TRAFFIC SIGNALS OR ROUNDABOUT AT THIS UNUSUAL INTERSECTION?

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1.0 INTRODUCTION

1.1 BACKGROUND AND PROBLEM STATEMENT

This paper describes an Intersection Control Study (ICS) undertaken for the intersection of Sawmill Road, Katherine Street and Crowsfoot Road. The location is the Township of Woolwich in the Region of Waterloo in southern Ontario. The site location is shown in Figure 1.1 and the study area is shown in Figure 1.2.

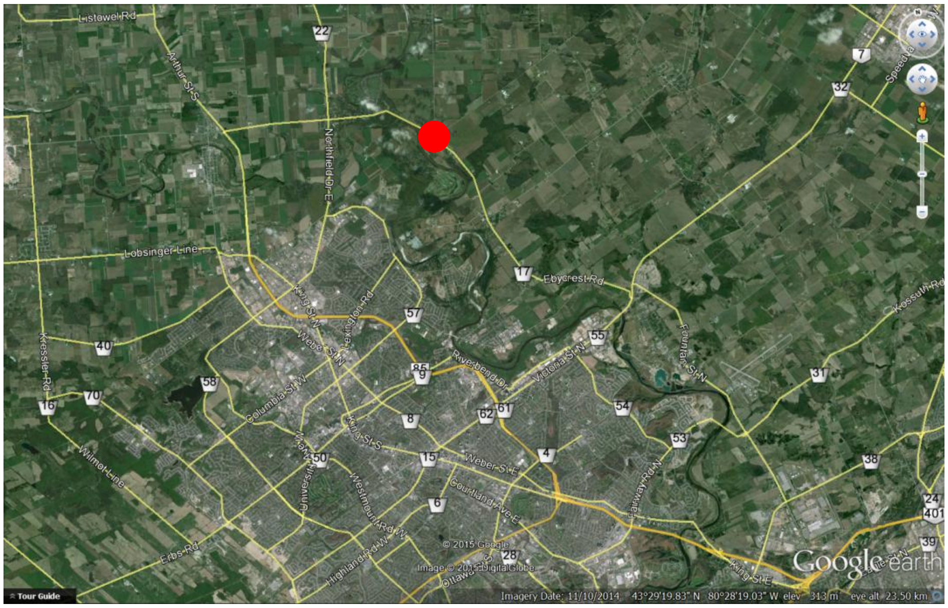


Figure 1.1 Site Location

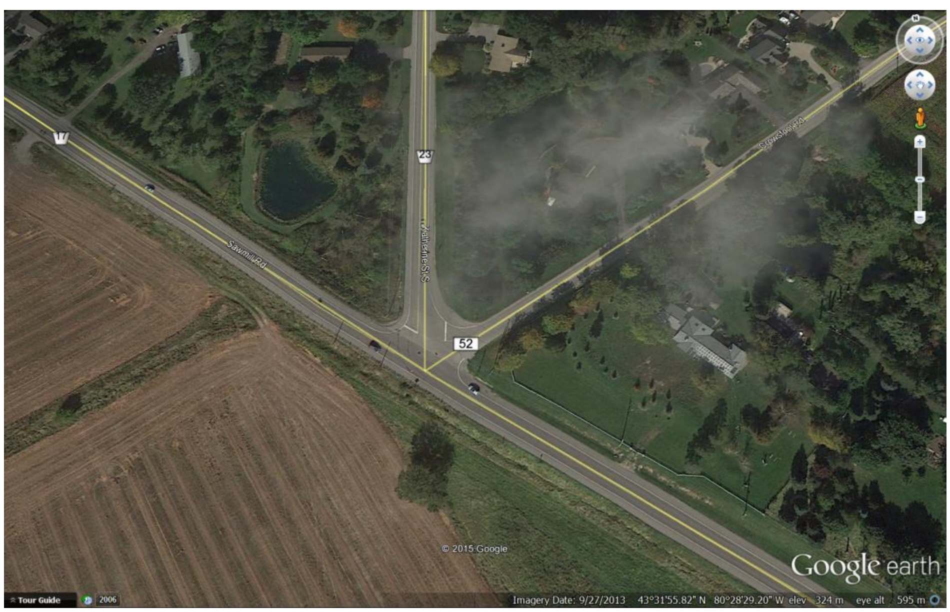


Figure 1.2 Existing Intersection

The intersection is of an unusual configuration in that Katherine Street and Crowsfoot Road both intersect the north side of Sawmill Road. Travelling clockwise, angles between legs are approximately 55 degrees between Sawmill Road, Katherine Street and Crowsfoot Road, and 70 degrees between Crowsfoot Road and Sawmill Road. Katherine Street and Crowsfoot Road are under stop control supplemented by overhead flashing beacons.

Motorists on Crowsfoot Road must stop, then stop gain on Katherine Street before entering Sawmill Road. The configuration also allows high-speed turns from Sawmill Road.

Skew angles are inherently a safety risk: research documented in the Highway Safety Manual (AASHTO, 2010) indicates a 28% increase in collision potential for a skewed approach at a four-way intersection on a rural two-lane highway compared to a right-angle intersection. As can be expected, collision frequency at this location is higher than for four-way intersections elsewhere in the Region of Waterloo with similar traffic volumes.

Traffic growth forecasted by the Region will warrant the installation of traffic signals. Because of this, and the safety problems being experienced, an Intersection Control Study (ICS) was undertaken as per Region of Waterloo policy.

1.2 REGION OF WATERLOO POLICY

Since 2003 the Region of Waterloo has required that an ICS be undertaken for:

- New intersections on Regional Roads
- Existing intersections where traffic signals are warranted
- Existing intersections where capacity or safety problems have been identified

An ICS is a formal comparison of intersection control alternatives, usually traffic signals and a roundabout. Before proceeding to an ICS an intersection is subjected to an Initial Screening Tool to ascertain whether a roundabout can be screened out. This might be the case where a roundabout would result in unreasonably high costs or excessive property impacts. The main part of the tool is an economic evaluation that requires the rough estimation of construction costs and the societal costs of motor vehicle collisions for the alternatives. If the results are close or in favour of a roundabout then an ICS is conducted.

In this case the Region completed the Initial Screening Tool and concluded that the comparison should proceed to an ICS.

An ICS compares alternatives in terms of several economic and non-economic criteria. The economic criteria comprise construction and study period costs (the latter of which include maintenance costs and the societal costs of motor vehicle collisions). In addition to future peak hour traffic operations, non-economic criteria in more urban locations may include access management, conditions for pedestrians and cyclists, impacts to transit and emergency services, etc.

An ICS is similar to but less onerous than a Municipal Class Environmental Assessment (EA), and the emphasis is on transportation. If a project is greater in scope than an intersection modification or it triggers the need for a Class EA because of natural, socio-economic or cultural impacts, then in the Region of Waterloo the ICS would become an input to a Class EA.

2.0 ALTERNATIVES DEVELOPMENT

2.1 SITE CONTEXT

Sawmill Road has a two-lane rural cross section and a posted speed limit of 70 km/h. Katherine Street and Crowsfoot Road have two-lane rural cross sections and a posted speed limit of 60 km/h. Truck percentages are high due to several nearby gravel quarries. No pedestrian facilities are currently in place in the study area. Sawmill Road and Katherine Street are on the existing Regional cycling network.

There are large rural residential properties in the quadrants between Katherine Street and Crowsfoot Road, and Crowsfoot Road and Sawmill Road. Agricultural land is on the south side of Sawmill Road.

Sawmill Road is on a 6% downhill grade from east to west, and there are grade drops on the south side of Sawmill Road and in the quadrant between Sawmill Road and Katherine Street. Photos are in Figure 1.3. Sawmill Road is considered to run east-west for the purposes of this study.

Sawmill Road Looking West

Sawmill Road Looking North

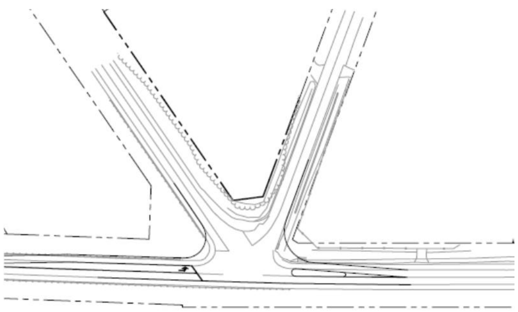
Sawmill Road Looking East

Katherine Street Looking South

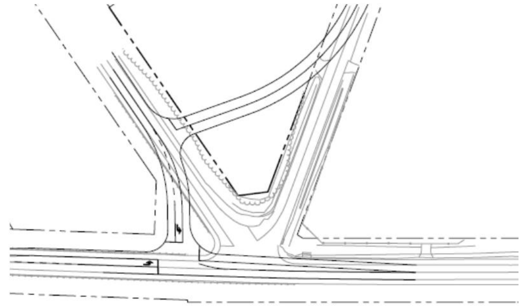
Figure 1.3 Representative Site Photos

2.2 INITIAL ALTERNATIVES

A number of alternative configurations for the intersection were initially developed and presented to the Region. The options are depicted in Figure 2.1.



Option 1



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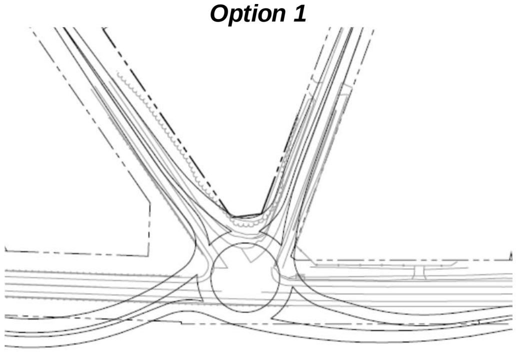

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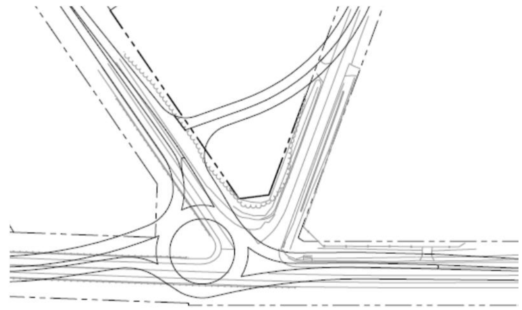

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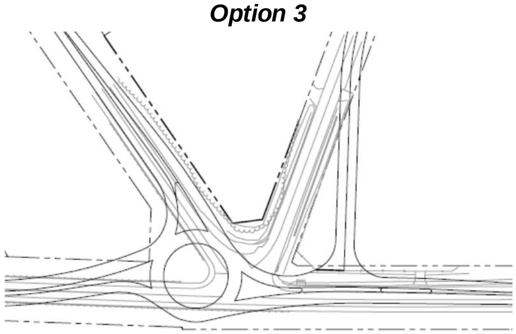

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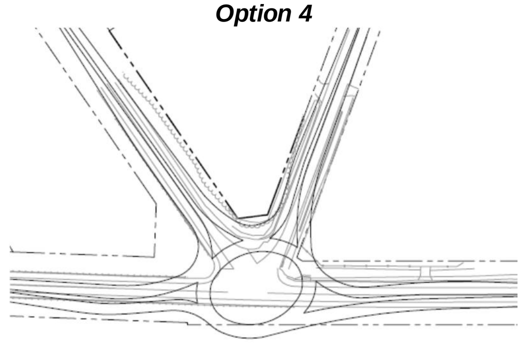

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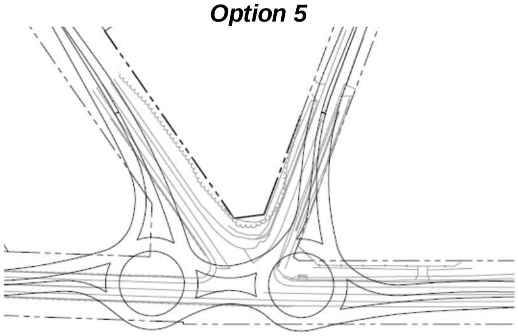

Option 7

Figure 2.1 Initial Intersection Options

The first two options are for traffic signal control at the existing four-leg intersection, or a three-leg intersection with Crowsfoot Road intersecting Katherine Street under stop control. The other five options are various roundabout configurations.

The roundabout options exhibit reasonable speed control for the site context, and accommodate a WB-20 design vehicle for through movements on Sawmill Road and a WB-17 for turning movements. However subsequent discussions led to the discarding of the oval roundabout and double-roundabout options. The oval roundabout is problematic in terms of achieving consistent speed control, especially for movements to and from Crowsfoot Road, and it was decided it would be difficult to refine into a good design. The double-roundabout would create a high level of geometric delay for drivers on Sawmill Road, which currently is free-flow.

2.3 REFINED ALTERNATIVES CARRIED FORWARD

The remaining five options were refined to a conceptual design level, and are illustrated in Figures 2.2 to 2.6.

Signals Alternative A maintains the current configuration of the intersection, but with signal control, a left-turn lane eastbound on Sawmill Road and a right-turn bypass southbound on Katherine Street. Signals Alternative B realigns Katherine Street approximately 40 metres west to intersect Sawmill Road under signal control, and Crowsfoot Road to intersect Katherine Street approximately 60 metres north of Sawmill Road under stop control. Left turn lanes are introduced on Katherine Street southbound and Sawmill Road eastbound.

Roundabout Alternative A maintains the current configuration of the intersection, but with a roundabout and right-turn bypasses in two quadrants. The bypasses are to facilitate right-turn movements for large trucks. Without them the legs of the roundabout would have to be separated further, as is the case with Option 3 in Figure 2. During the refinement of Option 3 into Roundabout Alternative A it was determined that the bypasses would be much less expensive to construct than dealing with the grade drop on the south side of Sawmill Road. The trade-off is some impact to the rural residential property in the quadrant between Katherine Street and Crowsfoot Road.

Roundabout Alternative B is similar to Signals Alternative B, and Roundabout Alternative C realigns Crowsfoot Road to intersect Sawmill Road approximately 40 metres east of Katherine Street under stop control. These two roundabouts are shifted approximately 25 metres to the north to minimize the need to encroach on the south side of Sawmill Road. All three roundabout alternatives consist of single-lane entries and an inscribed circle diameter (ICD) of between 44 and 46 metres.

There is no traffic signals alternative to correspond to Roundabout Alternative C. Exit speeds eastbound from a roundabout would be low, but prevailing speeds would remain high on Sawmill Road with traffic signals, and there would be insufficient distance to develop a standard deceleration taper for a left-turn lane.

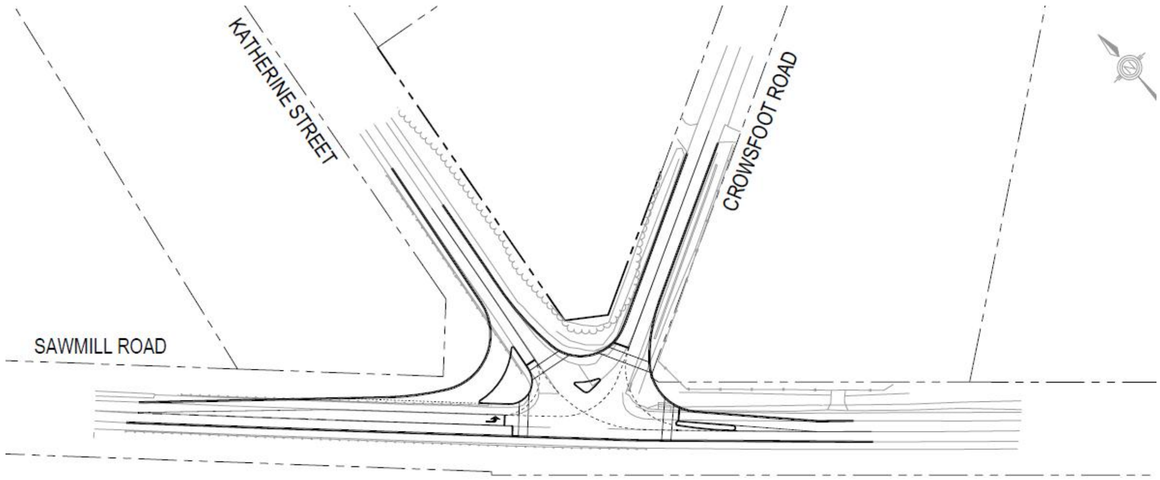

Figure 2.2 Signals Alternative A

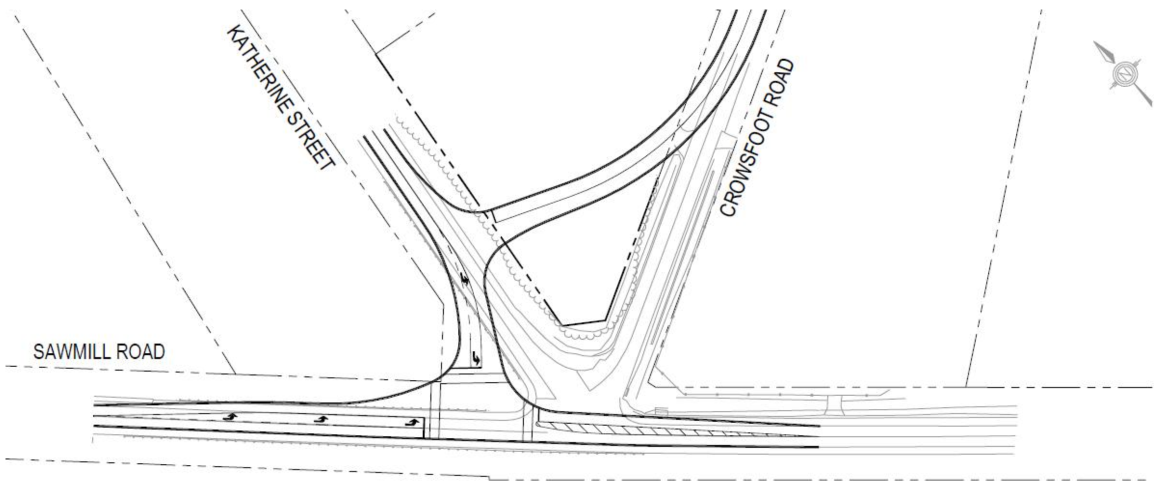

Figure 2.3 Signals Alternative B

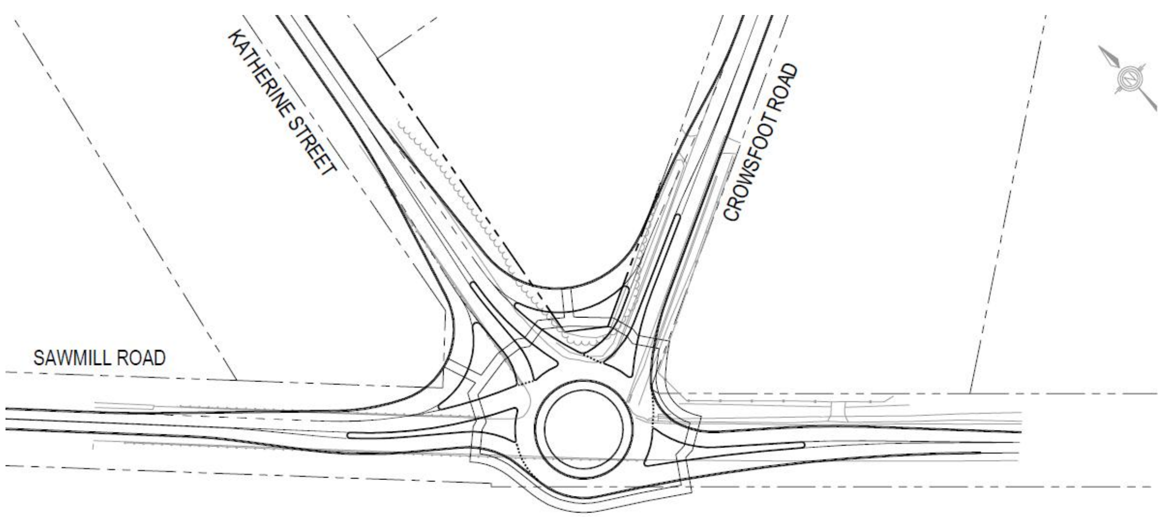

Figure 2.4 Roundabout Alternative A

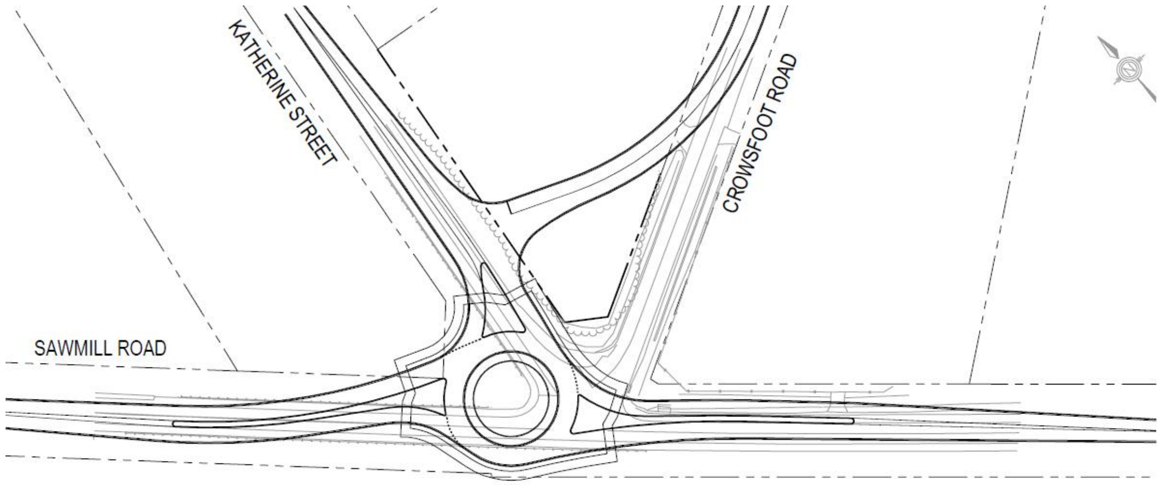

Figure 2.5 Roundabout Alternative B

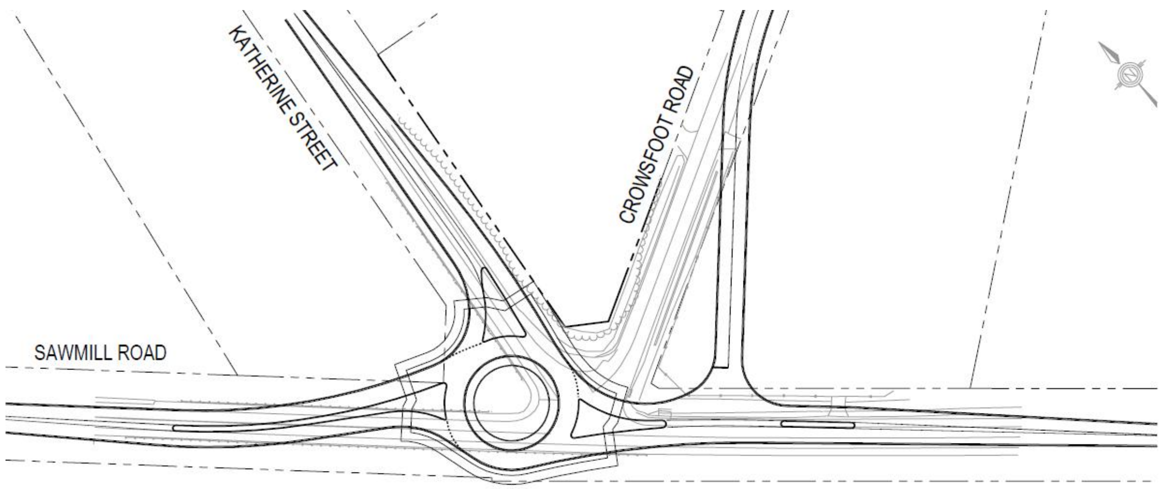

Figure 2.6 Roundabout Alternative C

2.4 CAPACITY ANALYSIS

Capacity analyses were undertaken as part of the design process using 2024 peak hour turning movement forecasts from the Region. Synchro was used for the traffic signal and stop-controlled intersections and ARCADY was used for the roundabouts. Peak hour level of service (LOS) results are shown in Table 2.1.

Low delays are predicted for motorists with one exception: a four-way intersection under traffic signal control (equivalent to Signals Alternative A). This is because a special 3-phase signal cycle would be needed to cater to movements on Katherine Street and Crowsfoot Road separately. This cycle and the longer all-red times required would act to increase delays from LOS ‘B’ to LOS ‘D’.

Table 2.1 – 2024 Peak Hour Capacity Analysis Results

Level of Service (LOS)	4-Way Signal	4-Leg Roundabout	3-Way Signal (Stop on Katherine)	3-Leg Roundabout (Stop on Katherine)	3-Leg Roundabout (Stop on Sawmill)	Stop on Katherine	Stop on Sawmill
AM Peak Hour	D	A	B	A	A	A	A
PM Peak Hour	D	A	B	A	A	A	A

3.0 ALTERNATIVES EVALUATION

3.1 SAFETY PERFORMANCE COMPARISON

Safety performance for motorists was predicted using Safety Performance Functions (SPF's) developed by the Region of Waterloo from the general methodology set out in the Highway Safety Manual.[1]

The Region's SPF for the prediction of total collisions at traffic signal and stop-controlled intersections is of the form:

$$\text{Total crash frequency} = \exp(a + b \times \ln(AADTmaj) + c \times \ln(AADTmin))$$

where: *a*, *b* and *c* = Total crash coefficients
AADTmaj and *AADTmin* = AADT for the major and minor approaches, respectively

The model is based on multiple-vehicle collisions within the Region and is assumed to apply to single-vehicle collisions as well. Total collisions were multiplied by a Calibration Factor and Collision Modification Factor (CMF) to account for the presence of exclusive left-turn lanes. Property-damage-only (PDO) collisions were predicted using:

$$\text{PDO crash frequency} = \text{total crash frequency} \times f_{PDO}$$

Fatal and non-fatal injury collisions were predicted using:

$$\text{Injury crash frequency} = (\text{Total} - \text{PDO collisions})(1 - Fatal\ Collision\ Ratio)$$

$$\text{Fatal crash frequency} = (\text{Total} - \text{PDO collisions})(Fatal\ Collision\ Ratio)$$

An Empirical Bayes (EB) procedure to weight observed and predicted crash frequencies was not employed since all the alternatives change the configuration and/or type of control compared to the existing intersection.

The Region's SPF for the prediction of total collisions at roundabouts is of the form:

$$\text{Total crash frequency} = 0.0004 \times (Total\ Daily\ Conflicts) + 1.8122$$

Unlike other collision prediction models that use AADT, the Region's roundabout SPF incorporates the number of potential conflicts between entering and circulating traffic. If, for example, a roundabout has roughly equal entering traffic on all legs, then it will have more potential conflicts than a roundabout with the same AADT but where most traffic is bi-directional (east-west, for instance).

For a single direction (say southbound), total daily conflicts for a single-lane roundabout are calculated as:

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[1] *Collision Estimation and Cost Calculation*, Region of Waterloo, March 24, 2014. Fatal collision ratios for urban or rural intersections, and crash coefficients, calibration factors, and left-turn (and right-turn) collision modification factors for 3-leg or 4-leg intersections, are provided based on data from locations in the Region of Waterloo.

$$\text{SB total daily conflicts} = (lesser\ of\ SB\ total\ vs.WB\ left + WB\ through) + (lesser\ of\ SB\ left + SB\ through\ vs.EB\ total) + (lesser\ of\ SB\ left\ vs.NB\ total)$$

In the SPF injury collisions are taken to represent 10% of all crashes at roundabouts, with all remaining collisions being PDO. Fatal collisions are assumed to be negligible at roundabouts.

The results of the safety analysis are presented in Table 3.1.

Table 3.1 – Predicted Future Annual Crash Frequencies by Severity

Collision Severity	4-Way Signal	4-Leg Roundabout	3-Way Signal (Stop on Katherine)	3-Leg Roundabout (Stop on Katherine)	3-Leg Roundabout (Stop on Sawmill)	Stop on Katherine	Stop on Sawmill
Fatal	0.01	-	NA	-	-	0.02	0.03
Injury	1.52	1.72	NA	1.08	0.76	0.93	1.19
PDO	2.97	15.51	NA	9.68	6.85	1.35	1.72
Total	**4.49**	**17.24**	**NA**	**10.76**	**7.61**	**2.31**	**2.93**

It can be seen that in this case a roundabout is predicted to result in a higher number of collisions than a signalized intersection. (Also note that at this time the Region does not have sufficient information to calculate safety performance at rural three-way signalized intersections.)

3.2 COLLISION COSTS

As per standard procedure in the Region of Waterloo, study period costs associated with motor vehicle collisions by severity were calculated as present costs (PC) using a 6% discount rate over 20 years and the formula:

$$PC = (\text{crash frequency})(\text{crash cost})\left(\frac{1.06^{20} - 1}{(0.06)(1.06^{20})}\right)$$

Two sets of costs were used:

- Comprehensive costs as per Transport Canada report *Analysis and Estimation of the Social Cost of Motor Vehicle Collisions in Ontario* (August 2007). They are $13,600,000 per fatal collision and $82,000 per non-fatal injury collision, plus a Region-specified cost of $5,000 per PDO collision.
- Human capital costs from Table 4A-1 of the Highway Safety Manual, adjusted from 2010 using the Consumers Price Index. They are $1,656,000 per fatal, $60,500 per non-fatal injury and $5,000 per PDO collision.

Human capital costs include monetary losses associated with medical care, emergency services, property damage and lost productivity. Comprehensive costs include human capital costs plus nonmonetary costs related to reduction in quality of life.

Table 3.2 presents the resulting 20-year study period collision costs.

Table 3.2 – Study Period Collision Costs (in thousands)

Collision Severity	Comprehensive Costs						
	4-Way Signal	**4-Leg Roundabout**	**3-Way Signal (Stop on Katherine)**	**3-Leg Roundabout (Stop on Katherine)**	**3-Leg Roundabout (Stop on Sawmill)**	**Stop on Katherine**	**Stop on Sawmill**
Fatal (PC)	$1,668	-	NA	-	-	$3,732	$4,749
Injury (PC)	$1,427	$1,621	NA	$1,012	$716	$877	$1,117
PDO (PC)	$170	$890	NA	$555	$393	$77	$98
Total (PC)	**$3,265**	**$2,511**	**NA**	**$1,567**	**$1,108**	**$4,687**	**$5,964**

Collision Severity	Human Capital Costs						
	4-Way Signal	**4-Leg Roundabout**	**3-Way Signal (Stop on Katherine)**	**3-Leg Roundabout (Stop on Katherine)**	**3-Leg Roundabout (Stop on Sawmill)**	**Stop on Katherine**	**Stop on Sawmill**
Fatal (PC)	$203	-	NA	-	-	$454	$578
Injury (PC)	$1,053	$1,196	NA	$746	$528	$647	$824
PDO (PC)	$170	$890	NA	$555	$393	$77	$98
Total (PC)	**$1,426**	**$2,086**	**NA**	**$1,302**	**$921**	**$1,179**	**$1,500**

The difference in sets of total collision costs is primarily because of the large difference in the value placed on fatal collisions between the comprehensive and human capital costs. Fatal collisions are possible with intersections under signal or stop control but technically not with a roundabout. In looking at “4-Way Signal” and “4-Leg Roundabout”, the latter is less costly by $754,000 using the comprehensive collision costs, and the former is less costly by $660,000 using the human capital costs.

It should be noted that crash costs are mostly a societal cost, and if there are any savings associated with an alternative then only a small portion of that savings may return directly to the Region.

3.3 CONSTRUCTION AND PROPERTY COSTS

Construction cost estimates were prepared as per Figures 2.2 to 2.6, and are based on the assumption the Region would undertake full-depth reconstruction of the existing road structure given the current pavement condition. The estimates are:

- $982,000 for Signals Alternative A
- $1,090,000 for Signals Alternative B
- $1,570,000 for a Roundabout Alternative A
- $1,597,000 for a Roundabout Alternative B
- $1,527,000 for a Roundabout Alternative C

The estimates are capital costs that account for utility pole relocations and property acquisition based on a 5 metre boulevard plus any impacts due to grade drops on the south side of Sawmill Road and in the quadrant between Sawmill Road and Katherine Street. A value to acquire residential property was used of $50 per square metre.

3.4 STUDY PERIOD COSTS

A comparison of overall capital and study period costs is shown in Table 3.3. Here, the collision costs are added for each intersection type. While Signals Alternative A has the same collision costs as “4-Way Signals” in Table 3.2, Signals Alternative B (for example) would use costs from “3-Way Signals” plus “Stop on Katherine”.

A cost of $3,000 per year was assumed for annual traffic signal maintenance, and that a complete re-build would occur after the 20-year study period. A cost of $1,000 per year was assumed for landscaping maintenance for a roundabout.

Table 3.3 – Total Study Period Costs (in thousands)

Cost Item	**Comprehensive Collision Costs**				
	Signals Alt. A	**Signals Alt. B**	**Roundabout Alt. A**	**Roundabout Alt. B**	**Roundabout Alt. C**
Total Capital	$982	$1,090	$1,570	$1,597	$1,527
Maintenance (PC)	$60	$60	$20	$20	$20
Total Collision (PC)	$3,265	$4,687 + NA	$2,511	$6,254	$7,072
Total Study Period (PC)	**$4,307**	**$5,837 + NA**	**$4,101**	**$7,871**	**$8,619**

Cost Item	**Human Capital Collision Costs**				
	Signals Alt. A	**Signals Alt. B**	**Roundabout Alt. A**	**Roundabout Alt. B**	**Roundabout Alt. C**
Total Capital	$982	$1,090	$1,570	$1,597	$1,527
Maintenance (PC)	$60	$60	$20	$20	$20
Total Collision (PC)	$1,426	$1,179 + NA	$2,086	$2,481	$2,421
Total Study Period (PC)	**$2,468**	**$2,329 + NA**	**$3,676**	**$4,098**	**$3,968**

In looking at the comprehensive collision costs, Roundabout Alternative A is expected to have the lowest study period cost by a margin of $206,000 over Signals Alternative A. This is a relatively slim margin given the uncertainties associated with the various cost estimates. The remaining alternatives all involve a stop-controlled intersection, which because of its higher probability of a fatal crash shows much higher total study period costs (even without having sufficient information to calculate safety performance at a rural three-way signalized intersection).

In looking at the human capital costs, Signals Alternative A is expected to have the lowest study period cost by a margin of $1,208,000 over Roundabout Alternative A. However here it is possible that Signals Alternative B would also fare well, had sufficient information been available to calculate safety performance.

4.0 CONCLUSION

4.1 GENERAL DISCUSSION

In looking at the comprehensive collision costs the preferred alternative is Roundabout Alternative A although the margin of $206,000 over a 20-year study period compared to Signals Alternative A should not be considered significant.

In looking at the human capital collision costs the preferred alternative is Signals Alternative A by a margin of $1,208,000 over Roundabout Alternative A, which should be considered significant.

Currently the 20-year study period cost of Signals Alternative B, using the human capital collision costs, is $139,000 less than Signals Alternative A and $1,347,000 less than Roundabout Alternative A. The human capital collision cost associated with the three-way signalized intersection is likely to be more than $139,000 but less than $1,347,000, so Signals Alternative B should therefore be considered the second most-preferred alternative when considering human capital collision costs.

In cases where the two sets of collision costs indicate different preferred alternatives, and an evaluation using non-economic criteria does not reveal a preference, it is usually left to the Region to decide on a recommended alternative. Here, low delays are predicted for motorists for all the alternatives except where 2024 peak hour LOS 'D' is expected for Signals Alternative A. However of question is whether this is enough to offset the more significant margin between it and Roundabout Alternative A using the human capital costs.

4.2 CHANGE TO ROUNDABOUT ALTERNATIVE A

Late in the study the Region proposed that the right-turn bypass in the quadrant between Katherine Street and Crowsfoot Road be eliminated. Very few trucks currently make that right-turn movement, and it was thought that those who do could be directed around the roundabout. This has been done elsewhere using a sign similar to that shown in Figure 4.1.

Figure 4.1 "Go Around Roundabout" Sign

With elimination of the bypass and corresponding savings in construction and property costs, the capital cost estimate for Roundabout Alternative A is $330,000 less than before, or $1,240,000. This closes the margin between it and Signals Alternative A to $878,000 using the human capital collision costs (and increases it to $536,000 using the comprehensive costs).

4.3 CONCLUSIONS AND RECOMMENDATION

Given the differences in 20-year study period costs resulting from the two sets of collision costs, and the uncertainties associated with the various cost estimates, and given that Signals Alternative A is predicted to result in 2024 peak hour LOS 'D' for motorists, it was recommended that Roundabout Alternative A be carried forward for construction by the Region.

However if in the meantime sufficient information becomes available to calculate safety performance at a rural three-way signalized intersection, then it was recommended that the 20-year study period cost of Signals Alternative B be calculated to ascertain whether it could become the preferred alternative.