or municipalities, roundabouts may not be a panacea for all circumstances. For a particular location, systematic evaluation is required to justify whether a roundabout is the most suitable option. The purpose of this paper is to provide several case studies to demonstrate the analysis procedures and show where roundabouts are or are not the best choice based on operation analysis, safety performance and economic analysis or comprehensive evaluations within specific project contexts.

2. Literature Review

Many studies showed that roundabouts have been demonstrated to be safer than other forms of at-grade intersections [1-5]. The safety benefit is particularly notable for fatal and injury collisions. The safety performance of roundabouts is due to the configuration. At roundabouts, vehicles travel in the same direction, eliminating the right-angle and head-on collisions associated with traditional intersections. In addition, modern roundabout design places a high priority on speed control through geometric features such as deflection at the entry, limited curve radius to naturally slowdown all movements and reduce gap-length requirement for entering vehicles. Lower vehicle speeds, together with other design features, can provide the following safety benefits [2,6]:

- Provide more time for entering drivers to judge, adjust speed for, and enter a gap in circulating traffic, allowing for safer merges;
- Provide more time for all users to detect and correct for their mistakes or mistakes of others;
- There is a lower speed differential between the users of roundabouts, significantly reducing the collision severity if a collision occurs;
- Roundabouts have fewer conflict points for vehicles, pedestrians, and cyclists;
- Compared to uncontrolled crossings, roundabouts increase the likelihood of drivers yielding to pedestrians;
- Pedestrian crossings at roundabouts are much shorter in distance and entail interruption in only one direction of the traffic stream at a time;
- Using splitter islands before the entry to physically separate entering and exiting traffic streams and provide a refuge for crossing pedestrians.

Persand et al. [1] performed a study on 24 intersections in the United States that had converted from signalized intersections and stop-controlled intersections to modern roundabouts. There are overall 39% reduction of total collision, 76% reduction of all injury collisions, 90% reduction of fatal and incapacitating injury collisions. From the data compiled in NCHRP Report 572 [2], there is evident difference in collision reduction rate between one-lane and multi-lane roundabouts. For injury collision, the reduction of two-lane roundabouts is a little lower than that of single-lane roundabouts. However, for all collision type, single-lane roundabouts have much higher reduction rates than two-lane roundabouts.

In operation analysis, there are three types of models that can be used for capacity analysis of roundabouts: regression models, analytical models, and microscopic simulations. Regression models are empirical models that are developed based on regression analysis using data collected at existing roundabouts. Analytical models are based on critical gap and follow-up gap theory to calculate the entry capacity based on the available gap in the circulating traffic. Microscopic simulation is often used for special cases, such as adjacent intersections. Corresponding to the models, there are three types of tools for roundabouts analysis: software based on regression, models, such as RODEL/ARCADY, based on analytical models, such as SIDRA, and microscopic simulation (VISSIM, PARAMICS, CORSIM etc.). SimTraffic and HCS2010 have also some functions for roundabout analysis. The calculated roundabout capacity from different software packages is dependent on the data used to develop the model and parameters used in analysis. Considerable capacity difference exists among roundabouts in Australia, UK and North America due to the difference in driving behavior and operation conditions. For example, RODEL/ARCADY estimated roundabout capacity may be 15-20% higher than that achieved in practice in North America [7]. Vlahos et al. [8] studied the capacity of single-lane roundabout and compared with a signal controlled intersection and found that within a total traffic demand volume, the roundabout has better performance. Beyond that point, the signal-controlled type intersection provided better operational performance than the roundabout.

Literature review may conclude that there is a general consensus that modern roundabout can improve intersection safety. Their capacity may be dependent on the tools used and varies with environments and traffic conditions.

3. Analysis Procedures and Methodologies

3.1 Data Collection

The first step for intersection improvement analysis is data collection, including existing plans and control measures, traffic volume, vehicle types and intersection users. During the field visit, driver interactions with the existing geometry and other users (e.g. transit, bicyclists and pedestrians), lane designations, conflicts, queuing, congestion and operations as well as sight distance on each approach should be accessed. Collision data are usually requested from relevant organizations.

3.2 Operation and Safety Overview

Collision data can be analyzed at the different level of details, from simple collision classification and frequency to detailed collision diagram, depending on project requirements and operational concerns. The collision frequency and patterns can be compared to regional collision statistics to evaluate whether there are specially high collision types that need special treatment. From field observation, safety performance and operation analysis, existing intersection deficiencies can be identified which helps to develop intersection treatment alternatives.

3.3 Traffic Projection

Future traffic is projected to the design horizon, which is usually 20 years after the project opening. Sometimes the traffic of interim characteristic years (such as 5 year, 10 year after construction) may be required for evaluation of alternatives or interim measures. For intersection capacity analysis, the design hour is usually the 30th highest hour in the design year. For locations where morning and afternoon peak hour turning movements may be significantly different, separate prediction and analysis of peak hour traffic is required.

There are primarily three methods for traffic projection: (1) historical trends, (2) cumulative analysis and (3) using area transportation plan or modeled volumes. The historical trends method assumes that the future growth trend will be similar to the historical trend. It is used mainly in rural or small urban areas where significant growth is not anticipated. The cumulative analysis method is generally used to forecast volumes for small urban areas that are growing at a fairly uniform rate or intersections with large land development nearby. It uses information on existing and planned land uses in addition to historical trends to predict total future traffic volumes. The use of transportation plan or modeled volumes is most applicable if the intersection is located in a region where development over a long period of time in an area of high growth is expected..

3.4 Development of Alternatives

Based on the projected traffic, operation characteristics and safety concerns, intersection alternatives can be developed. The potential alternatives should be able to solve major concerns. There are three major types of intersection control to consider for at-grade intersections: (1) stop control (STOP), (2) signal control and (3) roundabout control. There are sub-types within each control category. For example, signal control ranges from simple two-phase fixed cycle control to fully actuated multi-phase control or area-wide signal coordination. For stop-control, there are two-way STOP (TWST) and all-way STOP (AWST) options. For roundabouts, there is single-lane, multi-lane or combination of them, and with or without right turn bypasses.

3.5 Safety Evaluation of Alternatives

Safety evaluation of alternatives is necessary because it may eliminate some options that can survive traffic analysis but unsafe to users. For small projects, safety evaluation can also be performed implicitly in the development of alternatives. For any treatment alternative, the potential safety benefit and possible drawbacks can be identified based on the configuration and operation conditions. The output from safety evaluation is how many collisions may be reduced by implementing certain improvements. Literatures can provide collision modification factors [10] which can be used as a guideline. From literature review [1,2] and analysis, it can be estimated that the roundabout option can achieve the percentage of collision reductions as listed in Table 1.

Table 1: Estimated Collision Reduction of Roundabouts

Collision Category	Average Reduction (%) For Single-lane	Average Reduction (%) For Two-lane
Fatal Collision	90	70
Injury Collision	75	50
Property Damage Only Collision	40	20
pedestrian collisions	30-40	30-40

3.6 Traffic Analysis

Traffic analysis for the alternatives is carried out for the design horizon and each characteristic year, based on Highway Capacity Manual (HCM) [9] methodologies. In the case studies in this paper, Synchro was used for signal or stop controlled intersections, SIDRA was used for roundabout analysis and VISSIM was used in one case study to compare with SIDRA for roundabout analysis.

Average control delays, for intersection as a whole and for each movement are quantitative Measures of Effectiveness (MOE). They are associated with Level of Service (LOS), which is a qualitative measure of the performance as defined in HCM 2010 [9]. In addition to the delays and LOS, queue length is also important for some intersections. A long queue at some movement may cause the change of operation pattern, which in turn will affect analysis. For example, if a left turn (LT) queue is longer than the turning bay, the queue will spill over and block the through movement (TH). Most of software do not consider this factor in delay calculation. This problem can be shown clearly in microscopic simulation.

3.6 Economic Analysis and Final Evaluation

Two methods are often used in alternative evaluation: the economic evaluation approach, such as benefit-cost analysis, net present value (NPV) etc. and the rating scheme approach (evaluation matrix, which uses scoring or weighing factors to produce a scalar measure for project attractiveness). The difficulty with the former approach is that some benefits are often difficult to quantify. With the latter approach, the rating and weighting are often subjective and may be dependent on the group of people who perform the rating. Both methods can also be used jointly on the same project.

For intersection improvements, the cost includes initial capital cost, maintenance, operation cost during the service life and user cost. The benefit is mainly from collision reductions and operational improvements. The average unit cost for each collision category currently used by Alberta Transportation is:

- Property Damage Only Collisions (PDO) = $12,000/per collision;
- Injury Collisions = $100,000/per collision;
- Fatal Collisions = $1,345,068/per collision.

To simplify the analysis, relative economic value can be evaluated, in which only items not common to the alternatives are used in the comparison. The benefits and costs common to them can be left out. These simplifications will not affect the analysis results and conclusions. To compensate the possible uncertainty of benefit and cost estimation, a sensitivity analysis can be performed by varying the benefit and cost to a percentage. In the case studies presented later in this paper, it was assumed that collision reduction for the roundabout decreases 15% from the values in Table 1, unit cost per collision decreases 15% from the originally useed value and the average traffic growth rate drops by a certain percentage (such as 1% or 2%) from the original value. Under those unfavourable conditions, NPV can be calculated to determine the robustness of each alternative to risks.

Based on the planning, safety, operational and economic analysis, each alternative may have unique advantages and some shortcomings. Balancing competing needs is important and essential. Every intersection should be evaluated based on site-specific issues as well as the intersection's relationship to the adjacent roadway network to ensure the most efficient and safe intersection alternative is selected.

4. Case Studies

Following the procedures discussed above, five case studies are provided in this section to show how roundabouts are evaluated against other intersection types.

4.1 Case Study 1: Highway 28/Highway 37 Intersection

The intersection of Highway 37 and Highway 28 at approximately 10 km north of Edmonton, as shown in Figure 1. Highway 37 runs east-west direction and highway 28 runs north-south direction. Both of them are 2-lane, 2-way rural arterial highways. The existing intersection is operating under signal control and is scheduled for reconstruction along with the grade-widening of Highway 37.

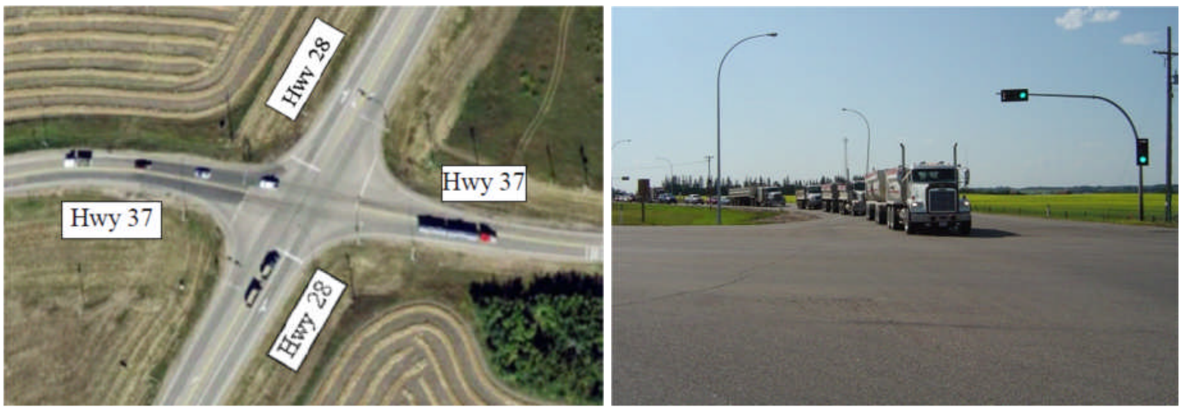

Figure 1 Existing intersection layout (Google map) and a photo looking west along Hwy 37

Operation and Safety Overview:

The major problem of this intersection is that there is very high left-turn (LT) volume with high truck proportion (23 % trucks) from the west leg to the north, causing long delays on the west approach during peak hours. There have been a total of 37 collisions reported at the intersection during five years period (2002-2006). Fifteen collisions were reported as injury collisions and none was reported as a fatal collision. The collision frequency is 7.4 collisions per year.

Traffic Projection

Simple growth rate method was applied for traffic projections to the design horizon year of 2030. The projected peak hour traffic turning movements are shown in Table 2 (for PM peak hour only as the AM peak is not as critical as PM peak at this location).

Table 2 Projected Traffic Turning Movements (veh/h)

	Highway 37						Highway 28					
	Eastbound			Westbound			Northbound			Southbound		
Year	L	T	R	L	T	R	L	T	R	L	T	R
2010	145	197	101	111	268	52	83	304	102	28	273	80
2020	179	243	124	137	331	64	102	375	125	35	337	99
2030	213	289	147	163	393	76	121	445	149	42	400	118

Development of Alternatives

Two alternatives were proposed: Alternative #1 is a signalized intersection with two through lanes in each through movement, exclusive left-turn and channelized right-turn lanes on all approaches. Alternative #2 is a two-lane modern roundabout. Two entry and two exit lanes are required on each leg of the intersection and two lanes are required for circulating. Conceptual design for the alternatives are shown in Figure 2.

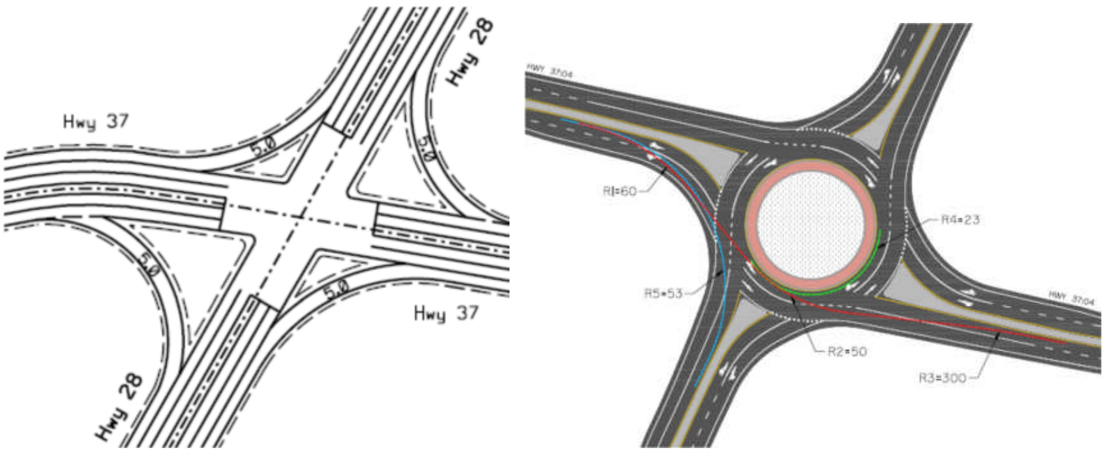

Figure 2 Channelized intersection and roundabout

Traffic Analysis

The average intersection delays and delays for the worst movement are plotted in Figure 3. As shown in the figure, both alternatives will have good traffic performance within the design horizon and they have similar delays.

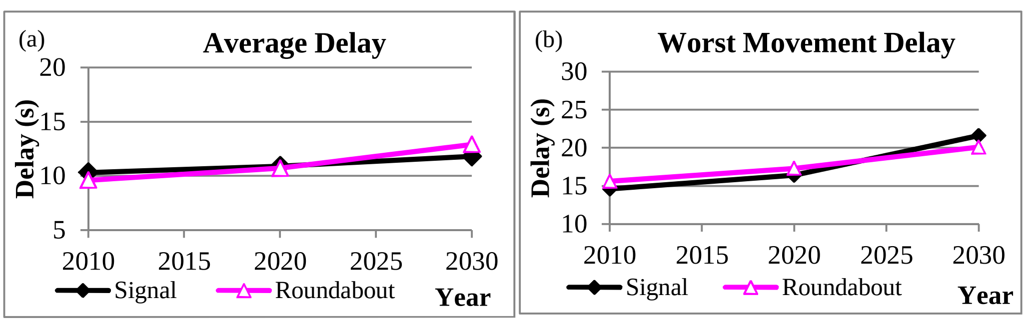

Figure 3 Average delays and delays on the worst movement

For this location, additional traffic analysis was made by comparing SIDRA with VISSIM to evaluate whether different software produces significantly different results. For the design year peak hour traffic, average delay on each approach is presented in Figure 4. As shown, the two software packages provide similar delay values on west, south and north approaches. On east approach, VISSIM predicted delays are 20% longer than that from SIDRA.

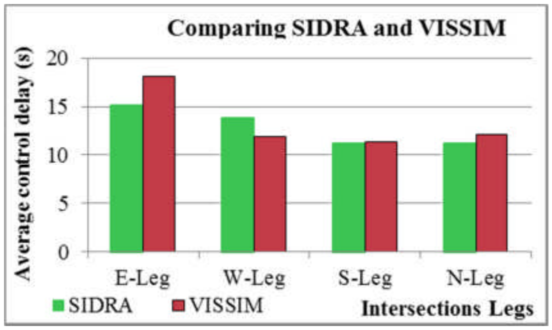

Figure 4 Approach delay comparison between SIDRA and VISSIM

Economic Analysis

A planning level cost estimates for the two alternatives (adjusted to 2010 price), relative net present value (NPV) for the roundabout (set the NPV of the channelized intersection as zero) as well as a sensitivity analysis are summarized in Table 3.

Table 3 Economic Analysis of Alternatives

Alternatives	Capital Cost (All inclusive)	Relative NPV	NPV in Sensitivity
Signalized Intersection	$5.40 million	0	0
Modern Roundabout	$5.20 million	$3.0 million	$2.1 million

As shown in Table 3, the roundabout option has a relative net present value (NPV) of $3.0 million over the signalized intersection in the analysis period. Under unfavourable conditions as assumed in the sensitivity analysis, the roundabout option still has a relative NPV of $2.1 million over signalized intersection. The recommended roundabout was accepted and will be in construction soon.

Additional Comments:

Major advantage of roundabout at this location is the expected collision reduction. With similar initial cost and traffic performance, roundabout has better NPV during the analysis horizon.

Long term (>20 year) traffic analysis showed that after 20 years, the LOS for roundabout deteriorate quickly, while the LOS for the channelized intersection deteriorate slowly. If the planning horizon is much longer than 20 years, two-lane roundabout may not meet traffic requirements. In general, the fully channelized intersection will have higher capacity than the two-lane roundabout while roundabout has more safety benefit because the signalized intersections have more flexibility to adjust timing and adding turning lanes to accommodate unbalanced traffic movements.

4.2 Case Study 2: Highway 15/Highway 37/Highway 825 Intersections

This site is located at approximately 10 km northeast of Edmonton and composed of two adjacent “T” intersections. At the “T” intersection of Highway 15 and Highway 37, Highway 15 forms southwest and northeast leg and Highway 37 forms northwest leg. This intersection is controlled by traffic signals. Highway 15 will be twinned in the future as the twinning is warranted based on the existing traffic volume. The “T” intersection of Highway 37/Highway 825 is located approximately 150m (center to center) northwest of the Highway 15/Highway 37 intersection. Highway 37 forms the through movement legs and Highway 825 is STOP controlled. There are four lanes on Highway 37 between the two intersections. The intersections are shown in Figure 5.

Figure 5 Existing intersection layout (Google map) and a photo looking south along Hwy 37

Operation and Safety Overview

Major operation problem for this site is that during peak hours, long queues are often formed on Highway 37 and the queue may block the Highway 37/Highway 825 intersection. There have been a total of 34 collisions reported at the two intersections during a five-year (2002-2006) period. Thirteen collisions were reported as injury collisions and one was reported as a fatal collision. The collision frequency is 6.8 collisions per year at the two intersections.

Traffic Prediction

As there is a large land development, Alberta Industry Heartland (AIH), to the north of the intersections, cumulative analysis method was used for traffic projection. The projected total design hour traffic volume and turning movements for the base year (2010), mid-term (2020) and design year (2030) were calculated and shown in Table 4. Traffic for a re-configured four-leg intersection is also projected in Table 5.

Table 4 Projected Traffic Turning Movements at Two Intersections (veh/h)

	Highway 15/ Highway 37						Highway 37/ Highway 825					
	Hwy 15				Hwy 37		Hey 37				Hwy 825	
	NB		SB		EB		EB		WB		SB	
Year	L	T	T	R	L	R	L	T	T	R	L	R
2010	275	500	590	580	630	235	140	405	350	505	460	70
2020	300	615	720	700	835	275	155	570	435	565	540	80
2030	320	730	860	810	1050	310	170	730	510	620	630	90

Table 5 Projected Traffic Turning Movements for Re-configured Intersection (veh/h)

	Highway 37			Highway 15			Highway 15			Highway 825		
	EB (W-Leg)			WB (E-Leg)			NB (S-Leg)			SB (N-Leg)		
Year	L	T	R	L	T	R	L	T	R	L	T	R
2010	140	395	10	590	340	240	15	265	500	240	220	70
2020	155	560	10	720	425	275	10	290	615	280	260	80
2030	170	710	20	860	500	310	20	300	730	330	300	90

Development of Alternatives

Three alternatives were proposed: Alternative #1 is directly adding lanes to the existing configurations. Both of the intersections will be under coordinated signal control. Alternative #2 is a re-configured 4-leg signalized intersection at a new location. The new intersection has two through lanes in each through movement, exclusive left-turn lane(s) on each approach and channelized right-turn lanes on three quadrants. Alternative #3 is a two-lane modern roundabout at a new location. Due to the high traffic volume, two right-turn bypasses have been added in southeast and northeast quadrants to reduce traffic entering the roundabout. Conceptual designs for Alternative #2 and #3 are shown in Figure 6.

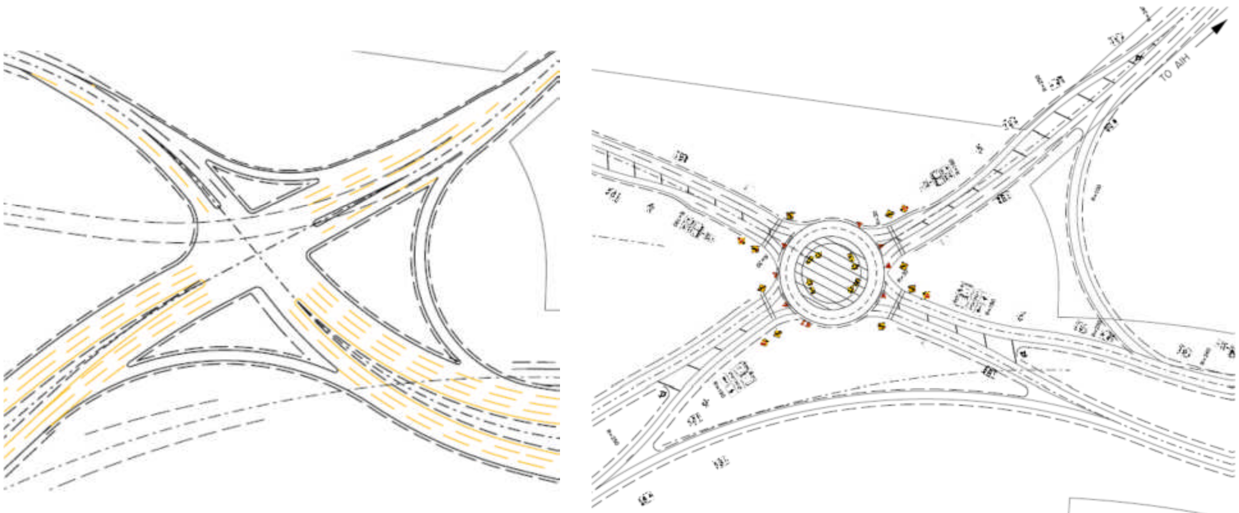

Figure 6 Conceptual designs for channelized intersection and roundabout

Traffic Analysis

The average intersection delays and delays for the worst movement are presented in Figure 7. As shown, both Alternative #1 and #2 can satisfy the future traffic demand at this intersection. Alternative #3 can only satisfy traffic demand for approximately 5 years after the construction.

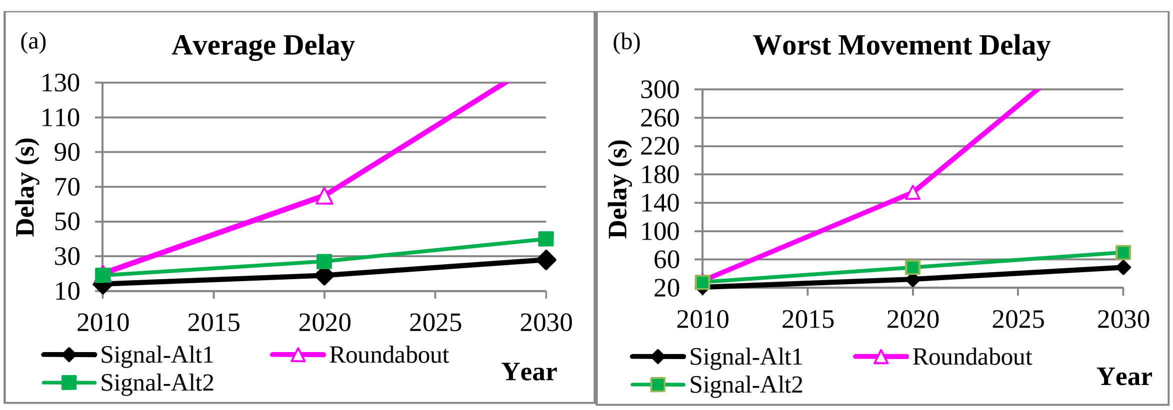

Figure 7 Average delays and delays on the worst movement

Evaluation of Alternatives

A planning level cost estimates for the three alternatives are made and they are $5.2 million (Alternative #1), $8.1 million (Alternative #2), $8.4 million (Alternative #3), respectively. An evaluation matrix was used to compare the three alternatives as in Table 6.

Table 6 Evaluation Matrix

Criteria		Weight	Alternatives					
			Alternative #1		Alternative #2		Alternative #3	
			Rating	Score	Rating	Score	Rating	Score
1	Capital Cost	20	5	100	3	60	3	60
2	Maintenance	5	3	15	4	20	5	25
3	Road Safety	30	3	90	3	90	4	120
4	Delay/LOS	20	4	80	4	80	0	0
5	Travel Distance	20	3	60	4	80	3	60
6	Emissions	5	3	15	4	20	2	10
Total	Higher score is better	100	360		350		275	

Rating Legend: 0=Very Poor, 1=Poor, 2=Fair, 3=Average, 4=Good, 5=Very Good

As shown in the evaluation matrix, the total score for Alternative #1 is the highest among the three options. The roundabout option has the lowest score because of the limitations on traffic capacity. Alternative #1 has slightly better overall score than Alternative #2 mainly because of its lower capital cost.

Additional Comments:

The main reason for a two-lane roundabout not feasible is that it cannot meet future traffic requirements. Compared with other rural intersections, the future peak hour volume is very high since it is close to Edmonton, City of Fort Saskatchewan and AIH. Three-lane roundabout may be able to meet the traffic demand but no further effort was made to analyze it because drivers in Alberta are not familiar with 3-lane roundabout. A complex roundabout may not achieve the expected safety performance. The study suggested that more options, such as interchange study may be performed for this location. This case study also shows that 2-lane roundabout has lower capacity than fully channelized intersection with two through lanes for through movement.

4.3 Case Study 3: Highway 29/Highway 41 Intersection

This site is located at approximately 230 km northeast of Edmonton. Highway 29 runs in east-west direction and Highway 41 runs in north-south direction. The existing junction is a large triangular intersection composed of a network of three road segments with three small intersections, as shown in Figure 8. Auxiliary lanes or tapers are not provided at each of the three corners of the intersection.

Operation and Safety Overview

At this intersection, many drivers, especially those who do not use it regularly, find it confusing. Intersection skew at each of the three corners is below the minimum requirements which can cause drivers difficulty in viewing other vehicles approaching the intersection. In addition, there are difficulties for large trucks to make a left turn at the three small intersections. There have been a total of 22 collisions reported within the intersection area or on the approaches to the intersection during five year period (2003 to 2007), of which, 3 were injury collisions, 19 were PDO. There is no fatal collision during this period.

Figure 8 Existing intersection layout (Google map) and a photo looking east from Hwy 29

Traffic Projections

Simple growth rate method was applied for traffic projections to the design horizon year of 2030. The projected peak hour traffic turning movements are shown in Table 7.

Table 7 Projected Traffic Turning Movements (veh/h)

	Highway 29						Highway 41					
	Eastbound			Westbound			Northbound			Southbound		
Year	L	T	R	L	T	R	L	T	R	L	T	R
2010	19	-	65				56	41	-	-	56	29
2030	30	-	101				88	65	-	-	88	45

Development of Alternatives

Alternative #1 is a “T” intersection by re-aligning Highway 29, with exclusive left-turn lanes and channelized right-turn lanes. Highway 29 will be under STOP control at the intersection. Alternative #2 is a single-lane, 3-legged modern roundabout at a new location within the existing triangle. A conceptual design is shown in Figure 9.

Traffic Analysis

The average intersection delays and delays for the worst movement are summarized in Figure 10. As shown in the figure, the two alternatives will have good performance. The “T” intersection has shorter delays than the roundabout.

Figure 9 Conceptual design of single-lane roundabout

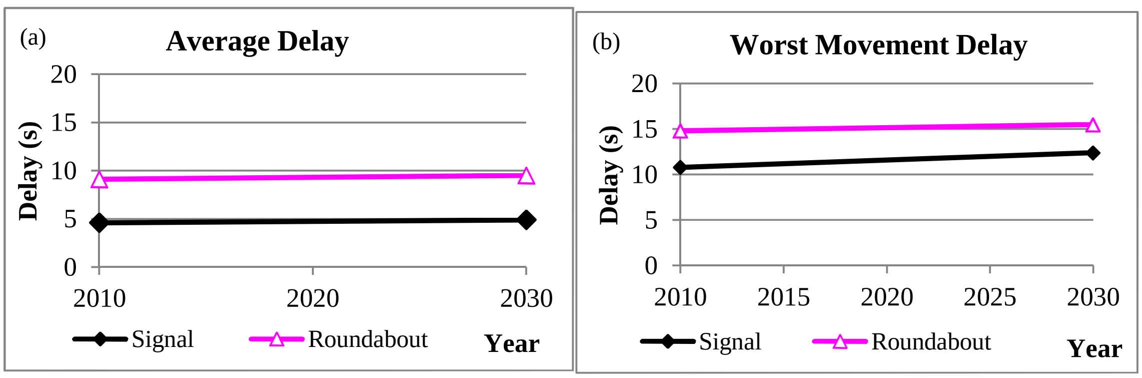

Figure 10 Average delay and delay of the worst movement

Economic Analysis

A planning level cost estimates for the two alternatives, relative net present value (NPV) for the roundabout (set the NPV of the “T” intersection as zero) and a sensitivity analysis are summarized in Table 8.

Table 8 Economic Analysis of Alternatives

Alternatives	Capital Cost (All inclusive)	Relative NPV	NPV in Sensitivity
Channelized “T” Intersection	$2.06 million	0	0
Modern Roundabout	$3.16 million	$0.11 million	$ -0.29 million

As shown in Table 8, both alternatives have similar NPV. Considering the higher initial capital cost of roundabout and funding limitations, the channelized “T” intersection was recommended for this location.

Additional Comments

This case study demonstrates that both alternatives are feasible. The T intersection has lower initial cost while both alternatives have similar NPV during analysis period. Since there is no fatal collision and the number of injury collisions is also low, the benefit from the collision reduction is limited. The recorded collision history may have a decisive factor in alternative evaluation. Alternatively, a long term expected collision reduction based on intersection types can be used in economic analysis, which may change the NPV and affect the recommendations.

4.4 Case Study 4: Highway 28/Highway 831 Intersection

This intersection is located at approximately 100 km northeast of Edmonton. Highway 28 runs east-west direction and Highway 831 runs north-south direction as shown in Figure 11. Both of them are 2-lane, 2-way rural arterial highways. Due to the long delays on Highway 831 and funding limitations in near future, both interim measures and long term solutions were requested for this intersection.

Figure 12 Existing intersection layout (Google map) and a photo looking north along Hwy 831

Operation and Safety Overview:

At existing intersection, Highway 831 is under STOP control while Highway 28 is free flow. Long queues are often formed on both south and north approaches on Highway 831. There have been a total of 25 collisions reported at the intersection during 2005-2009 periods. Eight collisions were reported as injury collisions and two was reported as a fatal collision. The proportion of fatal and injury collisions was high during the reported five years compared to other highways in the province. The collision frequency is 5.0 collisions per year.

Traffic Projection

Simple growth rate method was applied for traffic projections to the design horizon year of 2032 and interim years. The projected p.m. peak hour traffic turning movements are shown in Table 9.

Table 9 Projected Peak Hour Traffic Turning Movements (veh/h)

Time		Highway 28						Highway 831					
		Eastbound			Westbound			Northbound			Southbound		
Year		L	T	R	L	T	R	L	T	R	L	T	R
2012	p.m.	32	193	13	68	197	43	11	120	79	51	114	22
2022	p.m.	39	241	16	85	246	54	19	205	135	82	183	34
2032	p.m.	47	289	19	102	295	64	26	289	190	112	251	47

Development of Alternatives

Alternative #1 is a signalized intersection design, two lanes in each approach with shared LT/TH and TH/RT lanes. Alternative #2 is a single-lane modern roundabout.

As traffic demands on Highway 28 and Highway 831 are very similar at present and Highway 831 has higher traffic demand than Highway 28 in the future, AWST control has been considered as a possible interim measure at this intersection to reduce delays on Highway 831. In addition, adding turning lanes on Highway 831 and maintaining the existing TWST control was also analyzed.

Traffic Analysis

A summary of the average intersection delays and LOS for the two alternatives as well as for possible interim measures are presented in Figure 13.

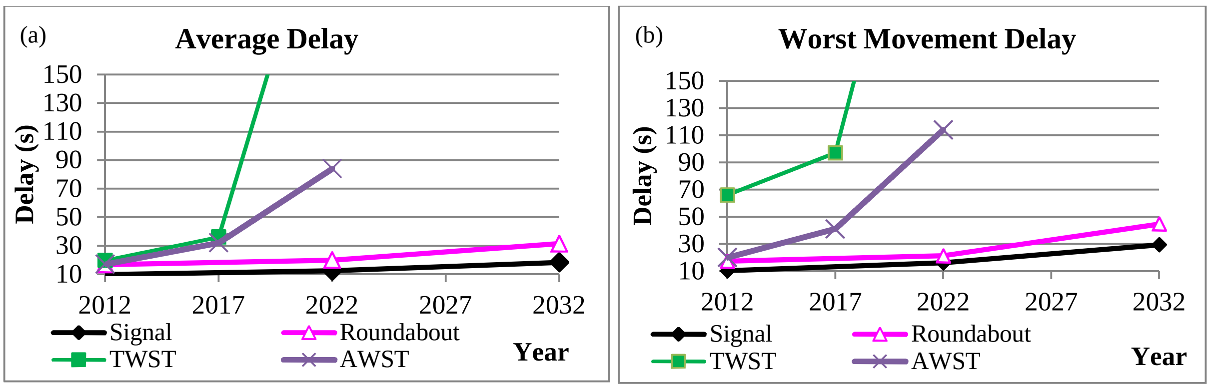

Figure 13 Average delay and delay of the worst movement

The TWST option (with added turning lanes on Highway 831 helps little to alleviate the congestion on Highway 831. The AWST option can meet the traffic capacity requirements for about five years.

As shown also in the figure, both Alternative #1 and Alternative #2 can satisfy the future traffic demand at this intersection. Alternative #1 will have shorter delay and better LOS than Alternative #2 in the design year.

Economic Analysis

A planning level cost estimates for the two alternatives, relative net present value (NPV) for the roundabout (set the NPV of the signalized intersection as zero) and a sensitivity analysis are summarized in Table 10.

Table 10 Economic Analysis of Alternatives

Alternatives	Capital Cost (All inclusive)	Relative NPV	NPV in Sensitivity
Signalized Intersection	$1.18 million	0	0
Modern Roundabout	$3.21 million	$10.2 million	$5.6 million

As shown in Table 10, the capital cost for the full signalized intersection is lower than the roundabout option. But the roundabout option has a relative NPV of approximately $10.2 million over the signalized option. Thus, the roundabout option is the preferred alternative.

Additional Comments:

The challenge for this intersection is that an interim measure is required to alleviate the long queue along Highway 831. Adding turning lanes based on TWST control does not help much for traffic operation. AWST can meet the capacity requirement for about five years. However, AWST is not an optimal measure for intersections of two rural highways with high speed. Therefore, it was recommended to build a roundabout as early as possible.

Due to the recorded fatal collisions, the roundabout has much higher NPV. This shows that the recorded collision history has very important impact on the economic analysis.

4.5 Case Study 5: Highway 1/Highway 46 Interchange

This site is located at approximately 20 km east of Regina, Saskatchewan. The existing intersection is an at-grade intersection where Highway 1 is a freeway runs in the northeast-southwest (east-west) direction and Highway 46 is a 2-lane provincial highway in the northwest-southeast (north-south) direction. There are serious safety and operation problems at the existing intersection that need to be addressed immediately. An interchange is designed and is under staged construction. A site map is shown in Figure 14.

Figure 14 Site map of Hwy 1/Hwy 46 intersection (Google map)

Traffic Projection

This case study is regarding the ramp terminal plans on the south side of Highway 1 (south intersection). As such, the traffic for this intersection is projected to the year 2032, as shown in Table 11.

Table 11 Traffic Turning Movements at South Intersection (Year 2032, veh/h)

	Highway 1EB Off Ramp						Highway 46					
	Eastbound			Westbound			Northbound			Southbound		
	L	T	R	L	T	R	L	T	R	L	T	R
a.m. Peak Hour	90	1	5	-	-	-	-	20	5	160	25	-
p.m. Peak Hour	295	1	5	-	-	-	-	25	5	235	15	-

Development of Alternatives

Three interchange alternatives were proposed, in all of which, Highway 1 remains at the existing elevation and Highway 46 overpass Highway 1 with a bridge. Alternative #1 is a standard diamond configuration with single lane ramps access to or exit from Highway 1. At the two ramp terminals, the through and left turn movements on the ramps will be controlled with STOP signs and the right-turn on the ramps with YIELD signs. Alternative #2 is a diamond interchange with a loop ramp, located in the southeast quadrant, for eastbound left-turn (EB LT) vehicles from Highway 1 to Highway 46. Alternative #3 is a diamond interchange with a single-lane roundabout for the south ramp terminal. The designed centerline for Alternative #2 and #3 are shown in Figure 15.

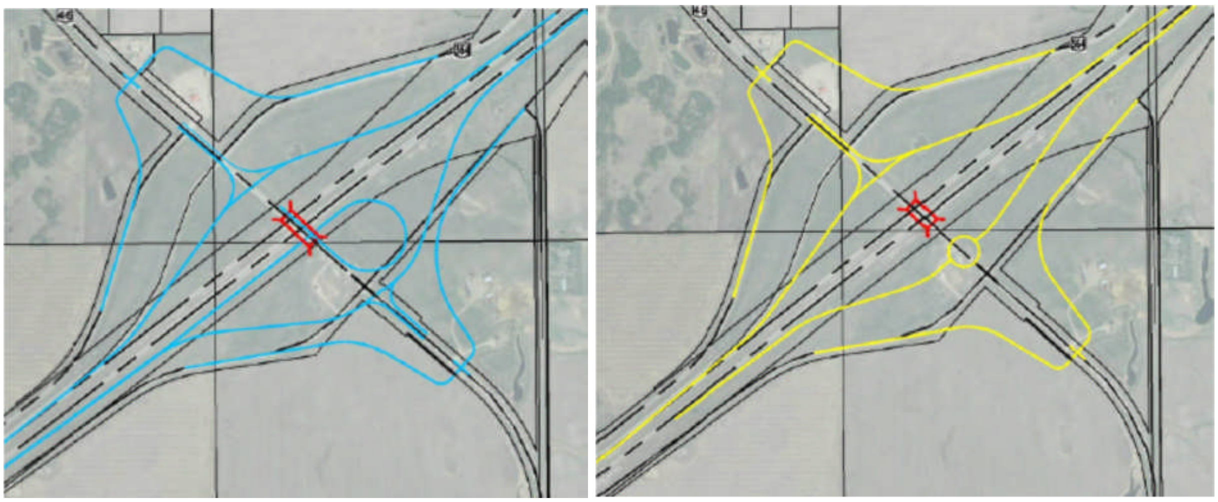

Figure 15 Centerlines of Alternative #2 and Alternative #3

Traffic Analysis

A summary of traffic analysis of the south intersection is given in Table 12. Both Alternative #2 and 3 have good traffic performance. In Alternative #1, there will be long delays for the eastbound left-turn vehicles. It should be noted that for the south intersection, although Alternative #2 has the lowest average intersection delay based on software analysis. However, it does not necessarily mean that this alternative has the lowest travel time. The EB LT movement will be accommodated by the loop ramp and thus eliminated from the intersection analysis. However, the path length for this movement is much longer than that in Alternative #1 and #3.

Table 12: South Intersection Traffic Analysis Summary (Year 2032)

	Alternative 1		Alternative 2		Alternative 3	
	a.m. Peak	p.m. Peak	a.m. Peak	p.m. Peak	a.m. Peak	p.m. Peak
Average Delay (s)	8.7	45.0	6.0	6.7	12.1	13.8
Intersection LOS	A	E	A	A	B	B
Worst Movement	EB LT	EB LT	SB LT	SB LT	EB LT	EB LT
Delay on Worst Movement	15.0	80.8	7.7	7.9	14.5	15.6
95% Queue (m)	7.0	85.7	3.3	5.0	6.2	24.4
LOS on Worst Movement	B	F	A	A	B	C

Evaluation of Alternatives

A planning level cost estimates for the three alternatives are $28.6 million (Alternative #1), $39.0 million (Alternative #2) and $29.3 million (Alternative #3), respectively.

A Comparison Matrix was designed for a comparative analysis of the three alternatives and it was concluded that Alternative #3 has the highest rating and was adopted for construction.

Additional Comments

The major traffic flow at the south ramp terminal is the southbound left-turn (SB LT) from Highway 46 to the east of Highway 1 and EB LT from the EB off-ramp to the north of Highway 46. Both of these movements have substantial proportion of large trucks. The creative use of the roundabout offered operational advantages that were otherwise unavailable with conventional stop-controlled intersections. For the SB LT, as there is no upstream circulating traffic in the roundabout, vehicles do not need to stop for a gap to enter the roundabout. This is especially beneficial to large trucks. For EB LT traffic, drivers need only check the left side traffic with low speed. It is much easier for them to enter the roundabout than stop-controlled intersections.

5. Concluding Remarks

Based on the literature review, analysis and engineering judgement presented in the case studies, it is concluded that in order for a roundabout to be feasible for an intersection, it should have adequate capacity, expected safety performance and superior economic value than other competing alternatives.

Under most circumstances, roundabouts are safer than other intersection forms. The capacity of single-lane roundabouts is higher than all-way-stop controlled intersections but lower than signalized intersections with properly designed through and turning lanes. The capacity of two-lane roundabouts is usually lower than channelized intersections with two through lanes in each direction and exclusive left-turn lanes.

While the capital cost of roundabouts is usually higher than other intersection improvement alternatives with comparable traffic capacity, the extra capital cost can often be compensated by the savings from expected collision reductions within the design horizon. In economic analysis of intersection improvement alternatives, the collision history has substantial impact on the estimation of the benefit from collision reductions.

Innovative use of roundabouts at some interchange terminals can not only provide safety benefits, but also offer operational advantages and avoid unnecessary stops, which is especially beneficial to large trucks using the roundabout.

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