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Safety Effects of Roundabouts

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Abstract:

The replacement of traffic light and stop sign intersections with roundabouts has been considered in municipalities around the world. In Canada, roundabout installations are among high priority transportation development projects to improve road safety and traffic flow. Currently, one of the biggest roundabout replacement projects is being conducted in the Region of Waterloo. This project started with two roundabout installations in 2004, and the number of roundabouts increased to 17 by November 2011. The purpose of this study is to investigate the safety effects of roundabouts using the Region of Waterloo collision data. In this report, the safety effects are mainly described by the number and severity of crashes. Regression modeling is the methodology used in this report and the results are estimated by the Ordinary Least Square (OLS) method in E-Views. The results of the regression models are used for the prediction of the number of crashes in a proposed roundabout expansion project in the region. Additionally, a cost-benefit analysis is performed by using data from the Region of Waterloo, Transport Canada, and Statistics Canada to estimate the associated social cost of roundabout installation in the proposed regional intersections. The results show that the estimated social costs of roundabout installation are significantly lower than traffic light intersections.

1. History:

The early structure of traffic circles dates back to the 18th century. Bath Circus (1754-1768) located in Somerset in the south west of England and Place Charles de Gaulle (Place de l'Étoile) in Paris, completed in 1777, in the junction of twelve avenues are examples of the first-built cyclic municipal structures. These traffic circles were significantly different in size and travel direction from current traffic circles, rotaries and modern roundabouts. In the early 1900s, the traffic circles was bigger in diameter, which enabled drivers to enter the cycle with high speed (at least 35 mph) while in the modern roundabouts which are being implemented since 1960s, the smaller size of the inner diameter leads drivers to enter with lower speeds (around 15 mph). Moreover, unlike the old traffic circles, in modern roundabouts, priority is not given to the entering flow. This has resulted in the reduction of the severity of crashes in modern roundabouts.

The first inventor of modern roundabouts was Frank Blackmore, a British traffic engineer at the Transport Research Laboratory in the UK. He developed the offside priority rule by setting the priority in favor of circulating flow (yield rule). Gradually, this rule was accepted as a law in the UK in 1966, the US and rest of the world. In the past 10 years, the construction of roundabouts has also been considered in Canada. The first roundabout in Canada was constructed in the province of Alberta in Fort McMurray, and the Ontario's first modern roundabout was built in Ancaster in October 2002. Nowadays, these structures are becoming more popular, but the long-term effects of their implementation are still under review.

2. Introduction:

The purpose of this study is to shed light on one of the current top news stories in the Region of Waterloo which is the safety effects of roundabouts. Since 2004, an ongoing project has been running in the Kitchener-Waterloo (KW) Region to build roundabouts in some intersections. Although there are safety concerns in the region about the intersection conversion, it is still one of the municipality's main projects. This project is the biggest project of its kind in the province of Ontario with 17 operative and 15 proposed roundabouts.

This is the first time that an academic research study is being conducted on regional roundabouts. The results are valuable for future intersection conversions.

The safety effects of roundabouts are investigated using two approaches. In each approach, a unique regression model is used to investigate the research question. The results of the first regression model show that roundabout intersections have 85% more crashes per year than traffic light intersections. The result is in contrary with the expectations implied by previous research studies. This can be attributed to the fact that the current study is a short-term investigation of the roundabouts. As a result, a long-term analysis may conclude differently. According to the literature, the trend shows that during the first years of roundabout operation, the number of crashes increases while it starts decreasing in long-term. The results of the second approach indicate that 2-lane and 4-leg[1] roundabouts result in a higher number of crashes than single lane and 3-leg roundabouts. This result is consistent with the literature. Additionally, the current study finds that the number of lanes has a larger effect on the number of crashes than the number of legs.

The regression results are further used to determine the safety effects of a proposed roundabout project in Franklin Blvd, in Cambridge. Since safety is a non-market and non-traded good, in order to specify a value that shows the safety effect of roundabout installation, the values of time delay, property damage, life lost, injury costs, and environmental pollution should be monetized. The obtained values will show the social cost of the roundabout installation project. Since the regression results show more crashes at roundabout intersections than traffic signal intersections, the calculation results for Franklin Blvd also indicates higher number of crashes if they had been converted to roundabouts in 2007. It is important to note that this study investigates the short-term effects, and the results are in agreement with the available literature.

3. Literature Review:

Various studies have been undertaken on different aspects of road safety such as seat belt, air bag, impaired driving, winter tire, etc. but only a small portion of the studies has been devoted to the safety effect of roundabout installation. During the past 15 years, many studies have been performed in order to explore a consistent and reliable answer to the question of whether the replacement of traffic light or stop sign intersections with roundabouts leads to a reduction in the likelihood of vehicle crashes. If the answer is positive, to what extent this modification affects society in terms of the changes in the types of crashes (i.e. injury collisions versus non-severe collisions such as property damage or non-reportable collisions)?

The majority of research work has been carried out in Europe and the United States but little has been done in Canada. For roundabouts located in KW, the Transportation Department of the Region of Waterloo has conducted analytical studies on the roundabout collision data. In this study, a comprehensive literature review is undertaken by studying municipality and government reports and major academic articles.

[1] The explanation for leg and lane variables is provided in page 13.

Transportation and Environmental Services of the Region of Waterloo has conducted a study to compare the operation of 15 regional roundabouts and traffic signals under similar conditions between 2006 and 2010. The results reveal that in the short run, the percentage of non-fatal injury collisions at roundabout intersections is 18% lower than traffic signal intersections with similar Annual Average Daily Traffic (AADT).This implies that the severity of crashes at roundabout intersections is lower than traffic light intersections. According to this report, the percentage of property damage collisions and non-reportable collisions (non-severe injury collisions) at roundabouts are 7% and 11% higher than traffic light intersection with similar AADT. Overall, non-severe injury collisions at roundabout intersections are 18% higher than similar traffic signal intersections. The conclusion of this research shows that roundabout implementation in the KW region had a positive long-term impact on road safety in terms of the decrease in the number and severity of crashes for both car/car and car/pedestrian collisions.

In the present research study, the effect of AADT on the number of crashes is investigated. Additionally, other variables such as number of legs, number of lanes and duration of operation are taken into account to obtain an accurate estimate for the effect of each variable on the number of crashes. All of these variables are reported to have significant effects on the number of crashes in the literature. This is the first time that regional roundabout data are analyzed in an academic research work, and the results will be valuable for future transportation decisions.   In the following, the academic articles elaborating on the effect of explanatory variables on the number of crashes are reviewed.

Since roundabouts are relatively new structures, the research articles are less than 50 years old. In general, they found that roundabout installation leads to a reduction in the number and severity of crashes. The common variables considered in the early analyses were the number of lanes, the geometry of roundabout and the width of entrance. The "before and after" methodology, capacity method and regression models are the most common methods that have been used in early studies (Arndt and Troutbeck (1998); Bassi et al (2004)). Since the last decade and after the worldwide operation of roundabouts in urban areas, the number of research papers on roundabout installation has been growing. In 1997, a comprehensive survey was conducted in Canada and the US to investigate the status of roundabouts in North America, the general perception of roundabouts and the level of satisfaction from roundabout installation[2]. The survey results showed 78% satisfaction. In this report, the most recent studies are reviewed, as listed in Table 1.

[2]Synthesis of Highway Practice 264, Modern Roundabout Practice in the United States, National Cooperative Highway Research Program, 1998.

Table 1: Summery of reviewed papers

Authors	Location	Number of roundabouts being analyzed	Type of Roundabout	Methodology	Considered Variables	Conclusion
Hydén and Várhelyi (2000)	Vaxjo Sweden	21 (April-October 1991), 4 out of 21 were being followed for 4 years	Single lane	Before and after analysis	Duration of the operation, Traffic volume, Mean speed	Overall number and severity of crashes decrease (after 4 month: number of car/car crashes increase, after 4 years: number of car/car crashes decrease)
Retting et al (2001)	United States (8 States)	24 During 1992-1997	15 single lane, 9 multilane	Empirical Bayes (regression model) & Before and after method	Traffic volume, Duration of the operation, Location (urban or rural)	Number and severity of crashes decrease (38% reduction in all crash severities, 76% reduction in crash injuries, 90% reduction in fatal and incapacitating injuries)
Šenk & Ambros (2011)	Czech Republic	90 During 2001-2004	Single lane and multilane	Regression Model	Accident frequency- Location (urban or rural), Annual traffic volume, Number of lanes, Geometry of roundabouts	Number of crashes decrease, (Two-lane roundabouts have significant effect on the number of crashes)
Daniels et al (2010)	Flanders-Belgium	90 During 1994-2000	Single lane and multilane	Regression risk model	Traffic flow, Geometry of roundabout, Number of legs, Number of lanes, Circling diameter	Number of crashes decrease, (AADT and number of legs have significant effect on the number of crashes)

As seen, some studies considered a small number of roundabout intersections while others conducted an extensive research study. The majority of the existing studies have used a police database for the number of crashes which means they have relinquished minor crashes that are not reported to the police. In this research paper, all types of crashes including fatal injury, non-fatal injury, property damage only and non-reportable crashes (minor crashes) are considered. Hence, the results are expected to be more accurate and comprehensive than the reviewed literature in which the minor crashes have been neglected.

The "before and after"[3] methodology proposed in some scholarly articles does not lead to accurate and robust results because the data for the duration before a specific change is compared to the data for the duration after the change. However, other factors may impact the results overtime which are not included in the analysis. Some of the articles have used the regression modeling which is a comprehensive economic approach with more reliable results.

Hydén and Várhelyi (2000) applied an empirical study to investigate the long-term and the large scale effects of roundabout implementation in Vaxjo, Sweden. Analyzing five-year police data indicated that 75% of accidents with injuries took place in intersections due to over speeding. Since roundabout structures are means to slow down the traffic and vehicle speed, they implemented 21 single lane roundabouts in high risk and high crash intersections and investigated the effect of this conversion. They found a statistically significant result ($P<0.05$) for the mean speed after four months. The mean speed reduced from 30.5 km/h to 27.2 km/h. They studied the intersections for a period of six months (between April-October (1991)). After the six month empirical period, they continued to monitor four intersections out of 21 for short-term (four months) and for long-term (four years) periods. They compared the results for the same period (April-October) before and after roundabout installation to investigate the short-term and long-term roundabout performance. Results indicate that in the short run, the number of car/pedestrian accidents reduced and the number of car/car crashes increased (from 223 to 231), but these crashes were less severe. After four months, the results indicated that the decrease in the mean speed was statistically significant. However, the mean speed after four years increased, but it was still significantly under the safety speed limit. In the long run, applying a 3-year before and after analysis indicated that the number and severity of car/car crashes decreased, while the number of car/pedestrian crashes increased. Since they picked their samples from high risk and high collision rate intersections, there is a sample

[3] The before and after comparison analysis is a method of comparing the differences in a treatment group before and after treatment

selection bias[4] problem in this study. They used video tapes, interview method, speed measurement, observation of the traffic volume and counting of crashes to collect required data for their analysis. Two out of these four roundabouts were rebuilt as permanent roundabouts with bigger inner diameter and the other two roundabouts were kept temporary. The results showed that the temporary roundabouts had been working efficiently in both short-term and long-term periods.

Retting et al (2001) investigated the effect of 24 traffic light and stop sign intersection conversions to modern roundabouts from 1992 to1997 in the US[5]. Their overall finding was 38% reduction in crash severities, 76% reduction in crash injuries and around 90% decrease in fatal and incapacitating crashes with injuries. They used the collisions data from the police database and then normalized them with respect to traffic volume in each intersection. They also considered the duration of roundabout operation and the change in traffic volume in their calculations. They used the "Empiric Bayes Approach" to estimate the expected number of crashes in an intersection. The author believed that unlike other road safety studies that overestimate the reduction in the number of crashes, they avoided this common defect by controlling the regression to the mean effect[6]. They estimated the expected annual number of crashes before intersection conversion in two steps. First, they estimated the expected annual number of crashes in the intersections completely similar to the retrofitted intersections. Second, they mixed the results from the first estimation as weighted average to the predicting regression. The author claimed that the obtained results were consistent because they compared them with other related international articles.

Šenk and Ambros (2011) conducted a unique study using a very large sample size of about 90 roundabout intersections in Czech Republic for a period of two years (2009-2010). They investigated the effects of traffic volume, number of lanes, vehicles speed, weather conditions and driver behavior on the number of crashes. They found that 2-lane roundabouts[7] perform significantly worse than single lane roundabouts at 10% significance level. The urban variable and road width variable were also significant at 10% significance level. They argued that variables such as weather conditions and driver behavior have small effect on the number of collisions. This study was based on a log linear regression model. The

[4] It causes the results of analysis to be less reliable. Since the sample of high risk and high collision roundabouts are selected the results may overestimate the regression effects and safety analysis.

[5] California, Colorado, Florida, Kansas, Maine, Maryland, South Carolina, and Vermont

[6] Regression to the mean effect is a statistical term that happens when there is a repeated measurement on the same units of observation or when the variable (observed characteristic) is in the extreme of its distribution in the first measurement. In the second measurement, this variable tends to be close to the mean. The error term in this case is a random error, but because the units of observation are the same for each measurement there will be a non-systematic variation around the mean in the observed characteristic.

[7] Roundabouts that have two lane road at least in one of the approaching roads

accident frequency was the dependent variable and there were independent variables such as location (urban or rural), annual traffic volume and number of lanes. They found large coefficients for rural variable, two-lane roundabouts and road width. They used a police database to find the number and types of crashes and National Traffic Census (2005) to find traffic flow data.

Daniels et al (2010) surveyed the variation of the safety effects of 90 roundabouts in Flanders, Belgium implemented between 1994 and 2000. It is a comprehensive study since it covers a large number of variables such as central island diameter, number of legs, number of lanes, traversable apron, existence of traffic signal before roundabout construction and circle diameter. They used a stratified random sampling method and collected cross sectional time series data for each roundabout. In this analysis, the Poisson[8] log linear risk model and the Gamma model was used and the results showed that the number of collisions is positively related to the traffic volume. In both models, they found a significant coefficient for average daily traffic (ADT) and the number of legs. However, the coefficients for geometric features (roundabout dimensions), central island diameter, inscribed circle diameter and road width (number of lanes) were not statistically significant. Moreover, they found that retrofitted intersections experience higher number of crashes. In the data collection process, they collected one or two observations per day in all entering lanes at roundabouts and adjusted them for a day based on the traffic volume. They obtained the crash and injury data from the Ministry of Mobility and Public Work and Statistics of Belgium.

Lord (2000) developed a model for future traffic pattern based on current traffic trends. He developed a model with upper and lower bound of traffic flow variables to predict the expected number of collisions in a fixed period of time. He proposed a method to obtain accident risk in an intersection by dividing the expected number of accidents in an intersection with known traffic flow by the multiplication of traffic flow and number of days in a year. This clearly shows a negative correlation between traffic flow and accident risk. It means that the heavier the traffic flow is, the lower the collision risk will be. In other words, light traffic flow leads to a higher chance of over speeding and collision.

There are some studies that monetize the social cost or benefit of intersection replacement by attaching a dollar value to safety which is categorized as a type of non-market goods. Since there is no trade in the market for safety, finding an accurate value is impossible. Common variables that previous studies have taken into account for monetization of the social cost are the value of lost lives, the value of time delay and the value of extra air/noise pollution (environmental damages). There are various

[8] Poisson regression is a type of regression analysis in which response variable has Poisson distribution.

methodologies for monetization such as the estimation of the value of the lives lost using Willingness-to-Pay (WTP) and GDP per capita methods[9].

There are similarities in the findings of the reviewed literature regardless of their methodologies, sample size or datasets. Most of the studies have used police database in the data collection process which means that they excluded the non-severe and non-reportable injury crashes. As a result, they underestimated the effects of roundabout implementation. The common outcome of these studies is that roundabout implementation has a crash reduction effect in the long run. The developed regression models are typically non-linear because of the weak correlation between the variable of interest such as the number of crashes and explanatory variables such as traffic volume and the number of lanes.

The variables and the regression model in the present research are similar to Retting et al (2001) and Daniels et al (2010) research papers which are comprehensive analyses without sample selection bias.

4. Methodology:

As mentioned, this research paper aims to identify the variables that influence the safety of roundabouts and estimate the safety effects of roundabouts at the proposed Franklin Blvd project in Cambridge. For this purpose, regression modeling is used in which the safety effects of roundabouts are studied using two approaches.

In the first approach, the effect of Annual Average Daily Traffic (AADT) and the existence of a roundabout in an intersection, as a dummy variable, on the number of crashes are investigated (Equation 1 & Equation 2). This is the basic regression modeling typically used in the literature[10].

$$\text{Number of Crashes} = \alpha + \beta_1(\text{AADT}) + \beta_2(\text{Existence of roundabout}) + \varepsilon \qquad (1)$$

$$\log(\text{Number of Crashes}) = \log(\alpha) + \beta_1 \log(\text{AADT}) + \beta_2(\text{Existence of roundabout}) + \varepsilon \qquad (2)$$

The pooled data (89 observations combining traffic light period and roundabout period data) and the sample of 48 roundabout period data are used to run the basic regression. The basic regression is run in linear form (Equation 1) and double-log form (Equation 2) in order to determine the best fitted model for the available regional collision data. The regression coefficients are estimated using Ordinary Least Square (OLS) method.

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[9] Hydén and Várhelyi (2000)
[10] Retting et al (2001)

In the second approach for the estimation of the safety effects of roundabouts, the impact of design features of roundabouts on the number of crashes is investigated. In this approach, only 48 observations from the roundabout period are used. The regression model in the second approach is an extensive form of the basic regression by including the design feature variables such as the number of legs, the number of lanes, duration of operation and the the central island (Equation 3 & Equation 4).

$$\text{Number of Crashes} = \alpha + \beta_1(\text{AADT}) + \beta_2(\#\text{of legs}) + \beta_3(\#\text{of lanes}) + \beta_4(\text{Duration of Operation}) + \beta_5(\text{Central Island}) + \varepsilon \quad (3)$$

$$\log(\text{Number of Crashes}) = \log(\alpha) + \beta_1 \log(\text{AADT}) + \beta_2(\#\text{of legs}) + \beta_3(\#\text{of lanes}) + \beta_4(\text{Duration of Operation}) + \beta_5(\text{Central Island}) + \varepsilon \quad (4)$$

The OLS method is used for the estimation of regression equations 3 and 4. While the basic regression is a benchmark to show the best fitted model, the second regression identifies the effect of all other important design variables on the number of crashes. In the second approach, the number of legs, the number of lanes and the duration of roundabout operation are considered: once with their actual numbers and once with dummy variables to check all possible regression results and pick the best model.

The regression results are used in the proposed roundabout project in Franklin Blvd, Cambridge to estimate the number of crashes if the proposed roundabouts were operational during the period of 2007 to 2010.

At the end, to illustrate the possible benefits or costs of the Franklin Blvd project, the negative externalities of the crashes are monetized to estimate the dollar value for the social benefits or costs.

5. Data:

In this study, the data is collected from three main sources: the Region of Waterloo reports and online sources, transportation staff at the Regional Municipality and onsite observations.

The roundabout projects have been running in the Region of Waterloo since 2004. In 2004, there were only two roundabout installed in the region and the number of roundabouts increased to 17 by November 2011. Since the regional data for AADT and the number of crashes is available until the end of 2010, this study uses data covering the period from 2004 to 2010. The total number of roundabout intersections constructed by the end of 2010 was 15, and the number of observations during this period is 48.

Also, there are 15 proposed roundabouts in the region that are expected to become operative by the end of 2015. Eleven of them are in a stretch of the road along Franklin Blvd, Cambridge. The safety effect of roundabout implementation in these 11 intersections is investigated in this research work. Table 2 summarizes the operative and proposed regional roundabouts in the Region of Waterloo.

Table 2: Summary of operative and proposed roundabouts in the Region of Waterloo

#	Location (Operative)	Introduced at	Location (Proposed)	Proposed Introduction Year
1	Ira Needles Blvd @ Erb St	2004	Hespeler Rd @ Queen St W	2012
2	Can-Amera Pkwy @ Townline Rd	2004	Fountain St @ Maple Grove Rd	2013
3	Ira Needles Blvd @ Highview Dr	2004	Ottawa St @ Homer Watson Blvd	2015
4	Arthur St @ Sawmill Rd	2006	Ottawa St @ Alpine Rd	2015
5	Fountain St @ Blair Rd	2006	Franklin Blvd @ Pinebush Rd	2013-15
6	Can-Amera Pkwy @ Conestoga Blvd	2006	Franklin Blvd @ Sheldon Dr	2013-15
7	Ira Needles Blvd @ University Ave	2007	Franklin Blvd @ Bishop St N	2013-15
8	Ira Needles Blvd @ Victoria St	2007	Franklin Blvd @ Can-Amera Pkwy	2013-15
9	Ira Needles Blvd @ Highland Rd	2007	Franklin Blvd @ Saginaw Pkwy	2013-15
10	Fischer-Hallman Rd @ Seabrook Dr	2007	Franklin Blvd @ Avenue Rd	2013-15
11	Fischer-Hallman Rd @ Huron Rd	2007	Franklin Blvd @ Clyde Rd	2013-15
12	Bridge St @ Lancaster St	2009	Franklin Blvd @ Savage Dr	2013-15
13	Pinebush Rd @ Thompson Dr	2009	Franklin Blvd @ Main St	2013-15
14	Ira Needles Blvd @ Boardwalk Access	2010	Franklin Blvd @ Dundas St	2013-15
15	Fountain St @ Dickie Settlement Rd	2010	Franklin Blvd @ Champlain Blvd	2013-15
16	Fountain St @ Kossuth Rd	2011		
17	Homer Watson Blvd @ Block Line Rd	2011		

Source: Region of Waterloo website (http://www.regionofwaterloo.ca/en/resources/Roundaboutmap.pdf)

Operative roundabouts are divided into brand new and retrofitted roundabouts. The brand new roundabouts are implemented in newly constructed intersections and the retrofitted ones are installed in existing intersections that have been controlled by a traffic light or a stop sign. As seen in Table 3, from 17 operative regional intersections, 9 of them are retrofitted intersections and 8 of them are brand new roundabouts.

Table 3: Brand new and retrofitted roundabouts in the Region of Waterloo

#	Brand New	Retrofitted
1	Ira Needles Blvd @ Erb St	Arthur St @ Sawmill Rd
2	Can-Amera Pkwy @ Townline Rd	Fountain St @ Blair Rd
3	Ira Needles Blvd @ Highview Dr	Bridge St @ Lancaster St
4	Can-Amera Pkwy @ Conestoga Blvd	Fountain St @ Dickie Settlement Rd
5	Ira Needles Blvd @ University Ave	Fountain St @ Kossuth Rd
6	Ira Needles Blvd @ Victoria St	Homer Watson Blvd @ Block Line Rd
7	Ira Needles Blvd @ Highland Rd	Fischer-Hallman Rd @ Seabrook Dr
8	Ira Needles Blvd @ Boardwalk Access	Fischer-Hallman Rd @ Huron Rd
9		Pinebush Rd @ Thompson Dr

The total number of observations before and after the installation of roundabouts is 89. Forty one observations are related to before roundabout installation period (when intersections were controlled by a traffic light or a stop sign) and 48 observations are for after roundabout installation period.

An assumption is made in arranging the dataset. Since all of the roundabout intersections were opened during the last three months of the year except for three of them, the first nine months of a year is assumed as a complete year, and if a roundabout becomes operative in the last three months of a year, the observations are transferred to the following year.

5-1. Variables:

The variables used in the analysis and the descriptive statistics for each variable are described in the following sections.

5-1-1) Number of crashes: It is the dependent variable in the regression equations. To measure the safety effects of roundabout installation, this variable is a good indicator of the safety level of an intersection. The data for the number of crashes is provided by transportation division staff of the Regional Municipality of Waterloo and is available for all new and retrofitted intersections since 2004 to 2010 in the form of per intersection, per year.

5-1-2) Annual Average Daily Traffic (AADT): It is an independent variable in the regression equation. The AADT data is generated by dividing the total volume of traffic in an intersection for a year by the number of days in a year[11]. Since the number of collisions is expected to be a function of traffic flow, this variable is considered in the analysis. The AADT data for the 2004 to 2009 are collected from the transportation division staff. The data

[10] Calculation of AADT is regardless to any factors that impacts daily traffic during a year (e.g. higher traffic due to the accidents during winter)

for 2010 is extracted from the Regional Municipality of Waterloo Traffic Counts report (2010) available in the Region of Waterloo website.

5-1-3) Duration of roundabout operation: It is considered in the regression equation because as time goes by and people become more familiar with the rules and driving behavior at roundabouts, the number of accidents is expected to decrease (learning effect). A dummy variable is used for the duration variable. A value of "1" is used for the first year of roundabout operation and "0" for the following years. As a result, the dummy variable can capture the learning effect in the first year of roundabout operation. To obtain the operation date of the roundabouts, the maps in the Region of Waterloo website and regional documents are used.

5-1-4) Number of legs: The number of legs indicates the number of roads approaching a roundabout (Figure 1). Regional roundabouts have three or four legs as listed in Table 4. A dummy variable is used for the number of legs in the regression equations; value of "1" for 4-leg roundabouts and "0" for other types of roundabouts.

5-1-5) Number of lanes: The number of circling lanes depends on the number of lanes in roads approaching a roundabout (Figure 1). There are 11 two-lane and four single-lane roundabouts in the region as listed in Table 4. A dummy variable is used to show the effect of the number of lanes on the number of crashes; a value of "1" for 2-lane roundabouts and "0" for other types.

Legs and lanes are conflict points at roundabouts and it is expected that the increase in the number of legs and lanes causes more crashes.

5-1-6) Central Island: The structure of central island is one of the characteristics that may affect the number of crashes (Figure 1). The structure of the central island for the regional roundabouts is listed in Table 4. A dummy variable is used to show the effects of central island; a value of "1" for islands with distracting objective in the middle and "0" for clear islands.

The data for the design features of the roundabouts were collected through onsite observations.

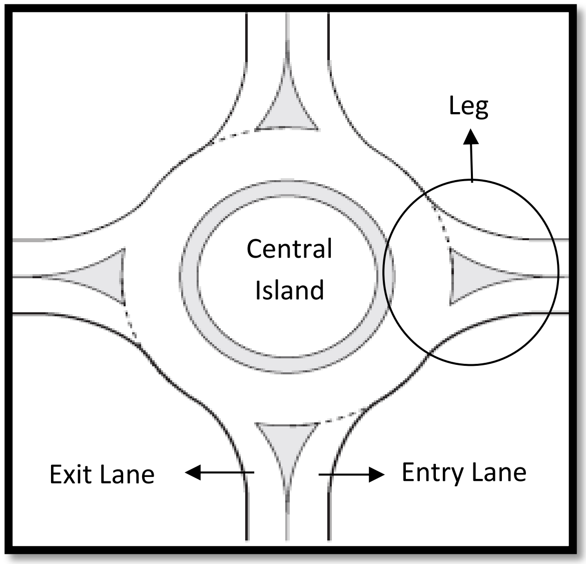
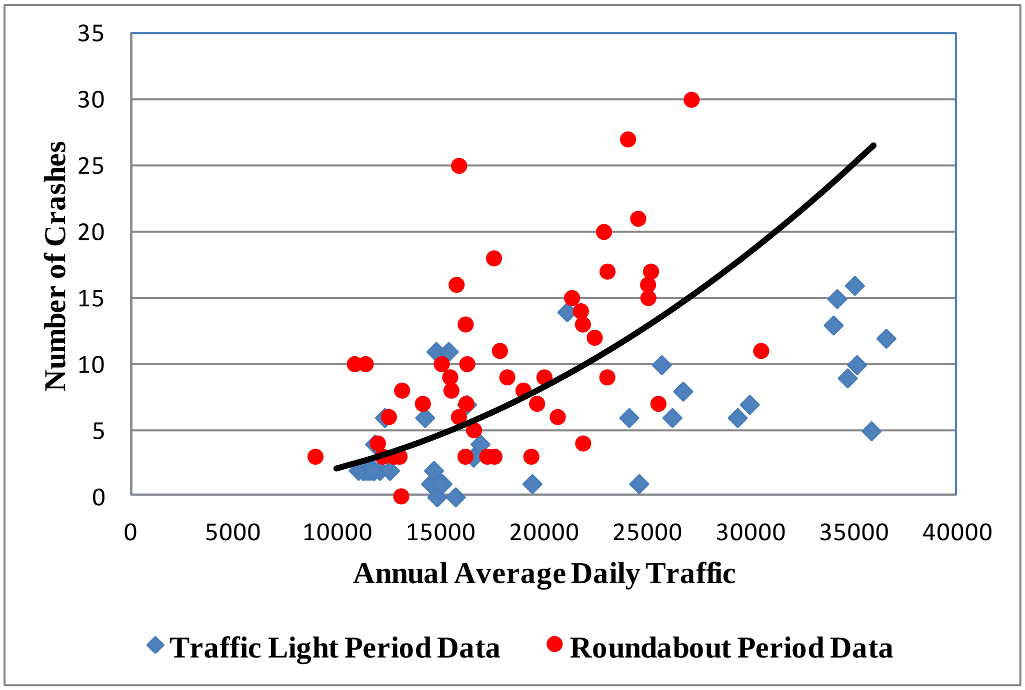


Figure 1: Layout of a roundabout

Table 4: Characteristics of regional roundabouts

Characteristics		Number of Roundabouts	Percentage
Number of legs	3	6	40
	4	9	60
Number of lanes	1	4	26.67
	2	11	73.33
Central island	Distracting object in the middle	10	66.67
	Clear	5	33.33

The scatter plot in Figure 2 shows the correlation between the number of crashes and AADT for all 89 observations before and after roundabout installation. The solid curve indicates the best fitted curve to the 89 observations.



Correlation between number of crashes and AADT in 89 observations is equal to 0.46.

Correlation between number of crashes and AADT in 48 roundabout observations is equal to 0.54.

Figure 2: Correlation between number of crashes and AADT using traffic light and roundabout data for the period of 2004 to 2010

According to this plot, the correlation between the number of crashes and AADT is positive, but the relationship is not strongly linear. This finding is supported by the available literature[12].

The descriptive statistics for the 89 observations (before and after roundabout installation) and 48 observations (after roundabout installation) are summarized in Table 5 and Table 6.

Table 5: Descriptive statistics, 2004-2010 (89 observations[13])

Descriptive statistics	AADT	Number of Crashes
Mean	19061.83	7.98
Median	16559	7
Stdev	6918.58	6.34
Maximum	36563	30
Minimum	8940	0

[12] Retting et al (2001)

[13] 89 observations include 41 observations related to traffic light period data and 48 observations related to roundabout installation period

Table 6: Descriptive statistics for roundabout operation period 2004-2010 (48 observations)

Descriptive statistics	AADT	Number of Crashes	Number of legs	Number of lanes	Duration of installation
mean	18385	10.29	3.625	1.77	2.60
median	17605	9	4	2	2
stdev	4916.35	6.75	0.49	0.42	1.41
max	30543	30	4	2	6
min	8940	0	3	1	1

As seen in Table 5 and Table 6, the average number of crashes is higher in intersections with roundabouts. It should be noted that the average age of regional roundabouts is about 2.5 years. As a result, this study is a short-term analysis of the roundabout operation.

Table 7 shows the correlation between the model variables. The correlation between some of the variables such as the number of legs and lanes or the duration and the number of legs are close to zero which implies that these variables are not correlated. Based on the reviewed literature, a negative correlation between the duration of roundabout operation and number of crashes was expected, but the regional data show a positive correlation. One reason can be the increase in annual average daily traffic in regional intersections which increases the chance of accident. Another reason is the period of analysis. In a short-term period, the number of crashes at roundabouts may increase as it takes time for people to adapt themselves to the driving rules at roundabouts. In long-term periods, the number of crashes is expected to decrease.

Table 7: Correlation matrix for roundabout operation period 2004-2010 (48 observations)

Variables	AADT	# of crashes	# of legs	# of lanes	Duration
AADT	1	0.545	0.340	0.310	0.545
# of crashes	0.545	1	0.349	0.365	0.428
# of legs	0.340	0.349	1	-0.115	0.027
# of lanes	0.310	0.365	-0.115	1	0.201
Duration	0.545	0.428	0.027	0.201	1

6. Results:

6-1. First approach:

The results of linear and double-log regression models obtained by estimating Equations 1 and 2 are presented in Table 8. Both regression models are run using the pooled data (89 observations) and the sample of roundabout data (48 observations).

Table 8: Regression modeling results for the first approach

Variables	(1) Linear (48 roundabout data)	(2) Log/log[a] (48 roundabout data)	(3) Linear (89 pooled[b] data)	(4) Log/log (89 pooled data)	(5) Linear (89 pooled data)	(6) Log/log (89 pooled data)
C	-3.46909 [-1.07399]	-10.34** [-3.46]	-0.04533 [-0.02565]	-10.89** [-4.61]	-3.96189** [-2.33832]	-11.88** [-6.00]
AADT	0.00075** [4.40677]	1.28** [4.18]	0.00042** [4.82736]	1.29** [5.36]	0.00047** [6.10939]	1.35** [6.69]
DV for RB[c]					5.70641** [5.43329]	0.85** [6.14]
R-squared	0.29685	0.28	0.21	0.26	0.41	0.49

- [a] Log/log regression, means taking log from both sides of regression equation
- [b] Pooled data = Traffic light period data (before roundabout implementation) + roundabouts period data (after roundabout implementation)
- [c] DV for RB = Dummy variable for existence of roundabout (roundabout=1, otherwise=0)
- The values in square brackets are t-Statistics
- ** Significant at 5% level

The results clearly show that double-log regression model fits better to the data for both samples. The estimated coefficients of the explanatory variables in the double-log form are all different from zero at 5% and 10% significance levels. The estimated coefficient for AADT is 0.00075 based on the first regression model. This means that if the annual average daily traffic increases by 1000 units, the number of crashes per year will go up by 0.75. According to the mean values for AADT from Table 6, if the average annual number of crashes increases by one unit per roundabout, the AADT will increase by 1346.4 units or 7.3% according to the following calculation:

$$(10.29 + 1) = -3.46909 + (0.00075) \times (\text{AADT}) \Rightarrow \text{AADT} = 19731.4$$

19731.4 – 18383 = 1346.4

For interpreting the coefficients of the second regression, it is important to consider that these values are elasticity as the regression is in double-log form. The estimated coefficient for AADT is 1.28. This means that if the annual average daily traffic grows by 7.3%, the number of crashes will increase by 9.4%. By using 18385 as the mean value for AADT, 7.3% increase in AADT grows the number of crashes by approximately 1 unit according to the following calculation:

$$\text{Change in the number of crashes} = (10.29) \times (9.4\%) = 0.97$$
$$\text{Avedrage number of crashes}: 10.29 + 0.97 = 11.26$$

As a result, the two analysis methods are in close agreement. Since the coefficients in the double-log model are significant at 5% and 10% level, the log model is a better fit. Additionally, since the double-log model has larger t-statistics and the p-values for the estimated coefficients are zero, this is a better fit for the regression model.

The R-squared values in the sample of 48 observations are relatively close in both linear and double-log regressions, but in the analysis of 89 observations the values are larger in the double-log regression model. As a result, the double-log regression estimates the number of crashes better than the linear form.

The positive coefficient of dummy variable for the existence of roundabout is in contrary to the expectations. This means that the roundabout intersections have 85% more crashes per year per intersection than traffic light intersections. This may be attributed to the duration of this study. Since roundabouts are new road structures in the Region of Waterloo, the available data is only related to a short-term study period. According to the literature[14], in short-term period, the number of car/car crashes at roundabout intersections is higher in comparison to traffic light intersections.

6-2. Second approach:

The second approach is the investigation of the impact of the design features of roundabouts on the number of crashes. In this approach, 48 observations during the roundabout operation period are used. Eight regression models are run to take all roundabout design features into account. In each regression model, a new variable is added to monitor the changes in the estimated coefficients. The regression results are listed in Table 9.

[14] Hydén and Várhelyi (2000)

Table 9: Regression modeling results for the second approach

Variables	Regression		Regression		Regression		Regression	
	Linear (7)	Log/log(8)	Linear(9)	Log/log(10)	Linear(11)	Log/log(12)	Linear(13)	Log/log(14)
C	-3.47430 [-1.08757]	-8.76** [-2.91]	-4.71281 [-1.51084]	-5.99** [-2.02]	-4.82547 [-1.38678]	-6.98** [-2.23]	-6.38258* [-1.83284]	-5.60* [-1.75]
AADT	0.00066** [3.70445]	1.09** [3.52]	0.00051** [2.75894]	0.75964** [2.43953]	0.00052** [2.62645]	0.86** [2.62]	0.00040* [2.00555]	0.69** [2.02]
DV for # of Legs [a]	2.55778 [1.42475]	0.34* [1.95]	3.52009* [1.97866]	0.44822** [2.67738]	3.50629* [1.93887]	0.43** [2.52]	4.36243** [2.40229]	0.51** [2.93]
DV for # of Lanes [b]			4.43966** [2.19076]	0.54391** [2.84040]	4.43915** [2.16561]	0.55** [2.85]	4.05477** [2.02453]	0.50** [2.65]
DV for Dur of operation[c]					0.14468 [0.07679]	0.18 [0.98]	0.41406 [0.22542]	0.17 [0.97]
DV for Central Island [d]							4.10830 [1.87593]	0.35 [1.58]
R-squared	0.32720	0.34	0.39337	0.44	0.39345	0.45	0.44034	0.49

- [a] Dummy Variable for number of legs (4 legs =1, otherwise=0)
- [b] Dummy variable for number of lanes (2 lanes =1, otherwise =0)
- [c] Dummy variable for duration of roundabout operation (roundabout =1, otherwise =0)
- The values in brackets are t-Statistics
- [d] DV for Central Island= Dummy variable for central island (there is a distracting objective =1, otherwise =0)
- The values in parentheses are standard errors
- ** Significant at 5% level
- *Significant at 10% level

The regression results indicate that the best fitted model is regression number (10) with dummy variables for the number of legs and the number of lanes as explanatory variables. According to Table 9, since the coefficients of dummy variables for the duration of operation and the central island structure are so small and are not statistically significant, these variables can be ignored in the regression model. The insignificant effect of the duration of operation is attributed to the fact that the average age of the regional roundabouts is 2.5 years and the learning effect is not big enough to affect the number of crashes.

The coefficient of dummy variable for the number of lanes is the most significant coefficient as it has the biggest t-statistics and the lowest p-value. According to this analysis, a 2-lane roundabout has 54% more crashes than a single lane roundabout. Additionally, the effect of the number of lanes on the number of crashes is larger than the effect of number of legs. The results show that the coefficient of 4-leg roundabout is positive and significant at 5% level. Accordingly, the number of crashes in 4-leg roundabout is 44% higher than 3-leg roundabouts.

The results clearly show that the double-log form of the regression equation is a better fit. In regression model (10), the t-statistics for all variables is significant in comparison to other regressions such as regression (14) that has insignificant coefficient for the three variables described above. Moreover, the p-value in regression (10) is close to zero for all variables, and the R-squared is reasonable.

The regression model (10) of this study is in agreement with the models provided in the available literature. According to the literature, the coefficients for AADT, number of lanes, and the number of legs are statistically significant[15]. However, Daniels et al (2010) found a significant negative coefficient for the construction year of roundabout which means lower number of crashes at newly constructed roundabouts.

7. Franklin Blvd Project:

The Regional Municipality of Waterloo has a proposed project to install 11 roundabouts in the stretch of Franklin Blvd, in Cambridge. The social cost related to the roundabout installations will be investigated in the next section.

In this section, the number of crashes for each proposed roundabout intersection is predicted using the regression models (6) and (10) in the previous sections (Table 8 and Table 9). The prediction is based on the assumption that roundabouts with the same number of legs and lanes as the traffic light intersections were operative from 2007 to 2010. The actual number of crashes for the Franklin

[15] Daniels et al (2010), Šenk and Ambros (2011)

intersections is available from 2007 to 2010. The predicted number of crashes for the same period will be compared to the actual numbers to investigate the safety effect of roundabout installation.

Table 10 shows the predicted number of crashes using the regression model (6). This regression model has a dummy variable to control the existence of roundabout by keeping AADT constant. According to the results of this study, five of the intersections have higher and the rest have lower number of predicted crashes. The correlation between the predicted number of crashes and average AADT is equal to 0.99 which is a strong positive linear relationship.

Table 10: Predicted number of crashes from 2007 to 2010 for 11 Franklin Blvd intersections using the coefficients of regression (6)

Observations	Average AADT 2007-2010	Average of annual number of crashes 2007-2010	Predicted Number of crashes 2007-2010
Franklin Blvd @ Pinebush Rd	46885.5	20.25	14.27
Franklin Blvd @ Sheldon Dr	37619	6.75	10.83
Franklin Blvd @ Bishop St N	35889.75	7	10.22
Franklin Blvd @ Saginaw Pkwy	45502.25	21.75	13.74
Franklin Blvd @ Avenue Rd	38103.75	8.5	11
Franklin Blvd @ Clyde Rd	31745.25	11.75	8.79
Franklin Blvd @ Savage Dr	27644.25	3.25	7.44
Franklin Blvd @ Main St	31689	11.75	8.77
Franklin Blvd @ Dundas St	31399.5	12.75	8.67
Franklin Blvd @ Champlain Blvd	16625.5	3.25	4.18
Franklin Blvd @ Can-Amera Pkwy	44744	28.5	13.45

Table 11 shows the predicted number of the crashes using the regression model (10). This prediction is more accurate since the regression model (10) has more control variables to capture the effects of roundabout design features.

Table 11: Predicted number of crashes from 2007 to 2010 for 10 Franklin Blvd intersections using the coefficients of regression (10)

Observations	Average AADT 2007-2010	Average of annual number of crashes 2007-2010	Predicted Number of crashes 2007-2010
Franklin Blvd @ Pinebush Rd	46885.5	20.25	23.90
Franklin Blvd @ Sheldon Dr	37619	6.75	20.22
Franklin Blvd @ Bishop St N	35889.75	7	19.51
Franklin Blvd @ Saginaw Pkwy	45502.25	21.75	23.37
Franklin Blvd @ Avenue Rd	38103.75	8.5	20.42
Franklin Blvd @ Clyde Rd	31745.25	11.75	17.77
Franklin Blvd @ Savage Dr	27644.25	3.25	10.22
Franklin Blvd @ Main St	31689	11.75	17.75
Franklin Blvd @ Dundas St	31399.5	12.75	17.63
Franklin Blvd @ Champlain Blvd	16625.5	3.25	10.87

There are 10 intersections in Table 11. The reason is that the dummy variable for the number of lanes in regression (10) is assigned to “1” for 2-lane roundabouts and “0” otherwise. This results in the removal of the 3-lane roundabout at the intersection of Franklin Blvd at Can-Amera Pkwy intersection. According to this table, the predicted number of crashes in comparison to the actual number of crashes is higher for all 10 intersections. This result is consistent with the regression model (6) in Table 8 which indicates 85% more crashes for roundabout intersections. Overall, the results show that the number of legs and lanes has a significant effect on the number of crashes.

8. Social Cost of Franklin Blvd Project:

According to the recent report published by Transportation and Environmental Services of the region of Waterloo[16], roundabouts have not had fatal injury collisions. These intersections have lower non-fatal injury crashes than traffic light intersections. The number of non-severe injury collisions such as Property Damage Only (PDO) and non-reportable collisions at roundabouts are higher than traffic light intersections (Table 12).

[16] 2010 collision report on roundabouts in the Region of Waterloo, Report: E-12-014, January 31, 2012

Table 12: Percentage of collision types at roundabouts and traffic lights

Collision Types	Roundabouts	Traffic Signals
Fatal Collisions	0%	0.09%
Non-fatal Injury Collisions	9%	27%
Property Damage Collisions	47%	40%
Non-reportable Collisions	44%	33%

To predict the social cost of roundabout installation, the average value of social cost for each crash type is obtained from the Transport Canada report (2007)[17]. The percentage of each crash type in all 10 Franklin intersections is calculated using Table 12, and the results are available in Table A1 in the appendix. According to the Transport Canada report, the average social cost of a fatal collision is $15.7 million in 2004. The average social cost of an injury collision was $82,000 and a PDO collision was $8,000 in 2004. Since these values are from 2004, the average inflation rate from 2007 to 2010 is considered to adjust the costs. The inflation rate in 2004 was %1.8 and the average inflation rate from 2007 to 2010 was %1.7[18]. The social cost estimation of accident at roundabout and traffic light intersections is presented in Table 13.

[17] Analysis and Estimation of the Social Cost of Motor Vehicle Collisions in Ontario, N0779, Aug 2007
[18] The inflation rates were taken from Statistics Canada: http://www.statcan.gc.ca/pub/11-621-m/2010084/t003-eng.htm

Table 13: Average social cost of crashes ($ Thousand) for the period of 2007-2010

Franklin Blvd @	Roundabouts			Traffic lights		
	Fatal collisions	Non-fatal injury	PDO collisions	Fatal collisions	Non-fatal injury	PDO collisions
Pinebush Rd	0	149.45	76.14	286.13	448.34	64.80
Sheldon Dr	0	49.82	25.38	95.38	149.45	21.60
Bishop St N	0	51.66	26.32	98.91	154.98	22.40
Saginaw Pkwy	0	160.52	81.78	307.33	481.55	69.60
Avenue Rd	0	62.73	31.96	120.11	188.19	27.20
Clyde Rd	0	86.72	44.18	166.03	260.15	37.60
Savage Dr	0	23.99	12.22	45.92	71.96	10.40
Main St	0	86.72	44.18	166.03	260.15	37.60
Dundas St	0	94.10	47.94	180.16	282.29	40.80
Champlain Blvd	0	23.99	12.22	45.92	71.96	10.40
Sum of each type	***0***	***789.66***	***402.32***	***1511.91***	***2368.98***	***342.40***
TOTAL	**$ 1191.98**			**$ 4223.29**		

The average social cost for non-reportable collisions is not available at Transport Canada report.

This analysis is a crude estimate because the values for social cost in the Transport Canada report were estimated using the Willingness-to-Pay (WTP) method[19]. Since, in this method, there is no obligation for people to buy a product or a service, they may overstate the cost regardless of their budget.

Another way to estimate the social cost of collisions is to estimate each component of social cost separately. The cost of time delay, extra fuel and extra emission (externality costs associated with collisions) due to an accident should be estimated and added to the cost of life loss, injury and hospitalization and property damage. Since the cost of life loss, injury and property damage is not available[20], only the estimation of the social cost for time delay, extra fuel and extra emission will be conducted in this study.

[19] The maximum amount of money that a person is willing to pay to have a product or service
[20] The “social” costs mentioned above for fatal, injury and PDO collisions include the value of time delay, extra fuel and extra emission.

In this study, the social cost of collisions in the Franklin Blvd @ Saginaw Pkwy intersection with highest number of crashes is estimated. The estimation is based on the data in Table A2 in the appendix and price adjustment for the period of 2007 to 2010. The estimation of social cost is as follows:

There is a consensus in the literature showing that the time delay in a roundabout accident is lower than a similar accident in a traffic light intersection. Assume that the average time delay for an accident at roundabout intersections in the Region of Waterloo is 15 minutes and the average time delay for an accident in traffic light intersections is about 25 minutes. The average AADT in the selected intersection (Franklin Blvd @ Saginaw Pkwy) is 45502.25 per day which means that the average AADT is equivalent to 474 vehicles in 15 minutes and 790 vehicles in 25 minutes.

- **Time Cost:** By assuming that the average number of passengers in each vehicle is 1.5 (based on Table A2 in the appendix), the total time delay is 178 hours for a crash at roundabout (15 min) and 494 hours for a crash in traffic light intersection (25 min). According to Statistics Canada, the average hourly wage in Ontario from 2007 to 2010 is $20.31. As a result, the value of time delay is $3615.18 and $10033.14 at roundabout and traffic light accidents, respectively.
- **Fuel Cost:** The fuel cost is divided into two categories: 1. fuel cost during idling time in traffic and 2. fuel cost for the extra time to drive to destination. The fuel usage per vehicle per idling hour is 2.25 liters and the fuel usage per extra hour driving to destination is 5.5 liters. Assume that 15 minutes more time is needed for each vehicle to drive to destination. The total fuel used in 15 minutes is 914.82 liters and in 25 minutes is 1817 liters. After adjusting the fuel price for the period of 2007-2010, the value of extra fuel usage in roundabout crashes is $905.67 and in traffic light crashes is $1798.83.
- **Emission Cost:** The emission for 15 minutes idling time for 474 vehicles in a roundabout crashe is 58065 kg and the emission for 25 minutes for 790 vehicles in a traffic light crash is 161318 kg[21]. If 15 minutes extra time for driving to destination is needed, the extra emission for driving is 21756.6 kg for 474 vehicles and 36261 for 790 vehicles. Considering the price for each ton of emission ($70 according to Table A2), the cost of extra emission is $5587.51 for 474 vehicles and $13830.53 for 790 vehicles.

As a result, the total cost of negative externalities (time delay, extra fuel and extra emission) for a crash at roundabout is $10108.4 and for a crash in traffic light is $25662.5. This method also shows that roundabout intersections have lower social cost compared to traffic light intersections.

[21] It is assumed that the average speed in regional road is 75 km/h.

9. Conclusion:

This report investigated the safety effects of roundabouts using the Region of Waterloo data. The safety effects were mainly described by the number and severity of crashes. Regression modeling using Ordinary Least Square estimation method was used for this analysis. The regression modeling incorporated several variables including the annual average daily traffic, duration of operation, and the design features of roundabouts (i.e., number of lanes, number of legs, and central island structure). By running several linear and double-log regression models in E-Views, it was found that the best fitted model was the double-log regression.

The basic regression models run on samples from before and after roundabout installation indicated that the existence of roundabout in an intersection causes 85% more crashes. The reason may be explained by considering the operational time period of the roundabouts which has also been supported by the literature. Roundabouts in the short run experience more crashes with less severity[22]. This is also the case for the Region of Waterloo where the roundabout implementation was started in 2004 .

It was also concluded that among the design features of the roundabouts, the number of lanes and legs have the largest effects. Additionally, the study showed statistically significant results for 2-lane and 4-leg roundabouts at 5% significance level. This is attributed to the fact that the number of conflict points at multi-lane and 4-leg roundabouts is higher than single lane and 3-leg roundabouts.

In this research paper, the results of the regression models were used for the prediction of the number of crashes in a proposed roundabout project in Franklin, Blvd in Cambridge for the period of 2007 to 2010. The prediction results show higher number of crashes for all intersections if the roundabouts were operative from 2007 to 2010. To obtain the estimate of social costs of the implementation of roundabouts, an intersection with the highest number of crashes was selected and the associated negative externalities were monetized. The results showed a decrease of $15554.1 in the social cost as a result of roundabout installation.

This study can be expanded by including other variables in the analysis such as the geometry of roundabouts (e.g., inner and outer diameter), diversity in traffic characteristics of each roundabout, the location of roundabout and the width of traversable apron. Overall, it is recommended that these roundabouts are analyzed in the long run to investigate the long-term safety effects of these structures.

[22] Hydén and Várhelyi (2000)

Appendix:

Table A1: Number of each type of collisions at 10 Franklin Blvd intersections

Observations	Fatal Collisions		Non-fatal Injury Collisions		Property Damage Collisions		Non-reportable Collisions	
	RB[a]	TL[b]	RB	TL	RB	TL	RB	TL
Franklin Blvd @ Pinebush Rd	0	0.02	1.82	5.47	9.52	8.10	8.91	6.68
Franklin Blvd @ Sheldon Dr	0	0.01	0.61	1.82	3.17	2.70	2.97	2.23
Franklin Blvd @ Bishop St N	0	0.01	0.63	1.89	3.29	2.80	3.08	2.31
Franklin Blvd @ Saginaw Pkwy	0	0.02	1.96	5.87	10.22	8.70	9.57	7.18
Franklin Blvd @ Avenue Rd	0	0.01	0.77	2.30	4.00	3.40	3.74	2.81
Franklin Blvd @ Clyde Rd	0	0.01	1.06	3.17	5.52	4.70	5.17	3.88
Franklin Blvd @ Savage Dr	0	0.00	0.29	0.88	1.53	1.30	1.43	1.07
Franklin Blvd @ Main St	0	0.01	1.06	3.17	5.52	4.70	5.17	3.88
Franklin Blvd @ Dundas St	0	0.01	1.15	3.44	5.99	5.10	5.61	4.21
Franklin Blvd @ Champlain Blvd	0	0.00	0.29	0.88	1.53	1.30	1.43	1.07

- [a] Roundabout
- [b] Traffic light

Table A2: Criteria for estimating the social cost

VARIABLE	DATA
Lost Time	
W-wage or value of time	$20.60 per hour-average of upper and lower bound estimates.
Occupants	1.5 per vehicle (includes all types of vehicles)
Vehicles affected (traffic volume)	24-hour traffic distribution data. Volumes were adjusted to reflect varying degrees of road closure from full to partial as described in COMPASS incident reports.
Additional Fuel Use	
Additional fuel use	2.25 litres per idling hour plus 5.5 litres per hour for additional driving time.
Fuel price	$0.766 per litre —Ontario price in 2004.
Additional Emission	
CO_2 emission	245 kg per 100 kilometers—double when idling.
[CO_2+CAC]$	$70 per CO_2 tonne- average of upper and lower bound estimates.

Note: The data are for 2004 per vehicle and/or per person

Source: The table has been rewritten from Transport Canada report: Analysis and Estimation of the Social Cost of Motor Vehicle Collisions in Ontario, N0779, Aug 2007.

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