Consideration of a Diverging Diamond Interchange in Saskatchewan

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ABSTRACT

The TransCanada corridor (Highway No. 1) east of the City of Regina, Saskatchewan has been the recent focus of several planning studies to address the ever increasing growth in traffic as development and communities expand. As this traffic has increased, the Ministry of Highways and Infrastructure identified the need to address safety concerns at the existing at-grade intersections. The first step was to complete the *Highway 1 East Functional Planning Study* (1) which identified future access improvements. This study was subsequently followed by the functional interchange designs being approved for Highway 1 and Highway 46 at Balgonie, and Highway 1 and Highway 48 at White City. The functional interchange design for the Pilot Butte access completes the rural interchange planning for Highway 1 from Regina to Balgonie.

This paper will present functional design considerations that led to the evaluation and selection of the preferred interchange option for the Pilot Butte access; a Diverging Diamond Interchange. Through consultation with many developers and local municipalities, traffic volume forecasts for future design horizons were established. Determination of these volumes considered the timing of possible developments and the origins and destinations of associated trips. As such, two predominant movements became apparent; the eastbound to northbound left turn and the northbound to westbound left turn. Based on a need to address these predominant movements, several conceptual interchange options were established with the Diverging Diamond Interchange expected to offer the greatest benefit from a safety, operational and cost perspective.

The design and construction of a Diverging Diamond Interchange at the Pilot Butte access is believed to be first such configuration to be considered within Canada. During the planning study, which reviewed several interchange options, local media coverage has created some excitement amongst the road safety and engineering communities, as well as local stakeholders. This could be a landmark project for the region, local communities and provincial government. The intent of this paper will be to present some of the design considerations made during the planning component of this work as well as feedback received from those facing the prospect of using this new innovative interchange design.

The possibility to stage the construction of this interchange has been reviewed. It is recognized that the ultimate lane configuration will not be required on opening day since development will still be at various stages. The expected traffic volumes that would need to be accommodated upon completion of the interchange assume completion in 2015 with the interchange design horizon established as 2045.

INTRODUCTION

The Saskatchewan Ministry of Highways and Infrastructure (MHI) recently completed the functional planning of various aspects of future road infrastructure that forms part of the Regina Bypass Project. This project seeks to implement infrastructure improvements around the south, east and west sides of the City of Regina (City) to address mobility and safety. The City, like the province of Saskatchewan, is currently experiencing a rapid growth in population largely due

to its stable economic position. The demand for housing in the region has seen the City expand at a rate that was unexpected a few years ago and this boom has led to satellite communities and rural development expanding at unprecedented rates to help meet this demand.

As the regional population has grown, so has traffic volumes into, through and around the City. The majority of satellite communities in this region are on the east side of the City, including the Town of Pilot Butte, the Town of White City, the Town of Balgonie, and Emerald Park (an unincorporated residential area adjacent to White City within the Rural Municipality of Edenwold). A significant portion of the recent residential growth in the City has focussed in the southeast area between Victoria Avenue (Highway 1/TransCanada Highway) and Arcola Avenue (Highway 33). These two corridors within the City, as well as Highway 1 to the east of the City limits are some of the busiest corridors within the province.

The section of the TransCanada Highway between Regina and Balgonie is the busiest rural highway with daily volumes ranging between 18,000 to 24,000 vehicles per day (vpd). These volumes have led to many concerns being expressed by those travelling this route on a frequent basis regarding the safety of road users entering and exiting the highway from at-grade intersections. In some instances, alternate routes are the preferred choice despite not being the most direct or quickest into the City. In addition, there are inherent delays while travelling on Victoria Avenue east of Ring Road/Highway 1 due to the numerous traffic signal cycles encountered.

To address the road user needs along the TransCanada Highway, MHI undertook the *Highway 1 East Functional Planning Study* (1) which identified future access improvements. This study was subsequently followed by the functional interchange designs being approved for Highway 1 and Highway 46 at Balgonie, and Highway 1 and Highway 48 at White City. The functional interchange design for the Pilot Butte access completes the rural interchange planning for Highway 1 from Regina to Balgonie. The planning of the remainder of the Regina Bypass Project from the east, to the south and then to the west has also just been completed by the Government of Saskatchewan.

PROPOSED ACCESS IMPROVEMENTS

The access improvements identified for the Highway 1 East corridor to improve the overall safety and operation included (proceeding east to west – refer to Figure 1):

- Implement left turn closures at Balgonie Main Street access (i.e. right-in and right-out access only for westbound traffic);
- An interchange at Highway 46;
- An interchange at Highway 48;
- Close the White City access;
- Implement left turn closures at the Great Plains access;
- An interchange at the Pilot Butte access;
- Implement left turn closures at the Gravel Pit access; and,
- An interchange at Tower Road.

MHI intends to implement these access improvements as part of the Regina Bypass Project, which seeks to alleviate congestion and safety issues along the road network in the south and east areas of the City of Regina. This project will also provide better connectivity through and around Regina to local, regional, national and international markets.

LOCAL SAFETY CONCERNS

Concerns related to the safety performance of the Highway 1 and Pilot Butte access intersection have been expressed by community leaders, local residents and the public in general. Forefront in the minds of many are recent high severity collisions at this and adjacent intersections along the TransCanada Highway. Concerns have also been raised regarding the increased time required for vehicles to enter Highway 1 due to increased traffic volumes and speeds. A review of the available collision history for Highway 1 between the Manitoba and Alberta borders (excluding the portion within the City of Regina limits) revealed that the section of the TransCanada Highway between Balgonie and Regina was ranked the highest in terms of the number of collisions per kilometre for the period 2003 to 2008. The collision rates for this period ranged from 2.94 to 4.73, with an average of 4.00 collisions per kilometre. A review of the latest annual report issued by the Saskatchewan Government Insurance (SGI) titled 2011 Saskatchewan Traffic Accident Facts reveals that the equivalent rate for this section of interest has increased to 5.49 collisions per kilometre.

From a provincial highway perspective, comparable collision rates are presented in terms of the number of collisions per million vehicle kilometres (MvKm). The section of Highway 1 between Balgonie and Regina reported a collision rate in 2011 of 0.83 collisions per MvKm. Compared to the provincial average of 0.85, this section is performing similarly to the province in general (all highway types considered; paved/gravel, two-lane/four-lane).

A geomap of recent collision history in the Regina area shows that fatal collision locations are concentrated along the Highway 1 corridor. This history considers the period from 2009 to 2011 as published by SGI. A breakdown of collisions from a recent planning study conducted by MHI indicates that of 25 collisions specifically reported at the Pilot Butte access intersection, nine were reported as an injury and one as a fatal between 2003 and 2009.

The implementation of the recommended road network plan as established by MHI in 2010, as referenced in Figure 1, including the construction of an interchange at the Pilot Butte access is expected to improve the safety performance of Highway 1 at this location and along the corridor between Balgonie and Regina. Along the Highway 1 corridor it appears that the number of collisions is increasing as traffic volumes continue to increase. The recommended road network plan includes the elimination of left turn and through movements at level crossings, which will reduce the number of conflict points along the corridor attributed to high severity collisions while seeking to lower the overall frequency of collisions. Such infrastructure improvements are not expected to eliminate collisions; however, they will seek to shift the collision type to those that are generally lower in severity (i.e. sideswipe instead of right angle).

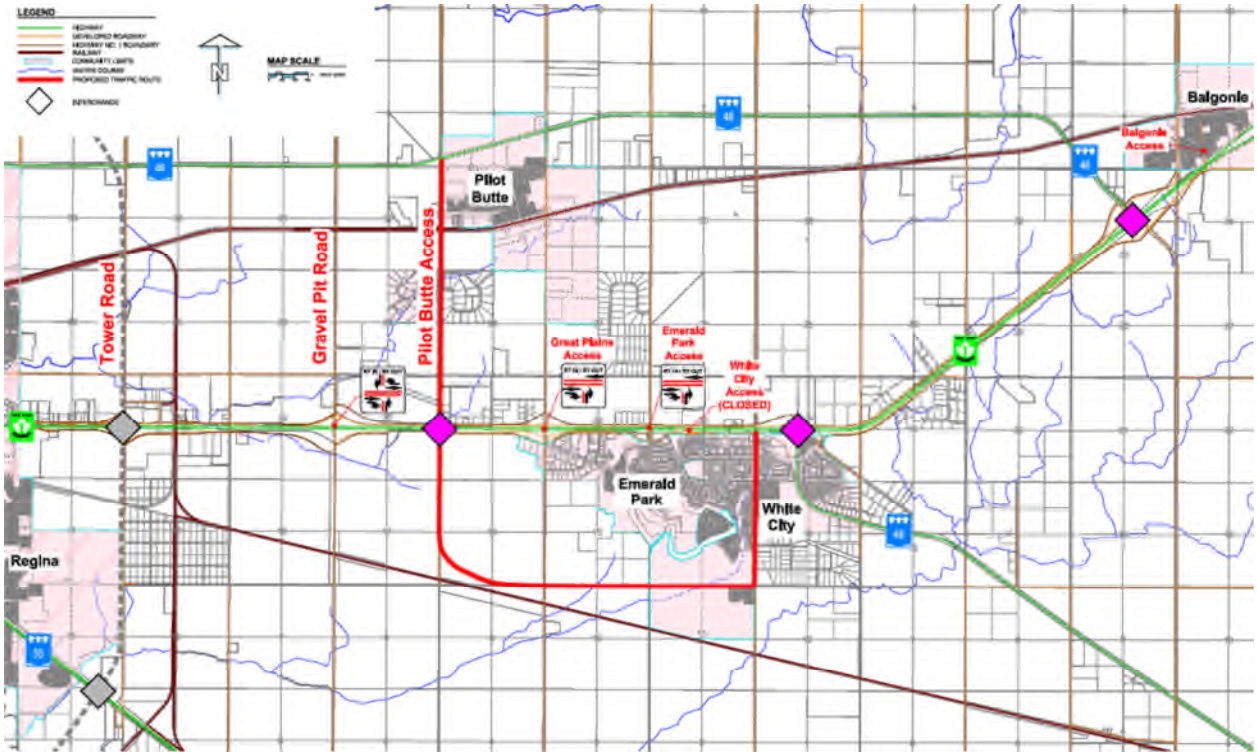


Figure 1 – Proposed Access Improvements along Highway 1 East of Regina

REGIONAL GROWTH

As development proceeds in the surrounding areas east of Regina, urban municipalities and the Rural Municipality of Edenwold (RM) are anticipating continued population growth. Recent census data from the Saskatchewan Population Report – 2011 Census of Canada shows the following growth:

Municipality	Census Population		Change in Population
	2006	2011	
Pilot Butte	1,872	1,848	-1.3%
White City	1,113	1,894	+70.8%
RM of Edenwold	3,606	4,167	+15.6%

Table 1 – Historic Regional Populations

The population of Emerald Park is estimated at 1,600, which is included within the 2011 estimate for the RM of Edenwold. The combined population for the urban municipalities is approximately 5,300.

The undeveloped areas within and surrounding these urban municipalities are currently the focus of many development initiatives. Residential, commercial and light industrial land use plans have and are continuing to be established in cooperation with regional approving authorities. There are many developments currently under construction or being planned that

will require access to the TransCanada Highway by utilizing the local road network at one of the three proposed interchange sites. The largest number of such developments tends to be focussed at or will need access to the Pilot Butte access and its future interchange.

Information for each of the known developments was obtained from developers and local municipalities to gain an understanding of the future land use plans, size and timing of each initiative. A plan showing the general location of these developments is shown on Figure 2. This information is considered, for the most part, to be conceptual and may be revised by individual developers based on their needs and approvals granted to implement these proposed plans.

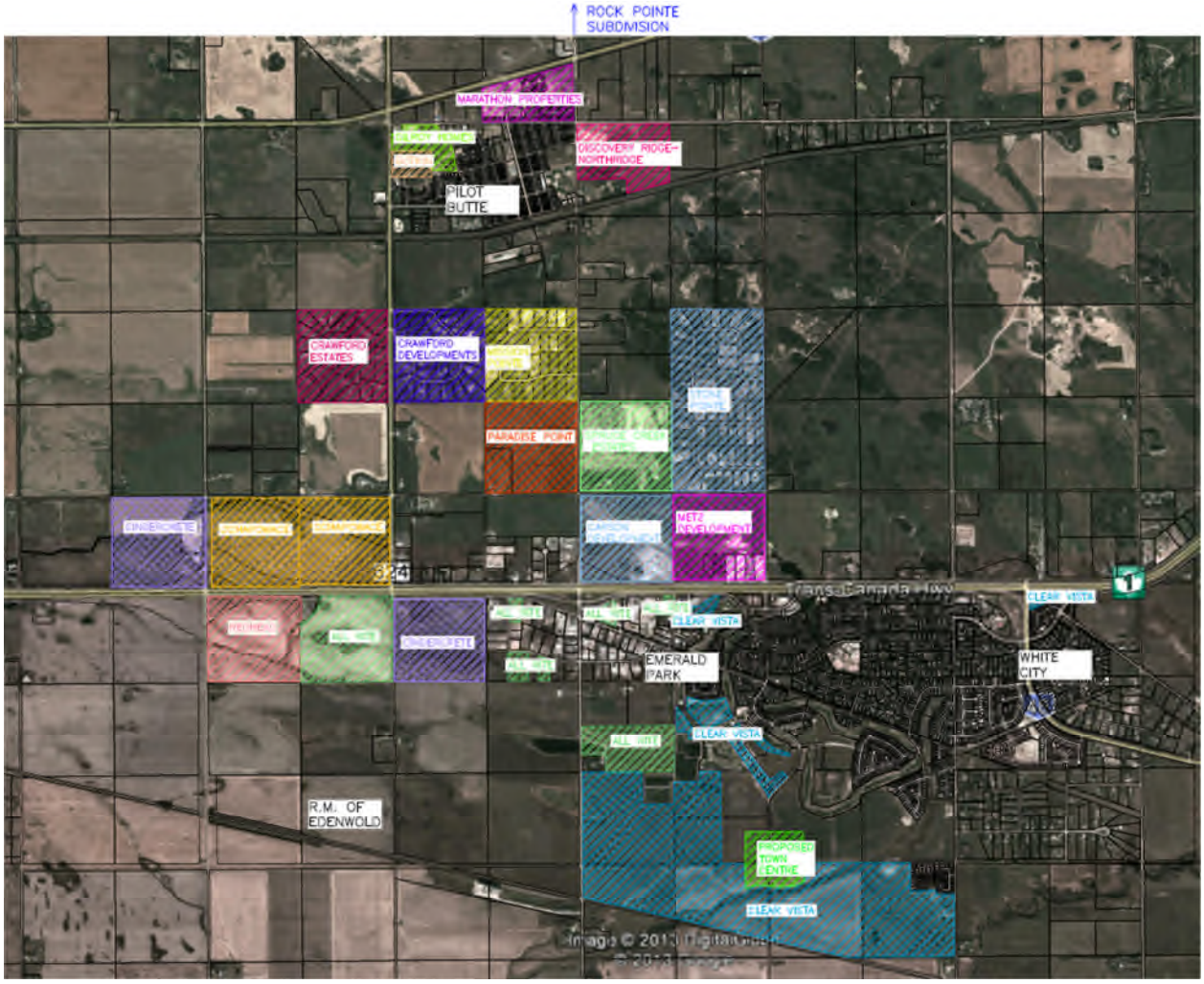


Figure 2 – Known Regional Development Areas

The estimated size of these development areas, both within and outside the urban areas, combined equates to 2,600 acres or 1,050 hectares. This would be the equivalent of more than 16 quarter sections or 4 complete sections being considered as future development areas. The

timing of these development areas is proposed to be largely within the next ten years; however, a significant portion will also continue into the ten to 20 year horizon.

Based on the future growth targets for these communities from known housing projections and proposed development plans, the following populations could be realized if such plans are implemented fully:

- Pilot Butte – 5,000 new homes within 20 years for a total population of 14,100;
- White City – 100 residential lots per year for the next 20 years, equates to 2,000 new homes for a total population of 6,800; and,
- RM of Edenwold – could expand to 10,000 to 12,000 based on future developer plans.

The combined regional population (urban and rural) within the next 20 years could grow from 7,900 to nearly 33,000, more than a 400% increase.

ESTABLISHING FUTURE TRAFFIC VOLUMES

A number of sources of traffic data were reviewed to assist in establishing baseline traffic conditions for the adjacent road network to the Pilot Butte access. These sources included the following:

- Previous planning documents along the Highway 1 corridor;
- Recorded traffic counts;
- The most recent traffic data as published by MHI in *Travel on Saskatchewan Highways*;
- Traffic projection growths for individual developments where estimates were established; and
- The regional transportation model being developed by MHI in cooperation with the City of Regina.

In addition to these sources of data, a comprehensive review of development size and land use was completed to estimate appropriate trip generation that could be realized and introduced onto the adjacent road network. Following well established procedures and methodologies, development generated traffic was assigned and distributed on the network. This took into consideration the proposed access management improvements that MHI sought to implement along Highway 1 as part of the Regina Bypass Project, as well as the redistribution of traffic along this corridor to account for such improvements.

The future horizon years established for the Pilot Butte Interchange looked at a 30 year and 50 year forecast of traffic volumes and development demands should the interchange open in 2015. At the time of this work, specific timelines for the construction of this interchange were unknown, so some assumptions were made. Traffic forecasts to 2026 were also reviewed to coincide with a 15 year horizon from the most recent traffic data available from a growth factor perspective (i.e. MHI considers growth factors over a 15 year period with the latest historical

data used to calculate the growth factor being in 2011). Therefore, horizon years of 2026, 2045 and 2065 were reviewed as part of this study, with the focus for determining future traffic operations being in 2045.

Horizon Year	Peak Period	Highway 1						Pilot Butte Access					
		Eastbound			Westbound			Northbound			Southbound		
		L	T	R	L	T	R	L	T	R	L	T	R
2015	a.m. Peak Hour	90	677	1	29	794	52	350	24	0	74	2	116
	p.m. Peak Hour	185	1,487	7	37	655	19	390	23	0	108	6	139
2045	a.m. Peak Hour	923	1,647	186	141	1,474	164	2,098	238	175	265	187	1,095
	p.m. Peak Hour	1,531	3,896	319	189	1,221	205	1,831	244	128	315	305	1,079
2065	a.m. Peak Hour	973	2,023	187	157	1,915	193	2,293	252	175	307	189	1,160
	p.m. Peak Hour	1,635	4,722	323	199	1,586	225	2,046	257	128	375	308	1,157

Note: L – left turn; T – through, R – right turn

Table 2 – Future Horizon Year Volumes for the Pilot Butte Interchange

These volumes were used to analyse the expected operation of the interchange options considered appropriate for this location.

DEVELOPING POSSIBLE INTERCHANGE OPTIONS

According to the traffic volume forecasts and turning movements, the eastbound left turning from Highway 1 to the Pilot Butte access and the northbound left from the south leg to Highway 1 are the two movements that will dominate the ramp configuration for this interchange. Based on the need to address these two predominant movements, several conceptual options were established.

The following conceptual configurations were reviewed at a high-level to determine their feasibility to accommodate the expected traffic volumes in the 2045 horizon year.

- Standard or spread diamond;
- Partial cloverleaf (Parclo) with loop ramps in the southeast and northeast quadrants (Parclo AB);
- Parclo with loop ramps in the southwest and northeast quadrants (Parclo A);
- Spread diamond with directional ramps for the two highest left turn movements;
- Spread diamond with directional ramps at the Pilot Butte access and Great Plains access;
  - The directional ramp at the Pilot Butte access addresses the eastbound left turn; and,
  - The directional ramp at the Great Plains access addresses the northbound left turn of traffic from White City and Emerald Park.
- A revised version of the spread diamond with directional ramps at the Pilot Butte access and Great Plains access to minimize the footprint required at the Great Plains access, which requires a basket weave to address westbound on and off movements;
  - This option could possibly delay or eliminate the need for the proposed Betteridge Road connection as shown on Figure 2 between the Pilot Butte access and White City.

- Diverging diamond interchange (DDI);
- Single point urban interchange (SPUI); and,
- Hamburger/rotary/roundabout interchange.

From a high-level review, several of these conceptual options were eliminated. It was determined that the footprints for the options containing directional ramps precluded any further consideration due to the expected land requirements and impact to existing developments. It was also recognized that these options would likely be the most cost intensive due to the number of bridge structures and land acquisition required. Upon review of the other concepts, it was felt that the spread diamond should be removed from further discussion due to the large turning movements, the need for signalization and possible safety implications with the number of conflict points at the ramp terminals. Standard diamond interchanges work well when movements on the minor road are relatively low; however, as the Pilot Butte access is expected to see a large increase in traffic volumes, the efficiencies gained from a diamond interchange would likely not be realized at this location for the ultimate interchange configuration.

The other concepts remaining were reviewed in terms of their ability to manage traffic flow and minimize delay. HCM software (Synchro 8) was used to confirm whether acceptable levels of service (LOS) could be maintained for the 2045 horizon year. From this review it was found that the delays experienced with the SPUI interchange were not acceptable and as such, this configuration did not accommodate any potential growth in traffic volumes without significant reconfiguration or other infrastructure needs. The roundabout interchange also did not operate at an acceptable LOS without requiring three or more lanes. Beyond a double lane configuration, the safety benefits introduced through a roundabout design are no longer realized, traffic operations become complicated due to driver unfamiliarity and costs rise considerably. Therefore, it was determined that these two options be dropped from the list of viable candidate configurations.

From this high-level review, three conceptual options were shortlisted; the Parclo AB, Parclo A and diverging diamond. All three options are service interchanges, which maintain free flow conditions for the through movements on Highway 1. Traffic on the Pilot Butte access is required to travel through ramp terminal intersections. Each of the three options has two at-grade intersections on Pilot Butte access, namely, the south intersection, which is the ramp terminal on the south side of Highway 1, and the north intersection, which is the ramp terminal on the north side of Highway 1.

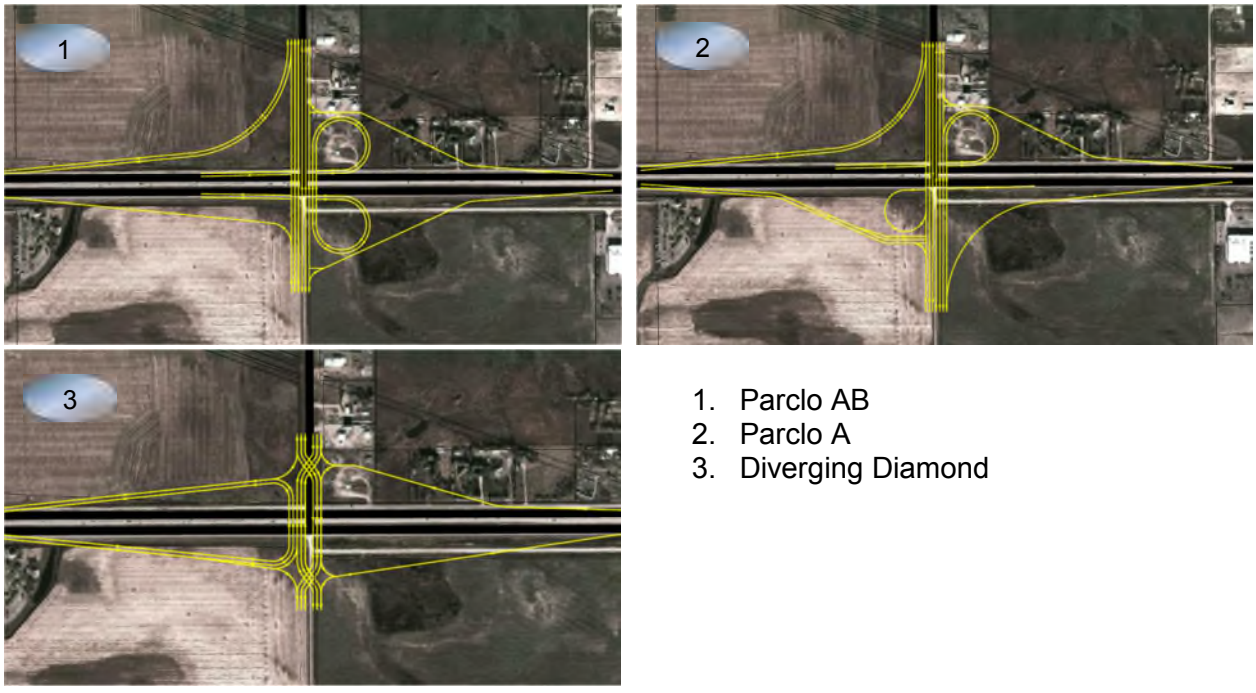
SHORTLISTED INTERCHANGE OPTIONS

The Parclo AB option utilizes a spread diamond configuration with ramps to access to or exit from Highway 1. Two left turn movements are accommodated through loop ramps to reduce the conflict points and increase capacity at the ramp terminal intersections. A loop ramp is provided for northbound to westbound left turning vehicles originating from future residential and commercial areas south of Highway 1 travelling towards Regina. In the future horizon years, this movement is expected to have the highest number of left turns with the a.m. peak being higher than the p.m. peak to account for commuters travelling into Regina. The other loop ramp is provided for eastbound to northbound left turning vehicles originating from Regina accessing

country residential, future commercial and the Town of Pilot Butte developments to the north of Highway 1. In the future horizon years, this movement is expected to have the second largest number of left turns with the p.m. peak being higher than the a.m. peak as commuters return from working in Regina.

Compared to the Parclo AB option, the Parclo A option maintains the northbound to westbound loop ramp; however, the other loop ramp is switched from the southeast quadrant to the southwest quadrant. Eastbound to northbound left turning vehicles are now required to stop at the south ramp terminal intersection operating under stop or signalized control. A loop ramp is introduced to accommodate southbound to eastbound left turn movements for the purpose of reducing traffic volumes at the south intersection and providing free flow movements for regional traffic, particularly truck traffic, travelling from Highway 46 to Highway 1 and continuing east. By providing this free flow movement, an alternate route is created between the TransCanada Highway to the east and the heavy industrial areas within the northeast sector of Regina. The Parclo A option eliminates the short weave required in the Parclo AB option.

A DDI is a type of diamond interchange in which the two directions of traffic on the minor road cross to the left side on the bridge before crossing back over to the right side after the bridge. The purpose of providing this crossover from one side to the other is to eliminate the need to accommodate left turn movements having to cross opposing lanes of traffic. The DDI does require opposing vehicles to cross opposing lanes; however, this crossing is controlled by signals and only the through movement is required at the signals, i.e. left and right turn movements are accommodated elsewhere within the interchange.



1. Parclo AB
2. Parclo A
3. Diverging Diamond

Figure 3 – Pilot Butte Interchange Option Concepts

Some initial considerations for each of the shortlisted interchange options were developed to assist in the evaluation of the options as well as to solicit feedback from stakeholders and members of the public consulted as part of this planning study. These considerations were based on readily available literature (particularly for the DDI) as well as experience in travelling through and designing such interchange types. It should be noted that no one solution will address all user wants and needs, and a balanced approach to managing impacts and costs is required, hence there are disadvantages associated with each of the options being reviewed.

Advantages	Disadvantages
Parclo AB Option	
▪ Relatively simple operation – NB and EB left turn loop ramps ▪ Free flow for two highest left turn volumes ▪ Common interchange configuration – driver familiarity ▪ Relatively small footprint and land requirement ▪ Reduced number of conflict points due to loop ramps ▪ Capacity can be increased with signals at the ramp terminals	▪ Larger bridge span to accommodate loop ramps ▪ Tight curvature of the loops can lead to vehicle rollovers ▪ Weaving required between loop ramps ▪ To increase capacity, traffic signals will be required
Parclo A Option	
▪ Relatively simple operation – NB and SB left turn loop ramps ▪ Free flow for NB left turn volume ▪ NB movements unaffected by signal at south ramp terminal ▪ Relatively small footprint and land requirement ▪ Weaving between loop ramps eliminated	▪ Signal control for EB left turn volume ▪ Larger bridge span to accommodate loop ramps ▪ Increased number of conflict points with the EB left turn controlled by signals ▪ Tight curvature of the loops can lead to vehicle rollovers
Diverging Diamond Option	
▪ Fewer conflict points (enhanced safety) ▪ Better sight distance at turns ▪ Wrong way entry to ramps difficult ▪ Ease of left and right turn movements ▪ Increased capacity ▪ Better vehicle storage between ramp terminals ▪ Shorter signal cycle times required ▪ Can synchronize signals at ramp terminals to minimize delays ▪ U-turns can be easily accommodated ▪ Typically requires less right-of-way ▪ Construction time reduced	▪ Driver unfamiliarity, particularly with merging on the left side and reversed flow ▪ No standards currently exist, requires more design time ▪ Additional signing, lighting and pavement markings required ▪ No direct re-entry for traffic exiting the main highway (doesn't support the bypass of over-height loads for a bridge that is too low) ▪ No experience in the Canadian context

Table 3 – Pros and Cons of Interchange Options

TRAFFIC OPERATIONS ANALYSIS

Each of the three shortlisted interchange options has two at-grade intersections on the Pilot Butte access. Due to the projected traffic volumes in 2045 (30 year design horizon), signal control is required at both of the at-grade intersections for all three options. This was considered to be an acceptable solution since the introduction of a systems interchange would severely impact existing and future development adjacent to both roadway corridors and within the nearby urban area. It may be some time after construction and the interchange is open to traffic that signalization of the Parclo options is required; however, this will depend on the rate of growth and development of the surrounding areas that will utilize the Pilot Butte Interchange. For the purpose of the analysis completed, the need for signalization is met within the first half of the design horizon, i.e. before 2030, given indications from future development plans.

For the two signalized intersections, the analysis was implemented using Synchro 8, which is a traffic analysis software based on the Highway Capacity Manual (HCM) operational methodology. The inputs were based on the conceptual design of each option and the projected traffic turning movements assigned to the north and south intersections. Pre-timed signals were assumed and the cycle length was optimized by the software. This simplification is only for functional planning study purposes and the specific timing design would need to be completed during the next stages of this work, and adjusted during operations when actual traffic volume and turning movements are available.

The summary of the analysis results from the Synchro outputs are shown in the following tables.

	Parclo AB		Parclo A		DDI	
	a.m. Peak	p.m. Peak	a.m. Peak	p.m. Peak	a.m. Peak	p.m. Peak
Average Delay (s)	7	7	5	9	2	2
Intersection LOS	A	A	A	A	A	A
Worst Movement	NB TH	WB LT	WB LT	WB LT	SB TH	SB TH
Delay on Worst Movement (s)	13	19	17	22	5	3
LOS on Worst Movement	B	B	B	C	A	A
95% Queue Length (m)	56	98	61	218	4	0
Longest Queue on Movement	NB TH	NB TH	NB TH	NB TH	SB RT	--

Table 4 – North Intersection Traffic Analysis Summary (Year 2045)

	Parclo AB		Parclo A		DDI	
	a.m. Peak	p.m. Peak	a.m. Peak	p.m. Peak	a.m. Peak	p.m. Peak
Average Delay (s)	7	6	13	19	1	11
Intersection LOS	A	A	B	B	A	B
Worst Movement	SB LT	SB LT	EB LT	EB LT	SB RT	NB TH
Delay on Worst Movement	28	24	25	31	1	15
LOS on Worst Movement	C	C	C	C	A	B
95% Queue Length (m)	111	84	137	168	0	127
Longest Queue on Movement	NB TH	NB TH	NB TH	NB TH	--	NB TH

Table 5 – South Intersection Traffic Analysis Summary (Year 2045)

Traffic operation analysis, including weaving analysis for the Parclo AB, shows that the Parclo A and the DDI can satisfy the expected future traffic demand, while the Parclo AB failed due to the short weaving section between the loop ramps. The DDI is expected to have shorter delays, shorter queue lengths and a better overall LOS for the interchange as a whole and for individual turning movements.

SELECTING THE DIVERGING DIAMOND

An evaluation methodology was adopted to determine which of the three interchange options to proceed forward with. This methodology considered the influence of certain criteria in several areas including:

- Operational conditions for daily road users as well as those unfamiliar with the local area;
- Enhancements to the road safety;
- Accessibility to the local road network;
- Property and right-of-way accommodations;
- Impact on managing future growth needs;
- Design flexibility;
- Construction staging; and
- Construction cost.

By considering each of these factors, the evaluation of the interchange options indicated that a DDI is the preferred configuration at this location based on the following justification:

- Conflict points are largely contained at two defined locations, the north and south intersections, instead of spread throughout the interchange configuration;
- There are no weaving movements required;
- The number of conflict points throughout the interchange is reduced;
- The north and south intersections are expected to operate at a more acceptable LOS than other configurations;
- Accessibility to the local road network is expected to be better as larger separation distances between accesses can be achieved;
- The introduction of signals slow vehicles down as they travel through the interchange, which assists to improve the overall performance along the Pilot Butte access given the need for closely spaced service roads;
- There is more capacity available in the future to accommodate increases in traffic volumes through this interchange option than alternate configurations;
- Greater amount of design flexibility;
- Requires the least amount of right-of-way and affects fewer existing developments;
- Appears to be less exposure for workers and conflict between the travelling public and construction traffic compared to Parclo designs by minimizing the amount of parallel ramps and work zone area requirements; and
- The most cost effective of these options.

FUNCTIONAL CONSIDERATIONS

In the development of interchange options and the functional design of the recommended configuration, the following general design principles were considered:

- The major roadway (Highway 1) alignment will not be altered;
- Only single destination ramp exits for the interchange are to be provided to simplify signing, avoid confusion and improve traffic safety;
- All interchange ramp exits and entrances are to be located on the right-hand side. No left-hand exit or entrance ramps will be allowed;
- Interchange exit terminals are to provide appropriate decision sight distance; and,
- Stormwater drainage is to be accommodated with open surface ditch drainage if possible.

A DDI is a type of diamond interchange in which the two directions of traffic on the minor road cross to the left side on the bridge before crossing back over to the right side after the bridge. This configuration requires opposing vehicles to cross opposing lanes controlled by signals. Two intersections are required as is the case with most service interchange configurations. These intersections handle through movements only. All right turning vehicles diverge from the minor road or the exit ramps prior to the intersections and can operate either by yield or free flow merges controlled with channelization. Left turn movements proceed through the signalized intersection and require that vehicles be in the inside lanes as the outside lanes accommodate through movements (common lane position practice for left turns). If exiting left from the minor road, vehicles should be in the inside lane(s), proceed through the first signalized intersection and crossover the opposing lanes at which point they are directed onto the entrance ramp through channelization. This channelization allows these vehicles to exit the bridge under free flow conditions. Similarly, if exiting the major road, vehicles should be in the inside lane(s) and wait to enter the bridge at the signalized intersection. After proceeding through the intersection, vehicles merge into the inside lanes and proceed through the next intersection while crossing back onto the right side of the road. Stated simply, if turning left, be in the left lanes and if turning right, be in the right lanes. The geometry and channelization through the interchange will direct vehicles to crossover, merge and diverge as required. A central median is required beyond each of the intersections and through the bridge structure to separate the opposing traffic flows except at the two intersection points.
The simplicity of the signalization phasing improves the overall intersection efficiency and the number of vehicles that can be accommodated compared to other interchanges requiring signals at the ramp terminals. With this design, there are only two clearance intervals (the time for traffic signals to change from green to yellow to red) allowing for the lost time for various phases in the signal cycle to be redistributed as green time. No protected or permissive left turn phasing is required.

At the Pilot Butte access, it is likely that three lanes in each direction are required along the minor road to accommodate the various turning movements. Three lanes on the eastbound off ramp are required to accommodate the expected queues formed at the south intersection and two lanes are required for the westbound on ramp. The other two ramps are expected to require a single lane only due to the higher efficiency of moving traffic with this interchange design.

A constant vertical grade along the ramps is desirable to achieve adequate acceleration and deceleration of vehicles entering or exiting Highway 1. The actual grades will depend on the constraints that dictate what can and cannot realistically be achieved such as embankment height, elevation differences at the tie in locations and other access needs. The vertical grades of the loop ramps for the Parclo options would be developed much quicker than the other ramps, including the DDI, as the vertical clearance under the bridge structure has to be maintained prior to introducing any vertical changes.

With the future developments as they stand today, the cross-section of the Pilot Butte access will need to accommodate additional lanes beyond the two existing lanes. The timelines for this will depend on how quickly development proceeds to the north and south of Highway 1. At full build out, it is anticipated that a six-lane cross-section will be required in the general vicinity of the interchange at least to the adjacent service roads. This cross-section can be used to develop the required turning lanes to and from the service roads as needed. The spacing of the service road intersections to the ramp terminal intersections should consider the transition length required to at least reduce the six-lane cross-section to a four-lane cross-section. If it is determined that a two-lane cross-section is adequate beyond the service road intersections, then another transition from four lanes to two lanes should be considered.

Based on the future traffic volume projections for the Pilot Butte access, the highest level of access management control that MHI specifies may be required. This of course would be dependent on the extent of development that locates in the adjacent areas and accesses the future interchange and approach roadways. The function and intent of the Pilot Butte access is to service local needs and provide adequate connections to Highway 1 and other regional roadways. As such, it is expected that a more flexible and relaxed access management control would be appropriate for this roadway such that service road access is achieved to serve land and future development needs. A minimum spacing of 400m along the Pilot Butte access was assumed.

As with any new infrastructure project, it is important to disseminate information to the travelling public that may be unfamiliar with the changes being implemented. The more complex the project, generally the more attention is given to providing adequate and timely information. With the introduction of a DDI at this location, which could be the first such implementation in Canada, never mind in Saskatchewan, MHI has begun the process to educate local authorities and communities as to the different features and operational conditions of such a new and unique design. It will be important to continue this during the next stages of the work and to ensure adequate signage, pavement marking and advance guidance is provided on all approaches and through the interchange. Maintaining pavement markings may be challenging given the winter driving conditions in the region; however, it will be an important factor in achieving a safer roadway facility.

Additional right-of-way in each quadrant is required to accommodate the future interchange footprint. The DDI option requires the least amount of additional right-of-way and is the most compact of the options considered. Future widening of Highway 1 within the vicinity of the Pilot Butte access is expected to be completed within the existing right-of-way and as such, no lands to accommodate a future six-lane facility have been considered. The land adjacent to Highway 1 to the east at Emerald Park and White City has limited opportunities to support any

future right-of-way needs due to the existing development on both sides of the highway corridor. By considering a service road network that does not run parallel to Highway 1 in this area, additional lands could become available should future widening be required.

Corner cuts both along the main and minor roads from each of the adjacent quarter sections are required to develop the interchange ramps and embankment height. Additional lands on the east side of the Pilot Butte access may be required beyond those for the physical interchange footprint to support a wider cross-section than currently exists. The right-of-way required along the south leg also includes widening of the road for a wider cross-section. As the northeast quadrant has multiple subdivided parcels, land will be required from the majority of those parcels adjacent to Highway 1 and the Pilot Butte access. In some cases, it may be more beneficial to the property owner to purchase the entire parcel due to the amount of land and severance required. Land acquisition for those areas required in the northwest quadrant is not anticipated to be problematic due to the landowner's desire to begin developing their lands as quickly as they can and their involvement in the development of the recommended option.

CONSTRUCTION STAGING CONSIDERATIONS

A possible staged approach to constructing this interchange was reviewed. It is recognized that the ultimate lane configuration will not be required at day one once the interchange is open to the public since development will still be at various stages.

Stage 1 of the DDI includes construction of three northbound lanes on the bridge structure to accommodate the two highest left turn volumes from the east and from the south. Two lanes would be required on the entrance and exit ramps on the west side of the interchange. The southbound direction would require two lanes on the bridge structure to minimize any impedance of traffic between the intersections with vehicles entering or exiting from the ramps. Single lane ramps are required for those on the east side of the interchange. Two lanes to the north and south of the bridge structure would be required for both directions of travel. This configuration is expected to be able to accommodate traffic volumes for quite some time until the demands placed on the interchange require additional lanes for both northbound and southbound travel.

Stage 2 of the DDI includes developing the interchange to the ultimate configuration to support traffic volumes in the magnitude of those projected in 2045 at full development build out. It should be recognized that the progress of development might be such that Stage 2 is never required within the design life of the bridge structure.

The implementation and lifespan of either Stage 1 or Stage 2 will be governed by the rate that development proceeds to the east of Regina and within the surrounding municipalities. As such, it is possible that a pre-Stage 1 concept could be considered. In many of the jurisdictions where DDIs have been implemented, the configuration was a conversion from a standard diamond interchange. Issues arising from capacity constraints have forced many municipalities to review ways to gain extra capacity while maintaining as much of the physical infrastructure as possible. With this in mind, it is possible that a standard diamond interchange could be

introduced to alleviate the safety and operational concerns that exist presently at the Pilot Butte access on Highway 1.

Until such times that development is realized and additional capacity is required above what is provided by the diamond interchange, the configuration could be converted to the recommended DDI. Information regarding the conversion costs associated with modifying a diamond to a DDI is limited since there are only a few DDIs in operation; however, this limited information suggests that, with minimal bridge work, cost could be as low as $5 million. Conversely, it is desirable to have built in capacity for an interchange from the outset. The DDI offers more growth flexibility at Stage 1 than the standard diamond does and with the uncertainty of development growth, it is more beneficial to have this extra capacity early on to avoid having to do any reconstruction within the first few years of operation.

Similar to what has been completed at other interchange locations along the Highway 1 corridor to the east, the construction of ramps in the intersection quadrants could be completed for the purpose of addressing safety concerns today. This of course is subject to available funding since MHI is currently reviewing procurement options to finance this and other needed infrastructure requirements around Regina. Construction of the ramps and service roads on the north side of Highway 1 could be considered as the larger traffic volumes currently are to and from the north. The overpass bridge on the Pilot Butte access, ramps and service roads on the south side could then be constructed as traffic demands or if safety problems emerge. Alternatively, the ramps and service roads may be implemented separately depending on access management and interchange configuration requirements as well as available funding and timing if a procurement method to deliver the entire project at once is not available.

STAKEHOLDER INPUT

This study included a comprehensive and collaborative stakeholder consultation process. Discussions with various stakeholders were ongoing for the duration of the study for the purpose of confirming future development plans, traffic volumes, concerns and impacts associated with the interchange plans, and to solicit input into the development of interchange options.

A Steering Committee was established to guide the overall process and direction the study took, which included representation from MHI, the urban and rural municipalities as well as a local First Nation. A Technical Committee comprising MHI staff was also formed to provide technical expertise at various study milestones. Both committees were involved in the development, selection and evaluation of the interchange options considered within this study. Presentations were made to municipal Councils to advise of the study progress and to receive input at key stages of the study. Both Councils expressed support for the study and for the study recommendations.

Interactive public open houses were held to present the shortlisted interchange options, to gain important feedback regarding these options, and to advise of the recommended option once it was selected. Media representatives were also in attendance who took the opportunity to

interview MHI staff and a member of the study team. A news broadcast was aired the night of the first open house capturing comments from the interviews as well as with a member of the public in attendance and the Mayor of Pilot Butte. From the feedback received, there was overwhelming support of the study and its recommendations.

CONCLUDING COMMENTS

The apparent benefits associated with the Diverging Diamond Interchange design compared to others have led to a significant increase in the number of DDIs being constructed in the U.S. The first DDI in North America was opened to traffic in June 2009 in Missouri and at the time of preparing this paper, it is understood that 18 such interchanges are open to the public with another 11 close to completion or currently being designed. This number is likely to increase as they continue to gain popularity elsewhere as subjective feedback for the most part is positive from jurisdictions and the public. The focus in the U.S. seems to have been to construct DDIs in urban areas to address congestion issues. Presently, there are no known DDIs being built in Canada.

The DDI will introduce horizontal curvature along the Pilot Butte access for the purpose of achieving a crossover from one side to the other. Two sets of reverse curves, one at each of the ramp terminal intersections, are required with the intersection located within the reverse curvature. Tight horizontal curves can be achieved due to the intent to slow travel speeds down upon entering the signalized intersections. A reduction in the travel speeds through the signalized intersections as well as the interchange design will seek to minimize the frequency and severity of collisions creating an improvement in the current safety performance at this location and along the TransCanada Highway corridor.

A DDI is considered to be the preferred interchange option for the Pilot Butte access along the TransCanada Highway east of Regina. The expected operational and safety benefits, cost savings, design and staging flexibility, as well as minimized land impacts were all considered to be favourable than other options reviewed from the perspective of the study team, road authority and local stakeholders. Local media attention of the functional planning work completed has created some excitement amongst the road safety and engineering communities, as well as local stakeholders regarding the prospect of not only improving the existing conditions for road users but of the possibility of creating a landmark project for the region, local communities and provincial government.

REFERENCES

1. AECOM Canada Ltd., Highway 1 East Functional Planning Study, Saskatchewan Ministry of Highways and Infrastructure and the White Butte Planning Commission, December 2010