Development of Usage Guidelines for Speed Display Units in School Zones

by

Kaitlin E. Hazzard

BScE, University of New Brunswick, 2014

A Thesis Submitted in Partial Fulfillment
of the Requirements for the Degree of

Master of Science in Engineering

in the Graduate Academic Unit of Civil Engineering

Supervisor: Eric D. Hildebrand, PhD, PEng, Department of Civil Engineering

Examining Board: James S. Christie, PhD, PEng, Department of Civil Engineering
Frank R. Wilson, PhD, PEng, Professor Emeritus
Guida Bendrich, PhD, PEng, Department of Chemical Engineering

This thesis is accepted by the Dean of Graduate Studies

THE UNIVERSITY OF NEW BRUNSWICK

May, 2016

Abstract

Road authorities are under increasing pressure from parents and the public to install speed display signs in school zones as a perceived means to improve safety for students. While isolated studies have shown that many of these supplemental countermeasures yield quantifiable changes in driver behaviour, little empirical evidence exists regarding collision experience within designated school zones to quantify whether a problem actually exists. This research analyzed collision history data for delineated school zones/areas from a sample of urban and rural locations in New Brunswick with the goal of developing usage guidelines for speed displays that can assist municipalities to make an objective decision regarding the implementation of this countermeasure.

Results from the collision analysis showed that only 21% of urban and 29% of rural schools are performing statistically worse than the group as a whole. Comparison of yearly collisions found only 2% of schools experienced statistically more collisions than a comparable road without a school. Results indicate that schools in both urban and rural locations are performing better than expected. A collision prediction model was developed using a Zero-Inflated Negative Binomial regression that relates collision data to explanatory school zone/area characteristics. Variables found to have the most significant effect on collisions within school zones/areas include road volume, presence of a signalized intersection, number of unsignalized intersections present, and number of through lanes. The resulting model subsequently provides a warrant system designed to evaluate whether a specific school site would justify the installation of a speed display unit that is based on contributing variables to school zone collisions.

Acknowledgements

I would like to acknowledge the following for their support and contributions to this research:

- Dr. Eric Hildebrand for his continuous support and guidance through the duration of both my undergraduate and graduate studies. Thank you for the encouragement to take on this study and the confidence you instilled in me.
- Dr. Jim Christie for his guidance with the statistical aspects of my research.
- Elaine Schifke, Jody Watson, and Jonathan Lewis with the City of Fredericton Traffic Branch for providing me with required traffic data for Fredericton.
- Stephane Thibodeau with the City of Moncton for providing me with full access to traffic data for Moncton.
- Tim O'Reilly with the City of Saint John and Angela Totten with the Saint John Police Department for providing me with required traffic data for Saint John.
- New Brunswick Department of Transportation and Infrastructure for providing me with traffic volumes for provincial roadways.
- Chris Hazzard for his help with the programming aspects of my research.
- Florence Allaire and Carly MacEacheron for their help collecting speed data used in this research.
- NSERC for helping to fund this research
- Friends and family, particularly my husband, for supporting and encouraging me throughout my graduate studies.

Table of Contents

List of Tables

List of Figures

List of Abbreviations and Acronyms

AADT	Average Annual Daily Traffic
ADT	Average Daily Traffic
CMF	Collision Modification Factor
FHWA	Federal Highway Administration
HSM	Highway Safety Manual
MUTCD	Manual on Uniform Traffic Control Devices
NBDTI	New Brunswick Department of Transportation and Infrastructure
NCHRP	National Cooperative Highway Research Program
PFI	Potential For Improvement
SPF	Safety Performance Function
TAC	Transportation Association of Canada
WTP	Willingness-to-Pay

1 Introduction

Improving safety within school zones is a high priority for many jurisdictions given the higher volume of child pedestrians and cyclists who are particularly vulnerable due to their lack of experience with traffic. Improving safety in school zones could also encourage children to use active transportation modes (walking, cycling, etc.) to school because parents/guardians are more likely to allow their children to participate in these activities when road conditions are safer. This would lead to more active children as well as fewer vehicles on the road, creating healthier and more sustainable communities (D'Amours Ouellet & Cloutier 2014). A more fundamental question for road authorities to address when dealing with the issue of school zones, however, is whether or not safety is a real or perceived concern. There is a lack of evidence regarding collision experience within designated school zones to quantify whether a problem actually exists.

Parents and guardians of school-aged children who hold a misguided belief that school zones are "unsafe" are often the source of pressure on school representatives and roadway authorities to improve school zone safety. In response, many road authorities have implemented costly countermeasures such as radar speed display boards and flashing beacons under the premise that safety will be improved. These measures are being taken to make school zones "safer" in the absence of empirical evidence that supports the assumption that school zones are, in fact, problematic. Many of the countermeasures have been shown through research to have significant impacts on driver behaviour that could contribute to safety outcomes; however, there is little evidence of their ability to reduce collision frequencies.

The first phase of this research strives to quantify existing safety performance of school zones by analyzing collision experiences within delineated school zones and areas in the province of New Brunswick. The second phase involves identifying adjacent road characteristics that were found to be contributing factors to schools with abnormally high collision frequencies. Understanding which factors are contributing to making a school zone less safe could be helpful when implementing safety improvement strategies to protect both drivers and pedestrians of all ages.

Roads adjacent to schools are typically designated as either school "areas" or school "zones". The Transportation Association of Canada (TAC) defines a school *area* as "a section of roadway adjacent to a school that is denoted by school area signage only". A school *zone* is defined as "a section of roadway adjacent to a school that is denoted by school area signage and a reduced speed limit sign" (TAC 2006). The difference in classification is a result of specific characteristics supposedly contributing to the safety performance of the school location and adjacent roadway. Proper establishment of roads adjacent to a school should be the first step when addressing safety in school zones. This should be done by following a consistent procedure to ensure establishment of roads adjacent to a school is done so in a non-arbitrary manner so that the effectiveness of school area and zone signage is not compromised. It is unclear whether or not consistent establishment has a significant effect on the overall performance of a school zone or area. This uncertainty is addressed in this research.

Speed reduction is one major aspect with respect to driver behaviour that is believed to improve safety within school zones. According to a recent study written by Schroeder *et* *al.* (2013) for the National Highway Traffic Safety Administration, nearly one third of all fatal traffic accidents in the United States are a result of speeding. The survivability of pedestrians increases significantly (by a factor of about 2.5) when vehicle-to-pedestrian collisions occur at a speed of approximately 30 km/h compared to 50 km/h. One method currently used as a countermeasure to high vehicular speeds throughout school zones are radar speed display devices. They are installed at both ends of a school zone and warn motorists of their oncoming speed in an attempt to encourage them to comply with the speed limit throughout the zone (traditionally lowered to 30 km/h in Canada). These display boards have been proven to be an effective technique for speed reduction, however, little research has been done to determine whether a school zone would require the use of this measure or not, as well as the effects of over-use of radar speed display boards as a speed reduction technique in school zones. Research in this area would be the final phase to this school zone study.

Research on this uncertainty is important to execute before future display board installation at every school zone occurs to determine if there is a decrease in effectiveness as more display boards are added to a network. This research will help guide authorities on the appropriate usage level of display boards that should be installed throughout a municipality to maximize their effectiveness. From this, a usage guidelines or a warrant system, similar to that used for the installation of traffic signals, would likely be justified. Municipalities would benefit from such a warrant so that implementing display boards in school zones would be a well-reasoned, objective procedure rather than an arbitrary or reactionary one.

1.1 Problem Statement and Hypotheses

The main focus of this study was to address a premise that an over proliferation and ungoverned use of radar speed display boards at the thresholds of school zones would decrease their effectiveness. It was hypothesized that if there is an increase in the number of radar speed display boards deployed, then the effectiveness of the display boards will decrease and a warrant system would be justified. The impact of the boards on drivers' speeds in school zones may decrease if they become accustomed to too many throughout a network. An extension of this problem is to develop a set of guidelines for speed display board usage in school zones to ensure they are being used efficiently.

A sub-problem of this study is to explore the linkages between vulnerable users, motor vehicle collisions, and school zones/areas. It is hypothesized that if a school zone/area has less safe characteristics, then it will increase the collision frequency involving child pedestrians in that school zone/area. It was important to understand which characteristics are explanatory for underperforming zones/areas as these would form the basis of the warrant system for radar speed display boards.

The final sub-problem that will be addressed as part of this study is to determine if a Canadian guideline for establishing school zones/areas (such as the document produced by TAC) is consistently used in New Brunswick. It is hypothesized that there is no consistent process used and that school zones/areas are established and signed arbitrarily, and if New Brunswick municipalities do not use a consistent guideline when establishing school zones, then the effectiveness of school zone/area signage will be compromised. This is an important area of research because consistently establishing school zones/areas should be the first step to maximizing safety within school zones/areas, which can be done using a guideline such as the one designed by TAC.

1.2 Research Goals and Objectives

The primary goal of this research was to develop a warrant system (or set of guiding principles) for supplemental safety measures in school zones.

The specific objectives of this study that were required to meet the overall goal include:

1. To examine compliance of school zone delineation/marking with current guidelines
2. To develop collision histories at school zones or areas
3. To relate collision performance to school site characteristics
4. To incorporate site characteristics into a warrant system/guidelines for radar speed display boards

1.3 Expected Outcomes

This research will help road authorities identify potentially problematic locations that might require higher levels of countermeasures to offset any safety concerns. There is currently no objective guidelines used for deciding the best locations for deployment of the speed display boards in a jurisdiction. The warrant resulting from this study has the ability to provide guidance to jurisdictions to ensure that display boards are not arbitrarily placed at every (or most) school zones. By having this warrant system available it ensures that resources are being used efficiently. This warrant system has been designed to be universally applied so that municipalities anywhere can employ it, if they so choose.

Another expected outcome of this research is to bring awareness to New Brunswick municipalities on how to properly establish school zones. There are no formal guidelines used in the province to establish a school zone, area, or neither. By consistently establishing schools, including proper signage to maximize safety, other, more expensive safety measures may not be necessary. This could potentially save the province money in the long term because the extensive measures taken to make school zones safer may not be necessary, or may have an easier and cheaper solution.

1.4 Scope

The focus of this research was on the analysis of public schools in both rural and urban locations within the province of New Brunswick. A sample of schools was selected for both urban and rural locations that were assumed to be representative of all schools. Selected schools within the province were evaluated based on collision histories. The province’s collision history databased consists of only collisions with police involvement. Collisions that warrant being recorded in New Brunswick include those that resulted in a property damage amount greater than $1000 or yielded an injury or fatality. For this study, the province’s collision history database was assumed to be representative of all collisions that have occurred within the province.

2 Literature Review

A literature review was conducted to address four main issues related to the current study: background on motorists' speed behaviour and effectiveness of countermeasures through school zones, the linkage between schools and collisions, guidelines for establishing school zones/areas, and existing warrants for the use of radar speed display boards or other countermeasures used in school zones.

2.1 Background

A school zone, as described in the previous section, is associated with a reduction in the posted speed limit. Part of the motivation behind the current research is the issue relating to driver compliance to lowered speed limits through school zones. To provide background for the rest of the study it is important to understand whether or not there is an issue with driver compliance to lowered speed limits through a school zone, what factors increase the likeliness of speeding, as well as the effectiveness of commonly used engineered countermeasures for encouraging driver compliance.

2.1.1 Motorist Behaviour through School Zones

School zones include reduced speed limits as an attempt to increase safety. There is a concern, however, that drivers are continuing to travel at inappropriate speeds throughout a school zone despite the lowered posted speed limit. Many studies have been performed to assess the behaviours of motorists throughout school zones.

A number of speed evaluation studies were performed by Lazic (2003) to contrast results at different school locations with varying characteristics in Saskatoon, Canada. All schools evaluated had recently introduced reduced speed zones of 30 km/h during school operating hours. Major findings included a reduction in mean speeds at all locations by an average of 10 km/h where a reduced speed limit was implemented. Alternatively, there were no significant changes in motorists' speeds outside of school operating hours when the reduced speed limit was not in effect. This suggests that school zones have no effect on drivers' behaviours outside of school hours. A notable finding was that although speed reductions were present, the majority of motorists' speeds still exceeded the 30 km/h limit, with the highest percent of motorists travelling between 30 km/h and 40 km/h (approximately 50%). Further analysis concluded that more significant speed reductions were achieved throughout school zones located on arterial roads versus local streets. The author stated that this finding could be a result of motorists on local streets already having a heightened awareness of pedestrian and non-motorized vehicle activity and are therefore already travelling at lower speeds to begin with.

A study by Kattan *et al.*(2011) evaluated driver compliance to lowered speed limits throughout school zones at a sample of school locations in Alberta, Canada. Playground zones were also evaluated as part of this study, however, the focus for purposes of the current research will be on school zone results only. Speed surveys were performed at 11 different schools with reduced speed limits of 30 km/h – effective during school operating hours – at non-peak hours of a school day only. Results from the before-and-after study showed a statistically significant reduction in average speeds when the posted limit was reduced from 50 km/h to 30 km/h; however, authors noted that approximately 55% of motorists were still exceeding the 30 km/h speed limit. The authors identified different characteristics of a school zone associated with those with higher speeds. ANOVA testing was done for each school within the study sample to determine which of the characteristics identified were statistically affecting motorists' speeds. The major finding was that a higher compliance to a lowered speed limit throughout a school zone occurred for those locations with at least one of the following characteristics: two lane road, fencing present, traffic control devices present, children present, and/or zones that were longer than 200 metres.

A number of studies recognize that speeding within school zones is often not a deliberate action taken by motorists. A study by Hawkins (2007) on evaluating speeding in school zones concluded that the presence of a signalized or stop-controlled intersection may result in lower driver compliance to a reduced speed limit within a school zone. This is due to motorists forgetting about the reduced speed limit when accelerating after having been stopped at the intersection present within the zone. An excessively long school zone can have a similar effect on motorists. The author identified driver distraction within school zones to be another cause of diversion from maintaining a lower speed within a school zone. The author states that the increase in traffic, both motor vehicle and pedestrian (particularly children), as well as an increase in more diverse traffic movements that are often generated from school zones during school hours are a cause of driver distraction through the zone.

Driver noncompliance to lowered speed limits was identified as a genuine issue in a study by Gregory *et al.* (2014), however, similar to findings by Hawkins (2007), the authors' state that inappropriate speeds may not be a conscious decision by drivers and may be influenced by road infrastructure and environment. One observation made was that a major contributing factor to motorists failing to comply with a lowered speed limit throughout a school zone is the presence of a signalized intersection within the zone again, similar to Hawkins. A sample of schools both with and without intersections present within the school zone were examined with respect to speeds. It was found that motorists had higher speeds when interrupted by signalized intersections compared to before the intersection as well as those who were uninterrupted. The authors proposed that the interruption in the school zone can cause motorists to forget to drive at the lowered speed limit when they resume driving after the intersection. Further analysis showed that school zones with a flashing speed display unit following the signalized intersection to serve as a reminder of the lowered speed limit resulted in a higher compliance to the speed limit by motorists as opposed to those without such a countermeasure. Both findings for difference in speeds were concluded at a 95% confidence level.

Findings from these studies may be relatable to the current study as it may suggest that school zones that include characteristics identified in the literature relating to lower compliance to reduced speed limits may benefit most from the use of radar speed display units or other safety countermeasures.

2.1.2 Effectiveness of Safety Countermeasures

The use of countermeasures to address the issue of driver compliance to reduced speed limits in school zones has been a well-studied area of research. The different techniques that were reviewed as part of this study are flashing beacons and radar speed display boards, as these methods are commonly used in New Brunswick, Canada.

Flashing beacons are one method used in schools zones to draw attention to a reduced speed limit. There are two different placement options, front-facing or rear-facing, which both have different benefits to motorists. Front-facing beacons are placed in conjunction with a reduced speed limit facing the traffic entering the zone. The benefit of this is to draw attention to motorists entering the zone and warn them of a change in speed limit. The main drawback is that it can be short-lived as motorists only receive the cue at the beginning of the zone. Rear-facing beacons are placed at the end of the school zone and are facing the traffic travelling within the zone as opposed to facing traffic as they enter the zone. The two main benefits of the difference in placement is that rear-facing beacons indicate to drivers where the end of the school zone is, as well as provide a visual cue that they are in a school zone as they travel through it – addressing the problem of benefits being short-lived with front-facing beacons (Hawkins 2007).

The study previously discussed by Hawkins (2007) evaluated the use of rear-facing beacons in school zones as a technique for visually reminding drivers of the lowered speed limit. Four school zones with different characteristics in Texas were used in the study. A flashing beacon was posted in conjunction with an “End School Zone” sign at both ends of the zones that faced traffic travelling through the zone. The school zones already had front-facing beacons installed for traffic entering the zone. Speed data were collected for vehicles midway through the zone at different times of day (peak and non-peak periods for morning and afternoon times when the school zones were active) both before and an unspecified period of time after the beacons were in operation. Results showed a statistically significant difference between before and after mean speeds (a reduction of approximately 10%) at all sites that contained an intersection (of any type) or had excessive length, but not at a “typical school zone” (i.e. no intersection and normal length). Results indicated that rear-facing beacons would benefit school zones where drivers are more likely to forget about the reduced speed limit part way through.

Front-facing beacons were installed at a number of schools in North Carolina to heighten the awareness of motorists to a reduced speed limit. Simpson (2008) performed a study to evaluate the effectiveness of the flashing beacons at 15 of the state’s school zones, with varying characteristics, that had the beacons in operation for a minimum of three years. Speed data were collected at the 15 treated sites and compared to data collected at 15 untreated school zones, or those without flashing beacons. Results showed only a small decrease in average speeds and a similar speed distribution between flasher and non-flasher locations, both with poor compliance to a lowered speed limit. The author concluded that overall, front-facing beacons had little effectiveness at encouraging driver compliance to a lowered speed limit throughout a school zone. The author noted, however, that speeds did decrease during school hours compared to non-school hours at all sites, treated or not, indicating that motorists are making an effort to reduce their speeds through school zones regardless of the presence of flashing beacons.

Speed display units are a popular countermeasure to encourage driver compliance in speed transition zones. School zones are one area shown in many studies to benefit from speed display boards. The North Carolina Department of Transportation (DOT) performed a study in 2012 with the Eastern Carolina Injury Prevention Program (ECIPP) that evaluated the effects of speed display signs (“Your Speed” signs) to encourage driver compliance to lowered school zone speed limits. The units were active during morning and peak periods of a school day. Front-facing flashing beacons were installed in conjunction with the speed signs to indicate to motorists when the reduced speed limit was in effect. Speed data were collected before installation of the units and up to a 12-month period after. Results from the before and after study showed a significant reduction in speeds during school hours of up to 4.5 mph compared to before the display signs were installed. It was concluded that “Your Speed” signs are an effective measure to achieve sustained significant speed reductions through school zones.

Similar results were found in the study by Kattan *et al.* who examined the effectiveness of speed display units through school and playground zones in Alberta, Canada. Results from this study indicate that speed display boards had a statistically significant effect on reducing the average speed of motorists. The use of radar speed display boards was recommended as an effective countermeasure throughout school zones where a reduction in speeds is desired.

Previous research by the University of New Brunswick Transportation Group performed a study that evaluated the long-term effectiveness of radar speed display units used as a safety countermeasure throughout school zones (Hildebrand *et al*. 2014). The study used before and after speed data up to four years after the display boards had been in operation. The units work by displaying oncoming motorists’ speeds in conjunction with the lowered speed limit in an attempt to encourage speed limit compliance. Findings show quantifiable reductions in average speeds throughout the zones as a result of this countermeasure even in the long-term. The study recommended that further research be done to determine the optimum number of radar speed display boards to use within a network to maximize their effectiveness. The concern is that the effectiveness of the display units may be compromised if drivers become accustomed to too many installations throughout a municipality. This provided motivation for the current research.

2.2 Schools and Collision Experience

The preliminary question for transportation engineers to ask when dealing with the issue of school zones is whether or not there is a need for improving safety risk. It has been determined that speeding is a genuine concern; however, it is unclear whether collision frequency is an issue. Counter-measures including speed display units and flashing beacons have been implemented to presumably create safer school zones when these precautions, in fact, may not be necessary.

According to a study performed by Schwebel, *et al.* (2011) children are at greater risk of being injured as a result of traffic collisions because they have not yet developed the motor tasks required to handle traffic and that risk increases near schools because of higher exposure rates. Their primary recommendation for ensuring children pedestrian safety is to provide children with traffic safety education. This only works to some extent because of a child's natural development – they state that children under the age of nine simply cannot gain the necessary skills. Beyond training, engineered roads by the use of traffic calming techniques are recommended. Appropriate techniques would include radar speed display boards, which will be further explored as part of the current study. This research, although relevant, lacked analysis on crash rates involving child pedestrians experienced in school zones explicitly. A more specific study by Warsh *et* *al.* (2009) examined the number of collisions exclusively in school zones in Toronto, ON. Zones of differing radii were delineated around schools on ArcGIS in increments of 150 m ranging from 0-150 m to 301-450 m. Their main conclusion was that the highest density of collisions involving child pedestrians (collisions/100 km^2) occurred in the smallest zone and decreased as distance from a school increased. The density of collisions resulting in child injuries and fatalities were 5.7 and 9.4 times greater, respectively, within the smallest delineated zone compared to outside the furthest extent. They recommend further research be done focusing on midblock crossing locations in school zones, as this was the location with the greatest frequency of collisions.

This study only examined child pedestrian involved collisions and did not analyze total collision occurrences within school zones. All collisions that occurred within predetermined circular zones were considered to have occurred within a school zone rather than actually having happened with an actual traffic school zone delineated on an adjacent street. The current study will examine all collisions occurring within designated school zones only.

Collision experience within school zones should be better understood so that potential safety hazards to children can be addressed. Armstrong and Petch (2013) proposed an evaluation framework to identify traffic risks to child pedestrians that warranted busing of the children to school. They identified lack of separation from traffic as the factor most connected to pedestrian collisions and, therefore, stated that areas of greatest risk were those without walking facilities and/or shoulders. Accesses and driveways were acknowledged as another concern for child pedestrian safety because of possible conflicts between vehicles. The final concern mentioned within this study was stopping sight distance. If a distance did not provide drivers with the proper amount of time to stop for a child pedestrian, it posed a serious risk to the child. A "Hazard Evaluation Flowchart" was created based on the findings to warrant use of buses because of unsafe road conditions for children walking to school. Characteristics found in this study to pose a significant safety threat to children along their route to school may be interchangeable to school zones themselves, making it applicable to the current study. Further research on this is required to determine if these characteristics are interchangeable.

2.3 School Zone/Area Establishment

Whether a school is established as a zone or an area is a determination by local road authorities. This decision would ideally be based on a set of standard guidelines developed to maximize safety. There is a Canadian guideline published by TAC (2006) for establishing school zones/areas. This reference provides guidelines which are contingent on criteria that characterize the surroundings of a school on the level of safety they provide. A simple worksheet where users can input these criteria to determine if a school should be classified as zone, area, or neither (and the respected action taken) is warranted. The criteria are given a weighted factor and a final score governs the outcome. A higher score indicates a greater need for a school to be designated as a 'zone' rather than an 'area'. Criteria included in the guideline are school type, road classification, presence of fencing, property line separation, type of school entrance, and location of any sidewalks.

With respect to the list of criteria the highest weighted school location would be an elementary school, located on a local road, is fully traversable (i.e. no fencing present), with a property line that abuts the roadway, where the main entrance is the closest point to the adjacent roadway, and has no sidewalks present. The lowest weighted location where a school would be designated as an 'area' would be a high school, located on a major arterial or freeway, is non-traversable, with a property line separation of greater than 50 metres, has no school entrance abutting the adjacent roadway, and has sidewalks present on both sides of the adjacent roadway. Some provincial jurisdictions, such as the Alberta Infrastructure and Transportation (2007), have adopted their own set of guidelines similar to TAC's.

The issue of non-compliance to school zone/area guidelines among New Brunswick jurisdictions was addressed in this study when a sample of New Brunswick schools were compared to TAC guidelines. School zones and areas should be designated in a consistent manor to ensure that all locations are treated objectively; this could be accomplished by municipalities adhering to whatever guidelines are adopted.

2.4 School Safety Countermeasure Guidelines

Actions are often taken by school authorities in an attempt to increase school zone safety without supporting evidence that they will actually produce benefits. To ensure that countermeasures are being used efficiently, a set of guidelines for proper installment is necessary. A study by Strawdernan *et al.* (2013) performed in Mississippi addressed the concern that signage in school zones is often installed based on public or political pressure without empirical evidence to support the assumption that speeds will be reduced. The authors hypothesized that driver compliance may actually be reduced with too much school signage in an area. Results from their study show the opposite affect from what the authors expected. Vehicle speeds were lower throughout the sample of school zones with a higher saturation of signage present (10 or more school zone signs within a 10 mile radius of the school under study) as opposed to lower (less than 2 school zones present within a 10 mile radius of the school under study). It is also notable that the highest speed limit compliance was found on 4-lane roadways with a high saturation of school zone signage. The authors also observed that more complex environments may be a factor affecting driver compliance to lowered speed limits through a school zone.

From this study the authors suggested guidelines for appropriate use of school zone signage. It is stated that school zone signs should be placed on an as-needed basis without the concern of over-saturation of signage causing negative speed compliance. Schools located on 4-lane roadways in urban settings are stated as having a higher compliance rate to the lowered speed limits associated with school zone signage. The authors state that further work is required to produce a standard policy for school zone signage placement.

The use of radar speed display boards as a safety measure in school zones should be governed by a well thought-out, consistent process, similar to that of school zone and area designation. This becomes more difficult for jurisdictions because of the lack of objective guidelines available for justifying the use of the devices. Many studies have proven the effectiveness of the display boards at reducing motorists' speeds throughout transition zones, but there is limited research on their justification. A study by Veneziano *et al.* (2010) presented a “General Guidance” and “Location-Specific Guidance” for warranting the use of display boards. The guideline was developed for use in California, however, authors state that it could be used elsewhere in the United States as well as internationally if local conditions are taken into consideration. The development these guidelines was based on the consideration of location, application, and factors and characteristics that require radar display sign usage. They argue that transition zones and locations where speeding is a problem are the most common applications for the boards. Their end product provides users with a set of standards that should be considered when determining if a display board should be used, as well as information on past applications of radar speed display boards. Recommendations for usage of the display boards were developed for general use in any transition zone; however, specific guidelines for schools were addressed in the “Location-Specific Guidance” section of the study. This guideline states that radar speed signs may be considered within half a mile (approximately 800 metres) of a school zone that has a posted speed limit greater than 15 mph (25 km/h). Other considerations include school zones where the 85th percentile speeds or mean speeds exceed the posted speed limit by 5 mph (8 km/h) or more, and where the average daily traffic (ADT) exceeds 500 vehicles.

The study by Veneziano *et al.* was a good starting point; however, it lacked a full warrant system based on weighted, objective criteria derived from empirical collision evidence that could be used universally. The goal of the current study is to provide this as an outcome. It is clear from the literature reviewed that more research must be done regarding all four issues before an accepted warrant can be designed.

TAC recently initiated a study to develop national Canadian "Application Guidelines for Speed Display Devices". The outcome of the project will be an established set of development guidelines for the more effective design of speed display device, for example color, brightness, flashing pattern, etc. as well as best practices for application of speed display devices. This guideline will be for general use of the display units, not specific to school zones. The project was initiated in May 2015 with the final guideline expected to be completed by April, 2017. The current project should be useful to the development team for the TAC project relative to providing insight relating radar speed display boards to school zones/areas specifically.

2.5 Collision Data Modelling

Collision histories must be normalized if different sites are to be compared in an equitable manner. In road safety this is often accomplished with the use of Safety Performance Functions (SPF). SPFs are models used to estimate the expected number of collisions at a given location dependent on the specific characteristics of the site. The expected annual collision frequency is then subtracted from the observed average annual collisions at a given site to obtain a Potential For Improvement (PFI). A PFI of zero indicates that a given site is performing as expected, a positive value indicates a site is performing worse than expected, and a negative value indicates a site is performing better than expected. After reviewing the literature related to SPFs, it is clear that there are currently no SPFs specifically designed for modelling collisions within school zones/areas.

Regression models are often used in road safety to relate predictive variables, often road or surrounding area characteristics, to collision frequencies. Selecting an appropriate regression model is important to ensure the most reliable statistical results. Collision frequencies are non-negative, random integers often separated by year and are, therefore, classified as count data. Literature on road safety statistics suggests that the commonly used ordinary least squares regression models are not suitable for modelling count data and, therefore, collision data as an extension (Washington *et al.* 2011).

Instead, the more appropriate regression models for handling collision count data are either Poisson or negative binomial. The difference in the two models used for count data is their ability to handle over dispersion. If over dispersion is present, which occurs when the variance is greater than the mean, then a negative binomial regression is used, otherwise Poisson regression is selected (Al-Dulaimi 2015).

Collision data often have an abnormally high number of zero counts for at least a portion of the years being analyzed for a given road. Literature on collision data modelling suggests the use of zero-inflated models to account for high percentages of zero counts. Incorporating zero-inflated models into Poisson or negative binomial (depending on whether over dispersion is present) assumes that excess zero counts are a result of a separate process than data modelled using Poisson or negative binomial alone.

Zero-inflated models are often used in road safety analysis for collision count data. This is due to the possibility of zero counts occurring from two different situations. The two processes are for zero counts that occur because a collision did not happen during one of the years evaluated (in other words it follows a Poisson or negative binomial regression and the zero count is part of the distribution); the other process resulting in a zero count occurs when the likelihood of a collision happening is extremely small compared to normal-count states that follow a Poisson or negative binomial regression (in other words, the evaluation period is too short for a collision to be expected to occur on a particular section of road) (Washington *et al*. 2011).

2.6 Road Safety Evaluation

There are various measures used in road safety evaluation to objectively determine if a given countermeasure is justified and to quantify its benefit. Those that will be used in this study include safety performance functions (SPF), crash modification factors (CMF), cost of collisions, and warrant systems or guidelines.

2.6.1 Safety Performance Functions

A specific section of roadway can be evaluated in terms of safety performance using SPFs. SPFs are mathematical models that are used to predict the average annual collisions at a location and are often a function of facility type (intersection or roadway), road volume(s), and length of segment. The Highway Safety Manual (HSM) is a commonly used reference for SPF models, which are recommended to identify locations that are performing worse than expected (i.e. have more observed annual collisions than would be expected as predicted by the SPF models). The HSM provides CMFs that can be used in conjunction with the SPF equations to estimate an increase in expected pedestrian-related collisions only at signalized intersections located within a close proximity of a school; however, there are currently no SPFs that exist that were developed specifically for school zones.

2.6.2 Crash Modification Factors (CMF)

The effectiveness of a safety countermeasure on reducing collision frequency is often represented as a CMF. A CMF is an adjustment-factor that is multiplied by the number of observed collisions occurring at a specific site to estimate the expected number of collisions after a specific countermeasure is implemented. Given that radar speed display boards are a relatively new safety countermeasure there is limited research regarding the effectiveness of the boards on reducing collisions. One study by Hallmark *et al.* developed a CMF for dynamic speed feedback signs on curves. The study was executed on a sample of 22 rural, two-way roadways in different states throughout the United States. Collision data were collected at the sites for up to four years before installation of the display signs and up to three years after. Control sites were selected to account for any trends regarding collision frequencies. SPFs were used to evaluate expected collisions and were compared using a full Bayesian analysis to collision data. Results showed collision reductions at all sites from five to seven percent; this corresponded to a CMF of 0.93-0.95 (Hallmark *et al.* 2015). No study was found regarding collision reductions with radar speed display boards used in other contexts (school zones, work zones, etc.).

2.6.3 Cost of Collisions

Collision reductions can be expressed in monetary terms by assigning a cost for collisions. Collision costs are often delineated by collision severity – property damage only (PDO), personal injury (PI, sometimes subdivided into minor and severe), and fatality (F). Fatal collision costs are contingent on the statistical value of life, often evaluated using a willingness-to-pay (WTP) approach where costs are measured by the amount people would be willing to pay for a countermeasure to reduce their risk of fatality (Lawrence *et al.* 2014). Collisions resulting in injuries are often based on the sum of the monetary value of lost quality of life (evaluated in the same manner as the statistical value of life) as well as average market costs including medical, emergency services, and lost productivity (in terms of the person's wage and benefits) costs. Property damage only collisions are often evaluated based on average costs required to repair/replace vehicles and property (FHWA 2005).

Various studies have been performed to evaluate the cost of collisions. Table 2.1 summarizes the findings from two specific sources – Gunter and Hildebrand (2008) and the Highway Safety Manual First Edition, Volume 1 (2010). All values were normalized to 2015 Canadian Dollars. An average of all values will be used in this study.

Table 2.1 Cost of Collisions

		Total Cost	
Source	**PDO**	**Injury**	**Fatality**
Gunter and Hildebrand, 2008	$7,132	$69,216	$5,036,158
HSM First Edition, Volume 1, 2010	$12,648	$141,183	$6,852,181
AVERAGE	**$9,890**	**$105,200**	**$5,944,170**

2.6.4 Other Road Safety Warrant Systems

A number of road safety related guidelines or warrant systems have been developed for usage by road authorities. In addition to the TAC School and Playground Areas and

Zones: Guidelines for Application and Implementation (2006), other examples include the Federal Highway Administration's (FHWA) Manual on Uniform Traffic Control Devices (MUTCD) warrant for signalized intersections (FHWA 2009), and the National Cooperative Highway Research Program (NCHRP) warrant for highway lighting (NCHRP 1974). Similar to TAC's school establishment guideline, these studies developed a worksheet to provide a final score based on a set of criteria that is compared to a threshold value to determine if the respective measure is warranted. Warrants such as these are often developed by a team of engineers and other professionals based on judgement. They often lack scientific evidence to support criteria values (and/or their weights) included in the warrant system itself. The final product of the current study will be an objective warrant system for installation of radar speed display boards in school zones based on scientific evidence and economic justification.

3 Methodology

There are three distinct areas to this research: examination of school zone/area establishment in New Brunswick, collision data analysis, and the development of a radar speed display board warrant system.

3.1 Data Collection

3.1.1 School Zone and Area Establishment in New Brunswick

The analysis of school zone and area establishment practices in New Brunswick involved determining recommended classifications for a sample of schools by following the described procedure in the TAC guideline. The sample consisted of schools with varying characteristics to represent all schools within New Brunswick.

The sample selected was the same as the sample of schools used in the collision data analysis section so that results determined through collision analysis could be applied to the establishment analysis. Specific information used from the collision analysis in the school type establishment analysis will be discussed in more detail in section 3.2.2. This sample also ensured a variety of schools with different combinations of the factors used in the TAC guideline for school zone and area establishment (TAC 2006). Factors included school type, road classification, fencing characteristics, property line separation, location of school entrance, and location of sidewalks. Including schools with different combinations of the TAC criteria enabled a representative sample.

Data corresponding to the criteria described in the TAC guideline were required for each of the schools so that the recommended classification could be determined. These data were collected using site or virtual inspection through Google Maps.

3.1.2 Collision Data Analysis

Motor vehicle collision data for the province of New Brunswick are collected by police departments at the time of a collision and did not involve the researcher in the process. The data collected were received in the form of electronic police reports from the New Brunswick Department of Transportation and Infrastructure (NBDTI) for the years 1997-2012. For research purposes, it was assumed that recorded collisions were representative of all collisions that have occurred. A sample of schools was chosen for analyzing collision histories in detail. The sample consisted of 35 urban and 24 rural schools thought to be representative of all schools in New Brunswick. Note that two of the urban schools (Fredericton High and Priestman St.) were analyzed as one because their close proximity requires they share a zone. The process of sample selection and filtering collision history data was done using two separate methods for urban and rural school zones, as described below.

Urban Schools

The sample of urban schools consisted of public schools from elementary to high school in three of the major cities within New Brunswick – Fredericton, Moncton and Saint John. All public schools were included from Fredericton and Moncton, and only a sample of public schools within Saint John due to insufficient data, to represent all urban schools in the province. Schools within these three cities were selected as the urban sample because the traffic departments from each city plot the collisions from the police reports using GIS software (ArcGIS). School zones were delineated on the GIS layer for each sampled location and collisions occurring within the designated zones were selected. This made it easier to identify specific collisions that occurred within the school zones/areas as they could be identified directly on the map. This reduced the chance of error when searching manually for collisions that had occurred within a school zone/area. Specific case numbers for the selected collisions within the GIS dataset correspond with the case numbers associated with the more detailed NBDTI reports. The information in the reports were analyzed for each case and only those collisions occurring between 7:30 a.m. to 4:30 p.m. and from September to June were included as these restricted data to only those that occurred within school operating times. GIS-based data were only available from 2007 to 2014 for Fredericton collisions and from 2009 to 2014 for Saint John; data for Moncton included the years 1997 to 2012.

Rural Schools

Collisions occurring within rural school areas were isolated by manually filtering them from the NBDTI database. A sample size of 24 rural school locations within New Brunswick were selected at random (ensuring a reasonable geographic coverage) and location information for each area was retrieved. The limits of each rural school area were delineated on a map. The NBDTI data were filtered by network component names of those that contained the sample school areas and then further reduced based on known distances to nearby road network components. Only collisions occurring between 7:30 a.m. to 4:30 p.m. and from September to June were included for the years 1997 to 2012.

3.1.3 Radar Speed Display Warrant System

Long-term Effectiveness

To determine whether radar speed display boards become less effective at reducing speeds with an increase in deployments within a network, a case study was performed as an extension of the study by Hildebrand *et al.* (2013) introduced in section 2.1.2. The case study involved testing the effectiveness of two sets of radar speed display boards at reducing speeds six years after they were installed, with the added factor of additional boards being installed in school zones throughout the same city within that time period. Test sites used in this case study were the same as those used in the previous study. The sites included two school zones in Fredericton, NB – Bliss Carmen Middle and Devon Middle – that had permanent radar speed display boards installed in 2009. Both sites had reduced speed limits from 50 km/h to 30 km/h and were the first two schools in Fredericton to install radar speed display boards to encourage driver compliance to the lowered speed limit. Speed surveys were previously completed at various time periods before and after the installation of the display boards to determine the long-term effectiveness of the units. Data were collected before, one-week, one-month, and approximately four-years after the two sets of boards were installed.

Since the installation of the original display boards, 10 additional sets of units have been installed in schools throughout Fredericton. A speed survey was performed for the current study at the two test sites six years after the installation of the initial boards. Speed surveys performed for the current study used the same methodology described in the original study. Data were collected at three reference points within each of the schools zones – at the zone limits where the display boards are located as well as the middle of the zone. Measuring speeds at three locations throughout the zone allowed a speed profile to be developed.

Data were collected at both schools during peak and non-peak hours, 7:30-9:00 a.m. and 9:30-11:00 a.m., respectively. Speeds were measured using a professional radar gun (Stalker ATS Radar) positioned at the smallest angle possible while still remaining inconspicuous to vehicles to avoid changes in drivers' behaviours if they were aware their speeds' were being monitored. Only speeds of independent vehicles with a minimum 5-second headway were included. Data consisted of a sample size of 40 vehicles per direction per reference point for both schools. Data were collected during school operating times excluding Mondays, Fridays, holidays, and adverse weather conditions to avoid any disruptions in typical traffic flow pattern.

These data, in addition to the data collected for the previous study, were used to analyze motorists' speeds throughout the two school zones since the installment of additional radar speed display boards in the city to determine if there is a familiarity factor that results in a decreased effectiveness of the boards.

Development of Display Board Warrant System

The display board warrant system was developed using independent explanatory variables for high collision frequencies. Data on all independent variables believed to be possible predictors of collision frequencies were required for all schools with known collision histories (i.e. the sample used in the collision analysis). These variables were selected based on those suggested in the literature to be explanatory of collision frequency, those used in TAC's *School and Playground Areas and Zones: Guidelines for Application and Implementation* (TAC 2006), variables used in typical SPFs, as well as any other variables that the researcher believed to be predictive of collision frequency.

The majority of these data were used in the initial phases of this research and were, therefore, already collected; traffic volumes and collision frequencies were used in the collision analysis and certain school location characteristics were used in the school zone/area establishment analysis. For schools with opposing characteristics throughout different sections of the zone/area the worst case scenario was used. Data on the remaining possible predictors were collected through virtual site inspections of each of the schools. Data were collected for both urban and rural schools. All data are assumed to be representative of all the years analyzed for collision history.

3.2 Analysis

3.2.1 School Zone and Area Establishment in New Brunswick

New Brunswick school zone and area establishment was analyzed by comparing existing practices to the recommended establishment practice described in the TAC guideline (TAC, 2006). Specific instructions are given on how to systematically use the criteria described as affecting school zone safety as well as how to complete the provided worksheet (Section 2.4 and Table 2.1 of the TAC guideline) to determine an outcome. Directions for the proper establishment as well as proper signing and marking for school areas and zones is detailed in Section 3.2 of the TAC guideline. Determining whether these directions are followed in New Brunswick was part of the analysis.

The worksheet provided in the TAC guideline to establish school type (zone, area, or neither) was followed for each of the schools based on their existing characteristics. The worksheet allocates points for each of the categories described in the TAC guideline – school type, road classification (based on the road classification directions in the TAC Geometric Design Guide for Canadian Roads, 1999), fencing characteristics, property line separation, location of school entrance, and location of sidewalks. All adjacent streets to a single school location were evaluated separately (as instructed in the guideline). A total score was determined for all adjacent roads for all schools in the sample and a corresponding recommendation on classification type was determined. The recommended TAC classification was then compared to the actual classification for each school.

Statistical analysis in the form of a two sample t-test was used to determine if the PFI (determined during the collision history analysis) of those schools where the actual establishment matched the TAC guideline recommended establishment were significantly different from those established differently from what the TAC guideline recommends.

3.2.2 Collision Data Analysis

The expected number of annual collisions to occur within each of the school locations under study was determined using different sources of Safety Performance Functions (SPF) representing similar street/facilities outside of a delineated school zone/area. A different SPF was used for each road facility type required: rural two-lane, undivided road segment; urban two and four-lane, undivided road segments; and all combinations of 3 and 4-legged and signalized and unsignalized intersections. The first SPF models used were from the Highway Safety Manual (HSM) (AASHTO 2010). The second SPF models were developed by Sayed *et al.* in 2008 for the Engineering Branch of the British Columbia Ministry of Transportation and Infrastructure (Sayed *et al.* 2008). Calibration factors were determined for each equation to adjust for jurisdictional differences. The calibration factors for each of the equations were determined using the methodology described in the HSM Volume 2, Appendix A.1.

The road facility types that would be required for this analysis were first identified – all facility types described previously required calibration. Typically, a total of 30 sample sites were selected for each road facility type and collision data retrieved. The predicative models described in the HSM were applied to each sample site then the calibration factor was calculated using the appropriate equation from the HSM Volume 2 (Appendix A.1). Calibration factors for all SPF models can be found in Table B.1 in Appendix B. Due to insufficient data for the city of Saint John a true calibration factor for the area was not determined. For purposes of this study the calibration factor was taken as the average of the Fredericton and Moncton factors.

Average Daily Traffic (ADT) volumes in vehicles per day were provided by the City of Fredericton, the City of Moncton, and the City of Saint John for all urban roadways and by the New Brunswick Department of Transportation and Infrastructure for rural roadways. For purposes of this study, these values were assumed to be representative of

Average Annual Daily Traffic (AADT) values. School zone lengths were determined by locating each zone on Google Maps and using the measuring tool option available. The expected annual collisions calculated for each of the schools analyzed were calibrated for local conditions and then multiplied by a reduction factor to estimate the expected annual collisions during school operating times. This factor was determined using the average distribution of annual collisions occurring from Monday to Friday, September to June, and 7:30 a.m. to 4:30 p.m. divided by the total annual collisions occurring for six years. Derived reduction factors can be found in Table B.2 of Appendix B.

Total observed collision frequencies were converted to actual annual collision frequencies by dividing the total number of collisions by the number of years of collision data analyzed. These values were compared to the expected annual collisions for each location. A Potential For Improvement (PFI) was determined for each by finding the difference between actual and expected annual collisions. A negative PFI indicates that the school zone or area is performing better than expected in terms of collisions. All schools were ranked from highest to lowest in terms of PFI (worst to best); this was done separately for rural and urban locations.

Statistical methods were used to analyze PFI values of the school; z-tests were used for urban schools ($n>30$) and t-tests were used for rural schools ($n<30$). Results of statistical analyses were used to determine which school zones and areas are statistically different ("worse" or "better") compared to the entire group of schools (statistical test 1). Statistical analyses in the form of a t-test were also done to analyze schools individually to determine if the PFI value by year for each school was statistically different from the expected PFI value of 0 (statistical test 2). These analyses collectively allowed the formation of conclusions on the overall performance of school zones/areas in New Brunswick by analyzing schools both separately and as a whole.

Paired t-tests were used to analyze the different types of school classification, zones, areas, and zones/areas to determine if any type is performing statistically significantly better than the others. Site characteristics were specified for school locations and compared between those classified as worse or better in terms of collision occurrences. These characteristics were considered as possible factors affecting school zone safety.

3.2.3 Radar Speed Display Warrant System

Long-term Effectiveness

Data from the previous study by Hildebrand *et al.* (2013) were included in the current case study for analysis purposes. Average speed data for the two schools calculated before installation of the display boards were compared using statistical analysis to average speed data collected approximately six years later, after additional radar speed display boards had been installed at school zones throughout the city. A t-test was performed on the two sets of data for both school zones to determine if the differences in average speeds between before installation and six years after were statistically significant. The null hypothesis that the mean speeds from before installation are equal to mean speeds six years after the boards have been in operation (after additional display boards have been added to the city) were tested at a confidence level of 95%. Results where the null hypothesis is accepted, indicating no change in speeds, would conclude that the effectiveness of the boards has been compromised with an increase in deployment of additional display boards.

Similar t-tests were used to compare data from two months to one year, one year to four years, and one year to six years after installation to identify any statistically significant changes between time periods when the display units were in operation. This was done to check whether average speed reductions during the entire study period since the boards were in operation remained consistent.

Development of Display Board Warrant System

A single warrant system was developed for radar display board deployment in either urban or rural locations (with an indicator differentiating area type). All possible explanatory variables initially considered for the warrant are listed in Table 3.1.

The traffic volume variable was transformed to use in the regression analysis by taking the natural logarithm of each value. This was to account for the known logarithmic relationship between collision rates and road volume. Ideally, all data would be normalized by length as well because of the linear relationship between collisions and length; however, this was not done because of the abnormally short segment lengths of school zones/areas for modeling collisions. School zone/area lengths are typically less than a kilometre and NBDTI collision data are not precise enough to identify exact locations at the level of accuracy that would be required. Length was instead included in the zero-inflated model to reflect the likelihood that smaller segment lengths would result in fewer collisions. Given that school zone/area road lengths sampled have a relatively small range, this simplification should not have a significant impact on results.

The initial list of explanatory variables of collision frequencies was refined by dropping highly correlated variables. A correlation matrix was developed, which was made up of correlation coefficients that indicated the relationship strength between two independent variables. If a strong relationship was present between two variables in the correlation matrix, the two variables were examined further and, where appropriate, one was dropped from the list of independent variables used in the warrant development. A strong correlation is considered to be a correlation coefficient of 0.8 or greater, though any above 0.6 were examined further to see if correlation between the variables made sense (Devore 2008).

Collision data were sorted by year for each of the schools under study. Separating collisions by year allowed them to be classified as count data as they are nonnegative integer values. Regression analysis was used to model collision frequency (dependent variable) with respect to school location characteristics (independent variables). An appropriate regression model for handling count data was required to ensure the most reliable statistical results. Due to the abnormal nature of count data (nonnegative integers), the commonly used ordinary least squares regression is unsuitable to model the collision data. A Poisson or negative binomial model was, therefore, more appropriate (Washington *et al.* 2011).

Table 3.1 – Initial List of Potential Variables for Urban and Rural School

	Variable	Category
Dependent	Number of Collisions (by year)	Discrete
Independent	School Type	Elementary
		Middle
		High
	Fencing Present	Fully Traversable
		Partially Traversable
		Non-Traversable
	Sidewalks Present	Both Sides
		School Side Only
		None or Non-School Side Only
	Intersection Present	4-leg Signalized
		3-leg Signalized
		Unsignalized
		None
	Number of Unsignalized Intersection	0
		1
		>1
	Road Volume (natural log)	Discrete
	Length	Continuous
	Classification	Zone (speed <30 km/h)
		Area or Area/Zone (speed >30 km/h)
	Average Speed	Continuous
	Crosswalks Present	Signalized
		Unsignalized
		None (or unmarked)
	Curb	Present
		Not Present
	Horizontal Curve	Present
		Not Present
	Location	Urban
		Rural
	Paved Shoulder	Present
		Not Present
	Number of Through Lanes	1
		2

The independent variables were modeled using the appropriate zero-inflated regression based on the over dispersion test to establish those with the best predictability of collision frequency. The model was refined to include only significant predictive variables by analyzing corresponding p-values. Independent variables that produced a p-value less than 0.1 (a 90% confidence level) were considered to be significantly related to higher collision frequencies and were included in the final model. The model was analyzed to determine the goodness-of-fit. This was done by plotting observed average collisions per year versus predicted collisions per year and applying a line of best fit. The most appropriate model would have a slope of the line of best fit approaching 1.0 indicating a linear relationship between observed and predicted values. The selected model would also have an R^2 value approaching 1.0 indicating a higher explained variation between observed and predicted values (i.e. data points are closer to the line of best fit).

The final model output yields equations that are used to predict collision counts based on the two processes. The first follows the normal Poisson (POI) or negative binomial (NB) distribution while the second follows the zero inflated (ZI). The final predicted collision count for a given area is calculated using Equations 3.1-3.4, below:

NB or POI $$a1 = intercept_{NB/POI} + \sum_{i=1}^{n} \beta_{i,NB/POI} X_{i,NB/POI}$$ [E. 3.1]

ZI $$a2 = intercept_{ZI} + \sum_{i=1}^{n} \beta_{i,ZI} X_{i,ZI}$$ [E. 3.2]

Probability ZI $$p(ZI) = \frac{e^{a2}}{1+ e^{a2}}$$ [E. 3.3]

Predicted Collisions $$y = e^{a1} * (1 - p(ZI))$$ [E. 3.4]

Where,

- $a1$ is the linear prediction established from the Poisson or negative binomial model;
- $a2$ is the linear prediction established from the zero inflated model;
- $p(ZI)$ is the probability of the predicted collision following the zero inflated process;
- y is the final predicted collision count based on both processes;
- β_i is the beta coefficient determined for the respective model; and
- X_i is the corresponding independent variable.

3.2.3.1 SPF-based Warrant System

These equations once developed essentially provide Safety Performance Functions specifically for school zones/areas. They can be used by a jurisdiction to calculate the number of collisions that would be expected for a school zone/area with a given set of characteristics. The PFI values for all schools within a network would then be calculated using the same process described in Section 3.2.2. Those ranked as the worst in terms of largest PFI would be given priority to be considered for the installation of speed display devices.

3.2.3.2 Worksheet-based Warrant System

A worksheet was also developed to provide a more efficient method for jurisdictions to determine if the installation of a radar speed display board at a school area/zone is warranted. This was developed using the significant independent variables found through the SPF regression model. The respective maximum point values (MPV) for each variable was the product of its maximum value and its model coefficient divided by the sum of all coefficients to develop a relative weighting.

Each of the variables were then divided into subcategories or “bins”. These bins represent the different possible states of each variable. For discrete (dummy) variables the different bins would either be “present” or “not present”; for continuous variables the different bins would be ranges of values. The subcategories were assigned weighted factors corresponding with their magnitude of effect on collision frequency. This was determined by multiplying each average bin value by the coefficient for the respective variable and comparing them back to the product of the maximum value of a variable and its coefficient (as a percentage). Values were adjusted accordingly by setting the highest value to 1.0 and calculating the percent change in coefficient of all other values relative to the highest. This was repeated for all variables.

The user of the warrant worksheet would obtain a final score by multiplying the weighted factor of the relevant bin that describes that site under analysis with the corresponding MPV for each category. The worksheet required a threshold value that represented the lowest final score that would still justify a radar speed display board (where its net benefits outweigh its costs). The average expected collision reduction after the installation of a radar speed display board at a school zone/area was determined using collision history data for New Brunswick schools with radar speed display boards already installed. This CMF was calculated as the average number of collisions after the display boards were installed divided by the average number of collisions before the display boards were installed. This was repeated for each applicable school and a total final average CMF was determined.

The total number of collision reductions required in order for the economic benefit of collision reduction to compensate the initial cost of the display boards was determined using the costs of collisions. The distribution of all collisions (for both urban and rural schools) was determined based on collision severity: property damage only (PDO), injury, or fatality. The total cost of a collision was determined as a weighted average of the total cost of a PDO, injury, or fatal collision based on the distribution. The costs of collisions by severity type were based on the average of the sources cited in section 2.6.3. The total cost of the radar speed display boards for a single school was divided by the average collision cost to obtain the required number of collision reductions.
The total number of collisions over the entire service life of the display boards that would need to occur in order to achieve the necessary collision reductions was calculated as the collision reductions divided by the CMF. The number of total annual collisions was obtained by dividing the total collisions by the anticipated service life of a radar speed display board. Finally, the threshold value was determined by plotting total expected collisions of all possible scenarios (using the SPF equations) against road volume. The road volume required for each scenario to reach the critical collision value was determined and a total score for each scenario was calculated using the worksheet. The threshold value corresponded with the lowest score of all scenarios that met the critical collision value.

4 Analysis and Results

The following sections synthesize the analysis and results from the three veins of research undertaken: New Brunswick school zone/area establishment, correlation between school zone/areas and collisions, and the development of a radar speed display board warrant system.

4.1 School Zone and Area Establishment in New Brunswick

Results for the school establishment analysis are summarized for urban and rural schools in the following sections. The total worksheet score for each roadway adjacent to each of the schools in the sample is presented as a sum of the points from the separate criteria described in the TAC guideline. The total score for each corresponds to a suggested classification by the TAC guideline that uses the scoring system represented in Table A.1 in Appendix A. For schools that score in the range corresponding to a recommended classification of “school area or zone”, it states that local conditions must be considered for the appropriate classification and is to be left to the examiners best judgement.

4.1.1 Urban Schools

Results presented in Table 4.1 indicate that 8 of the 34 urban schools (24%) had at least one adjacent roadway classification not in compliance with the TAC guideline recommendation for a roadway with their respective characteristics. Results suggest that school establishment for urban schools in New Brunswick does not closely follow the TAC guideline. There is also no indication that any of the three cities sampled are more consistently established according to the TAC guidelines. It is possible, however, that a set of criteria specific to each city is used when establishing a school.

Table 4.1 – School Type Establishment: Actual vs. TAC Recommended (urban)

Urban School	Street	TOTAL TAC SCORE	TAC Recommended Class	Actual Class
Bayview	Loch Lomond	**70**	Zone or Area	**Area**
	Courenay Ave	**76**	Zone or Area	**Area**
George St	Regent	**38**	Area	**Area**
	George	**66**	Zone or Area	**Zone**
Moncton High	Church St	**53**	Area	**Area**
	Mountain Rd	**46**	Area	**Area**
Fredericton High/Priestman	York	**60**	Area	**Zone**
	Priestman	**85**	Zone	**Zone**
Garden Creek	Golf Club Rd	**83**	Zone	**Zone**
	Woodstock Rd	**57**	Area	**Area**
Hillcrest	St George Blvd	**70**	Zone or Area	**Area**
	Parlee Dr	**96**	Zone	**Zone**
Loch Lomond	Loch Lomond Rd	**60**	Area	**Area**
	Evergreen	**93**	Zone	**Area**
Nashwaaksis Memorial	Main St	**80**	Zone or Area	**Zone**
	Johnston Ave	**98**	Zone	**Area**
Ecole Champlain	Mill Rd	**67**	Zone or Area	**Zone**
Beaverbrook	Mountain Rd	**80**	Zone or Area	**Area**
	Savoie Dr	**78**	Zone or Area	**Zone**
Forest Hill	Forest Hill	**75**	Zone or Area	**Zone**
Nashwaaksis Middle	Fulton Ave	**51**	Area	**Zone**
Bliss Carman	Kimble Dr	**43**	Area	**Zone**
Devon Middle	MacLaren Ave	**66**	Zone or Area	**Zone**
	Neill St	**72**	Zone or Area	**Zone**
	School St	**74**	Zone or Area	**Zone**
	Dobie St	**76**	Zone or Area	**Zone**
Harrison Trimble	Echo Dr	**48**	Area	**Area**
Montgomery	Montgomery St	**75**	Zone or Area	**Zone**
Sunny Brae Middle	Chemin McLaughlin	**44**	Area	**Zone**
Lewisville	McAuley Dr	**59**	Area	**Zone**
Evergreen Park	Evergreen Dr	**90**	Zone	**Zone**
Arnold H. McLeod	Storey	**83**	Zone	**Zone**
Ecole Sainte-Bernadette	Chapman	**85**	Zone	**Zone**
	Upton	**83**	Zone	**Zone**
Barker's Point	Carman Ave	**93**	Zone	**Zone**
Forest Glen	Glencoe Dr	**83**	Zone	**Zone**
	Monaghan Dr	**98**	Zone	**Zone**

Park St	MacDonald Ave	**90**	Zone	**Zone**
	Longwood Dr	**76**	Zone or Area	**Zone**
Connaught St	Connaught St	**83**	Zone	**Zone**
Northrup Frye	Ryan St	**75**	Zone or Area	**Zone**
Birchmount	Ayre	**78**	Zone or Area	**Zone**
Champlain Heights	Champlain Dr	**70**	Zone or Area	**Area**
Royal Road	Royal Rd	**70**	Zone or Area	**Area**
Kingsclear	Fairview Dr	**86**	Zone	**Zone**
	Woodstock Rd	**55**	Area	**Area**
Edith Cavell	Park St	**80**	Zone or Area	**Zone**
	Weldon St	**70**	Zone or Area	**Zone**
Liverpool St	Centerbury Dr	**78**	Zone or Area	**Zone**
	Liverpool St	**80**	Zone or Area	**Zone**
Bessborough	Bessborough Ave	**80**	Zone or Area	**Zone**
	Milner Rd	**70**	Zone or Area	**Zone**
Prince Charles	Union St	**30**	Nothing	**Area**

* Those highlighted in red indicate that the actual classification does not match the TAC recommendation

It is notable that 75% of schools not in compliance with the TAC guideline were all over signed (i.e. were classified as a zone when the TAC recommended classification was an area or were classified as an area when the TAC recommended classification was nothing). It is also notable that for 19 of 25 schools (76%) with a corresponding TAC recommendation of a “zone or an area” classification, the actual classification was a “zone” (TAC recommends using judgement on local conditions for final decision). Further observations indicate that of the six schools with a TAC recommended classification of “zone or area” and an actual classification of an “area”, two of them were located on a four-lane roadway (the only four-lane roadways in the study). Moreover, three of the schools recommended as a “zone or area” and signed as an “area” were located in Saint John; this can be explained because school zones were not used in Saint John at the time of study. These observations indicate that road authorities responsible for school establishment may be arbitrarily over-classifying schools.

A brief discussion was held with each of the traffic engineers/technicians for the three cities in order to better understand their respective classification procedures. The classification of schools in the City of Fredericton is generally tied directly to location and school type. The TAC guideline is referred to in the process, however, in practice it generally is a matter of school type and location. School zones are implemented at elementary and middle schools located on local and minor collector roads; zones include reduced speed limits of 30 km/h. It is also notable that all elementary school zones within the city have been equipped with radar speed display boards. High schools as well as schools located on major collector/arterial or provincially designated roads are classified as areas.

The City of Saint John recently implemented a similar procedure for school classification. The TAC guideline is referred to as part of their new School Zone Safety Program. The city also takes proper sight line into consideration when deciding on the implementation of a radar speed display board at a particular zone (i.e. whether or not motorists' could see the sign at an adequate distance). This specific program reduces speeds through zones located on arterial and major collector streets to 40 km/h while speeds are reduced to 30 km/h through zones located on local and minor collector streets. The data presented in this research does not take into consideration the City of Saint John's new program as it was not yet introduced during the time period of the study.

The City of Moncton follows their own establishment guidelines dependent on school type and location. All elementary and middle schools located on local or collector roads are classified as a school zone with speed limits reduced to 30 km/h in conjunction with flashing beacons. Elementary and middle schools located on arterial roadways are classified as a school zone with speed limits reduced to 50 km/h in conjunction with radar speed display boards that provide feedback when a motorists' speed exceeds 51 km/h. All high schools are classified as school areas with no supplemental countermeasures.

The PFI values for each school developed in section 4.2.1 were used in this section for analysis purposes. The average PFI for urban schools with classifications in compliance with the TAC recommendation was 0.16 while the average PFI for schools with classification that were not in compliance was 0.12. Statistical analyses in the form of a t-test compared the PFI values for schools with classifications that corresponded to the TAC guideline to those schools with classifications that did not. Results showed no significant difference in performance between the two, suggesting that the cities respective classification systems are sufficient compared to using the TAC guideline in terms of safety performance.

4.1.2 Rural Schools

Due to insufficient data, 5 of the rural schools from the collision analysis could not be analyzed within this phase of the research. Of the remaining rural schools examined, 6 of 19 (32%) had adjacent roadways classified differently than what the TAC guideline would recommend for a roadway with their respective characteristics. Results from Table 4.2 suggest that the TAC guideline is not followed when establishing rural schools.

Table 4.2 – School Type Establishment: Actual vs. TAC Recommended (rural)

Rural School	**Street**	**TOTAL TAC SCORE**	**TAC Recommended Class**	**Actual Class**
Belleisle Regional High	Rte 124	**58**	Area	**Zone**
Millville Elementary	Rte 104	**80**	Zone or Area	**Area**
Lawrence Station Elementary	Rte 003	**80**	Zone or Area	**Area**
Riverside Consolidated	Water St	**85**	Zone	**None**
Stanley Consolidated	Rte 620	**72**	Zone or Area	**Area**
Harvey	Rte 003	**53**	Zone or Area	**Area**
Minto Elem.-Middle	Cedar Rd	**77**	Zone or Area	**Area**
Blacks Harbour	Rte 176	**70**	Zone or Area	**Area**
Brown's Flat Elementary	Wallace Rd	**85**	Zone	**Area**
Janeville Elementary	Rte 340	**90**	Zone	**Area**
Pennfield Elementary	School House Ln	**77**	Zone or Area	**Area**
Ecole La Villa-Des-Amis	Rte 11	**80**	Zone or Area	**Area**
Millerton School	Rte 108	**90**	Zone	**Area**
Miramichi Rural	Rte 117	**72**	Zone or Area	**Area**
Ecole Notre-Dame	Rte 115	**72**	Zone or Area	**Area**
Ecole La Decouverte-De-Saint-Sauveur	Rte 106	**72**	Zone or Area	**Area**
Upper Miramichi Elementary	Rte 625	**90**	Zone	**Area**
Back Bay Elementary	Rte 172	**72**	Zone or Area	**Area**
Bonar Law Memorial High	Rte 134	**56**	Area	**Area**

* Those highlighted in red indicate that the actual classification does not match the TAC recommendation

Following a discussion with the New Brunswick Department of Transportation and Infrastructure (NBDTI) it was determined that there are no criteria used for classifying schools on provincial roadways at the time of the study. Schools are typically classified as “areas” with the posted limit placed before the school area sign. A number of schools had reduced speed zones established in close proximity of the school area signs and were, therefore, initially misinterpreted as zones, however, the change in speed limit is likely for the roadway itself, independent of the presence of a school. NBDTI is in the process of implementing a new classification scheme for schools on provincial roadways, though access to this was not available during the time of the study.

The average PFI for rural schools with classifications in compliance with the TAC recommendation was -0.01 while the average PFI for schools with classifications that were not in compliance was 0.02. Statistical analyses were performed to compare the PFI values of rural schools with classifications that corresponded to the TAC recommendation to schools with classifications that did not. Comparable to the urban school findings, results showed no statistically significant difference in performance between the two.

Results from both the rural and urban school establishment analysis of this research indicate that there exists varied approaches among municipalities and NBDTI. Despite the lack of uniform approach to classifying school zones/areas there appears to be no statistical differences from a safety perspective.

4.2 Collision Data Analysis

An analysis of collision experiences within delineated school zones/areas in the province of New Brunswick was conducted to quantify existing safety performance of school zones/areas. Schools in both rural and urban locations were analyzed to provide an overall understanding of how their collision performance compares to the road system outside of delineated school zones/areas. Detailed results from the analyses are summarized in Appendix B. Condensed results for urban and rural schools are summarized in the following sections. The baseline used to represent the 'norm' is the expected collision frequency for similar roads outside of a designated school zone/area.

It should be noted that many of the SPFs do not include independent variables that account specifically for pedestrian activity. In the context of school zones/areas there is often more pedestrian activity than normal (at least in the urban context) so it is likely that the expected collision frequencies predicted are low. This would have the consequence of inflating the PFIs generated by this study. In other words, the percentage of school zones/areas found to be underperforming might be slightly overestimated. That said, it was found that pedestrian collisions represent a very small proportion of those experienced near schools (section 4.2.1).

The information in Table 4.3 shows the percent distribution of collision configurations for urban and rural schools. The majority of collisions occurring in all New Brunswick school zones/areas (both urban and rural) were right angle and rear-ended collisions. It is notable that even with an increase in pedestrians at school locations, only 6 percent of collisions in New Brunswick school zone/areas involved pedestrians.

Table 4.3 – Distribution of Collision Configurations (Percent)

Collision Configuration	Urban	Rural	Combined
right angle	38	40	38
rear-end	32	20	31
single vehicle	4	27	6
unknown	12	0	11
pedestrian-involved	6	7	6
side-swipe	4	0	4
head-on	2	7	2
object	2	0	2

4.2.1 Urban Schools

Data presented in Table 4.4 indicate that 16 of the 34 urban schools had a positive PFI, meaning that 46% of urban schools have a greater number of observed annual collisions than expected annual collisions (performing worse than expected). Alternatively 18 (or 53%) of the urban schools were performing better than expected.

Comparing the **average** PFI value for each school to the group of schools as a whole (statistical test 1) shows only 7 (21% - indicated with a red checkmark) are statistically worse than the others (at a 5% level of significance). Similarly, 18 are statistically better (53% - indicated with a green checkmark).

Comparing **yearly** PFI values for each school separately (statistical test 2) indicates that only 1 school (or 3% - indicated with a red checkmark) had a PFI statistically greater than the expected value of zero (performing worse). Alternatively, 13 schools (or 38% - indicated with a green checkmark) were statistically less than zero (performing better). Based on these results it is clear that urban school zones/areas studied are performing better than expected.

The average PFI for urban school zones was found to be 0.03 while it was 0.27 for urban school areas. While these values might suggest that school zones perform better than areas in urban environments, the results are not statistically significant at a 95% confidence level. The average PFI for urban schools consisting of both a zone and an area was 0.29. No statistically significant difference was found between schools with both a zone and an area present compared to schools consisting of a zone or an area only at a 95% confidence level. This suggests that school classification type does not play a significant role in the overall performance of the school.

Table 4.4 – Urban School Collision Analysis Results

School	Class	Actual Cols/Yr	Expected Cols/Yr	PFI	Stat. Test 1	Stat. Test 2
Bayview	Area	2.83	1.64	1.19	✓	-
George St	Zone/Area	2.13	1.03	1.10	✓	-
Moncton High	Area	2.69	1.60	1.09	✓	✓
FHS/Priestman	Zone	1.38	0.64	0.74	✓	-
Garden Creek	Zone/Area	0.88	0.27	0.61	✓	-
Hillcrest	Zone/Area	0.75	0.38	0.37	✓	-
Loch Lomond	Area	0.67	0.40	0.27	✓	-
Na'sis Memorial	Zone/Area	0.38	0.13	0.25	-	-
Ecole Champlain	Zone	0.31	0.08	0.23	-	-
Beaverbrook	Zone/Area	0.88	0.68	0.20	-	-
Forest Hill	Zone	0.25	0.06	0.19	-	-
Na'sis Middle	Zone	0.25	0.09	0.16	-	-
Devon Middle	Zone	0.25	0.14	0.11	-	-
Bliss Carman	Zone	0.20	0.11	0.09	-	-
Harrison Trimble	Area	0.13	0.04	0.09	-	-
Montgomery	Zone	0.13	0.09	0.04	-	-
Sunny Brae Middle	Zone	0.06	0.07	-0.01	✓	-
Lewisville	Zone	0.00	0.02	-0.02	✓	✓
Evergreen Park	Zone	0.00	0.02	-0.02	✓	✓
Arnold H. McLeod	Zone	0.00	0.03	-0.03	✓	✓
Sainte-Bernadette	Zone	0.06	0.09	-0.03	✓	-
Champlain Heights	Area	0.33	0.36	-0.03	✓	-
Barker's Point	Zone	0.00	0.05	-0.05	✓	✓
Forest Glen	Zone	0.00	0.05	-0.05	✓	✓
Park St	Zone	0.00	0.05	-0.05	✓	✓
Connaught St	Zone	0.00	0.08	-0.08	✓	✓
Northrup Frye	Zone	0.00	0.08	-0.08	✓	✓
Birchmount	Zone	0.13	0.21	-0.08	✓	-
Royal Road	Area	0.00	0.13	-0.13	✓	✓
Kingsclear	Zone/Area	0.50	0.63	-0.13	✓	-
Edith Cavell	Zone	0.00	0.16	-0.16	✓	✓
Liverpool St	Zone	0.00	0.34	-0.34	✓	✓
Bessborough	Zone/Area	0.31	0.67	-0.36	✓	✓
Prince Charles	Area	0.50	1.09	-0.59	✓	✓

*Check marks in RED or GREEN represent statistically significant PFI values for statistical test 1 and 2 at a 5% significance level.

The data presented in Table 4.3 indicate that the majority of collisions occurring in urban school zones/areas were rear-end or right-angle collisions. It is noteworthy that only 6% of all reported urban collisions involved a pedestrian.

There does not appear to be a clear difference in the origin city of the school zones/areas that are performing statistically better or worse than expected. The City of Fredericton began installing radar speed display boards at school zones in 2009 as a countermeasure to safety concerns with respect to speeding. Installations were staged over the course of a few years, and there are currently 12 of the 17 school zones equipped with display units. These units are placed in conjunction with the lowered posted speed limit of 30 km/h at the thresholds of the school zone and display an oncoming motorists' speed as they approach the zone. The display will flash if the motorists' speed exceeds the speed limit by greater than 5 km/h. The units are in operation from 7:30 a.m. to 4:00 p.m. to capture school operating hours.

The City of Moncton began posting a lowered speed limit sign of 30 km/h and a flashing beacon in conjunction with standard school zone signage in 2006. A sign states to motorists' that the lowered speed limit is only effective when the flashing beacon is in operation. This occurs during the peak morning and afternoon periods when school aged pedestrian and cyclist activity is at its highest. The process of installing this countermeasure at all elementary and middle schools located on local or collector roads within the City of Moncton was completed by 2008.

The City of Saint John only recently began implementing school zones with reduced speed limits as part of their “Safer School Zone Program”. This program aims to incorporate reduced speed limits as well as radar speed display boards at schools determined to benefit most from such a change. This program was initiated in 2014, therefore, data used in this research does not reflect changes made through the program.

It would be beneficial to explicitly explore the impacts of these different safety measures on collision frequencies further by analyzing collision data at each location before and after the measures were implemented as well as analyzing collision data between locations. Statistical analyses should be performed to determine if collision frequencies are statistically different after a specific measure was implemented as well as if there is a statistical difference between countermeasures.

The data summarized in Table 4.5 show the facility types present in each school zone/area. Those above the solid line are the schools performing worse than expected. It is notable that school zones/areas with intersections that are performing statistically worse than others tended to have much larger differences between volumes on the major and minor roadways that make up the intersection (a difference of 4000 vpd or more). It is also notable that the schools observed with signalized intersections present were found to be performing the worst with respect to collision experiences indicating that the presence of a signalized intersection may be a contributing factor to collision frequency in urban school zones/areas. This is logical as intersections introduce a greater number of conflict points for traffic.

Observations were made of other characteristics that may be contributing to urban schools performing worse than expected. Cursory analyses show that no other characteristics stand out as being predictive of higher collision frequencies. General observations are that school zones/areas performing worse tend to be located in more dynamic environments such as more central, downtown areas. Further analyses are presented in section 4.3.2 to explore the contributing factors to safety in urban school zones/areas**.**

4.2.2 Rural Schools

Results from rural school data presented in Table 4.6 below indicate 8 of the total 24 schools observed had a positive PFI, meaning that 33% of the schools were performing worse than expected. Alternatively, 16 (or 67%) were performing better than expected. Results from statistical test 1 show that 7 (29% - indicated with a red checkmark) of the schools were performing statistically worse on **average** than the overall group while 8 (33% - indicated with a green checkmark) were performing statistically better.

A comparison of **yearly** PFI values for each of the schools separately, however, indicated that 13 (or 54% - indicated with a green checkmark) schools had PFI values statistically lower than the expected value of zero, meaning they were performing statistically better over the years analyzed. There were no rural schools found to have yearly PFI values statistically higher than the expected value of zero. This indicates that rural schools are performing better than expected on a yearly basis when compared to similar road facilities outside of the influence of schools.

Table 4.5 – Urban School Facility Type(s) by School

School	School Zone/Area Facility Type	
Bayveiw	two road segments, three 3-leg unsignalized intersections, 3-leg signalized intersection	↑ Performing Worse Than Expected
George St	two road segments, 4-leg signalized intersection	
Moncton High	road segments, 4-leg signalized intersection, 4-leg unsignalized intersection, four 3-leg unsignalized intersections	
FHS/Priestman	two road segments, 3-leg signalized intersection, 3-leg unsignalized intersection	
Garden Creek	two road segments, three 3-leg unsignalized intersections	
Hillcrest	two road segments, 3-leg unsignalized intersection	
Loch Lomond	two road segments, 3-leg unsignalized intersection	
Na'sis Memorial	two road segments, 3-leg unsignalized intersection	
Ecole Champlain	road segment	
Beaverbrook	road segment, 4-lane road segment, 3-leg unsignalized intersection	
Forest Hill	road segment	
Na'sis Middle	road segment, 3-leg unsignalized intersection	
Bliss Carman	road segment	
Devon Middle	three road segments, two 4-leg unsignalized intersection	
Harrison Trimble	road segment, 3-leg unsignalized intersection, 3-leg all-way stop intersection	
Montgomery	road segment	
Sunny Brae	road segment	↓ Performing Better Than Expected
Lewisville	road segment	
Evergreen Park	road segment	
Arnold H. McLeod	road segment, two 3-leg unsignalized intersections	
Ecole Sainte-Bernadette	two road segments, 4-leg unsignalized intersection, 3-leg unsignalized intersection	
Forest Glen	two road segments, 3-leg unsignalized intersection	
Park St	two road segments, three 3-leg unsignalized intersections	
Connaught St	road segment, two 3-leg unsignalized intersections	
Northrup Frye	road segment, 3-leg unsignalized intersection	
Birchmount	road segment, 3-leg unsignalized intersection, 3-leg all-way stop intersection	
Champlain	road segment, 3-leg unsignalized intersection	
Barkers Point	road segment, 3-leg unsignalized intersection	
Royal Road	road segment	
Kingsclear	two road segment, three 3-leg unsignalized intersections	
Edith Cavell	two road segments, 4-leg all-way stop intersection	
Liverpool St	two road segments, two 3-leg unsignalized intersection	
Bessborough	two road segments, 4-leg unsignalized intersection, 4-leg all-way stop intersection, three 3-leg unsignalized intersections	
Prince Charles	road segment, two 3-leg unsignalized intersections	

*Segments are 2-lane/2-way and unsignalized intersections are minor road stop unless stated otherwise

Combining results, it appears that on average, rural schools are performing as expected when analyzed as a whole; however, separate yearly analyses indicate that the majority of rural schools are performing significantly better than the base value of zero.

Table 4.6 – Rural School Collision Analysis Results

School	Class	Actual Col/Yr	Expected Col/Yr	PFI	Stat. Test 1	Stat. Test 2
Belleisle Regional High	Zone	0.19	0.04	0.15	✔	-
Millville Elementary	Area	0.13	0.04	0.09	✔	-
Lawrence Station Elem.	Area	0.13	0.05	0.08	✔	-
Riverside Consolidated	n/a	0.06	0.01	0.05	✔	-
Stanley Consolidated	Area	0.06	0.02	0.04	✔	-
Harvey High	Area	0.06	0.03	0.03	✔	-
Juniper Elementary	n/a	0.06	0.03	0.03	✔	-
Central NB Academy	n/a	0.06	0.05	0.01	-	-
Minto Elem.-Middle	Area	0.00	0.01	-0.01	-	✔
Blacks Harbour	Area	0.06	0.07	-0.01	-	-
Dorchester Consolidated	n/a	0.00	0.01	-0.01	-	✔
Brown's Flat Elementary	Area	0.00	0.01	-0.01	-	✔
Janeville Elementary	Area	0.00	0.01	-0.01	-	✔
Pennfield Elementary	Area	0.00	0.01	-0.01	-	✔
Ecole La Villa-Des-Amis	Area	0.06	0.08	-0.02	-	-
Millerton	Area	0.00	0.02	-0.02	-	✔
Debec Elem.	n/a	0.00	0.03	-0.03	✔	✔
Cambridge-Narrows	n/a	0.00	0.03	-0.03	✔	✔
Miramichi Rural	Area	0.00	0.03	-0.03	✔	✔
Ecole Notre-Dame	Area	0.06	0.10	-0.04	✔	-
Ecole La Decouverte-De-Saint-Sauveur	Area	0.00	0.06	-0.06	✔	✔
Upper Miramichi Elem.	Area	0.00	0.06	-0.06	✔	✔
Back Bay Elementary	Area	0.00	0.07	-0.07	✔	✔
Bonar Law Mem. High	Area	0.00	0.09	-0.09	✔	✔

*Check marks in RED or GREEN represent statistically significant PFI values for statistical test 1 and 2 at a 5% significance level.

For comparison purposes, rural schools where motorists are required to adjust their speeds due to a posted change in speed within a close proximity (a few metres) to a school area sign were compared to those with no speed limit signs posted (or posted but with no change in speed). This was done to determine if a change in speed limit near a rural school area had a significant effect on performance. The average PFI for rural schools with a change in speed limit sign posted within close proximity was found to be 0.02 while those with no speed limit signs present was 0.002 for rural schools. Not surprisingly, the results are not statistically significant.

Results from Table 4.3 show that the majority of collisions occurring in rural school zones and areas are fairly evenly distributed between right-angle, rear-end, and single-vehicle. Again, a small proportion (only 7%) involved a pedestrian.

Characteristics of the rural schools analyzed can be found in Table 4.7 below. There are no obvious patterns with respect to features for schools performing worse or better than expected and no sound conclusions can be made regarding contributing factors. A potential pattern was observed with respect to rural schools with speed limit signs posted in close proximity to the school area sign. Rural schools that were performing worse than expected had speed limit signs posted either in conjunction with the school area sign at the entrances or a few metres after. Rural schools that performed better had speed limit signs posted before the school area sign. Further analyses with a larger sample size would be required to determine if this is a potential contributing factor to safety in rural school areas. No further patterns were found with respect to rural school areas.

Table 4.7 – Rural School Characteristics by School

School	School Zone/Area Characteristics	
Belleisle Regional High	Speed limit change from 80 km/h to 50 km/h (change in speed limit sign posted with school area sign at entrances), horizontal curve, narrow shoulder	Performing Worse Than Expected ↑
Millville Elementary	No speed limit change (50 km/h throughout), straight road segment	
Lawrence Station Elementary	Speed limit change from 80 km/h to 70 km/h (a few metres after school zone sign)	
Riverside Consolidated	No school zone/area signs	
Stanley Consolidated	No speed limit change (50 km/h throughout)	
Harvey High	Speed limit change from 80 km/h to 50 km/h at entrance (after school area sign)	
Juniper Elementary	n/a	
Central NB Academy	n/a	
Minto Elementary-Middle	No speed limit change (50 km/h throughout)	↓ Performing Better Than Expected
Blacks Harbour	No speed limit change (50 km/h throughout)	
Dorchester Consolidated	Turn off road to school from main road	
Brown's Flat Elementary	No speed limit change (60 km/h throughout)	
Janeville Elementary	No speed limit change (80 km/h throughout)	
Pennfield Elementary	Turn off road to school from main road	
Ecole La Villa-Des-Amis	No speed limit change (80 km/h throughout)	
Millerton	No speed limit change (80 km/h throughout)	
Debec	n/a	
Cambridge-Narrows	No speed limit change (80 km/h throughout)	
Miramichi Rural	No speed limit change (80 km/h throughout)	
Ecole Notre-Dame	No speed limit change, nicer road, flashing beacons for pedestrian crossing adjacent to school	
Ecole La Decouverte-De-Saint-Sauveur	Speed limit change from 80 km/h to 50 km/h at entrance (a few metres before school area sign)	
Upper Miramichi Elementary	No speed limit change (80 km/h throughout)	
Back Bay Elementary	Speed limit change from 80 km/h to 50 km/h at entrance (a few metres before school area sign)	
Bonar Law Memorial High	Speed limit change from 80 km/h to 50 km/h a few metres before school area sign	

4.3 Radar Speed Display Warrant System

Speed observations at the two test sites in Fredericton, NB that had radar speed display boards installed in 2010 were analyzed to determine their long-term effectiveness after additional boards have been deployed within the city. The radar speed display warrant system was then developed based on all previous data obtained through this study.

4.3.1 Long-term Effectiveness

Average speeds were determined at each of the three observation points in both directions and combined to obtain a total average speed for before and each time period after installation of the display boards. Detailed values for average speeds at the various observation points are presented in Tables C.1-C.4 in Appendix C. Results from the statistical analyses are also shown in Tables C.1-C.4. A summary of total average speeds is illustrated in Figure 4.1. The results included for before installation to the 4-year after period were taken from the previous study by Hildebrand *et al.* (2013). Since the installation of the original two radar speed display boards in Fredericton, NB, a total of 10 additional sets of units have been installed throughout the city.

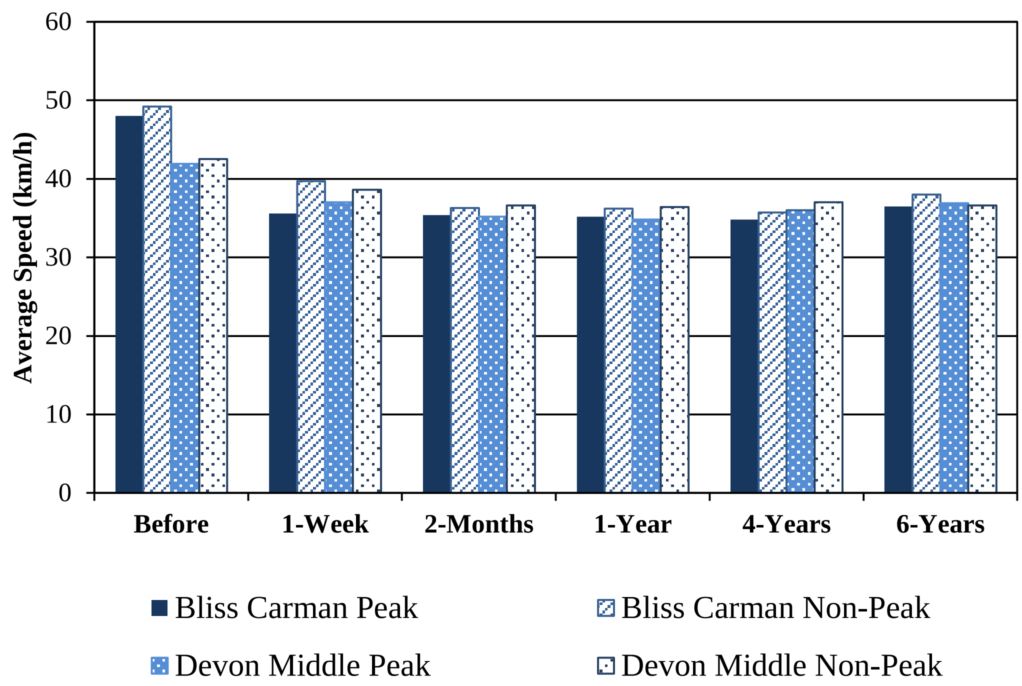

Figure 4.1 – Mean Speeds Before/After Speed Display Installation

Summarized results indicate that both Bliss Carman Middle School and Devon Middle have maintained a fairly consistent reduction in average speeds throughout all time periods after installation of the display units. Results from the t-tests show statistically significant reductions in average speeds for all periods after the display units were installed with the exception of a single observation at the 1-week period. Another finding of equal importance was that no statistically significant changes in speeds were found between 1-year and 6-years after the boards were installed. This indicates that speeds are still as low 6-years after the initial boards were installed as they were in the short-term period after installation (with no additional units in the network yet). Collectively, these results can conclude that radar speed display boards are still effective at reducing speeds even with additional boards added to the network.

4.3.2 Development of Radar Speed Display Warrant System

The warrant system for radar speed display usage in school zones was developed using two different approaches: 1) application of an SPF developed specifically for schools that involves estimating a PFI for individual sites, and 2) a more traditional points-based worksheet founded on relative weights of explanatory variables. In either case, a major task was the requirement to develop an SPF.

The results from the analyses on over-dispersion concluded that the variance of the data set exceeded the mean, indicating that a negative binomial regression model should be used. A zero-inflated model was selected because of the two different zero-count processes present for collision data. Combining these results, a zero-inflated negative binomial regression was used to model predictors for expected number of collisions in a school zone/area.

Urban and rural schools were modeled together because the development of an accurate model for predicted collisions at rural schools separately would not be possible given the characteristics of rural schools within this research. This is because of the lack of diversity in values for explanatory variables between the different rural schools. All rural schools had reasonably high speeds on long, relatively straight segments of roadways with no intersections present and comparable road volumes. Another contributing factor to the inability to model rural schools separately was the extremely low number of collisions occurring at each school. With such little variability in the study sample it would be difficult to accurately model the population of rural schools used in this research separately. For this reason, urban and rural schools were modeled together with an added dummy variable indicating whether a school was in a rural or urban location. This added predictor would determine if location (urban or rural) would significantly affect predicted collision frequency. Further research that involved more diverse rural school locations would be required to obtain an accurate model for expected collisions in rural school zones/areas separate from urban.

Potential explanatory variables were first tested for correlation using a correlation matrix to determine which should be excluded from the analysis. A correlation matrix was calculated using the statistical analysis toolpak available in Excel and is represented in Table 4.8.

Table 4.8 – Correlation Matrix Variables with Strong Correlations

	Unsig.nalized Intersection	**Avg. Speed**	**Classification**	**Crosswalk Present**	**Location (Urban or Rural)**
Unsignalized Intersection	1				
Avg. Speed	-0.45	1			
Classification	±0.36	±0.71	1		
Crosswalk Present	0.69	-0.64	±0.53	1	
Location	0.74	-0.70	±0.63	0.70	1

*Only variables with one or more strong correlations present (highlighted in red) were included in table

The potential explanatory variables found to be strongly correlated were presence of an unsignalized intersection and presence of a crosswalk; average speed and presence of a crosswalk; average speed and classification (zone, area, or zone/area); and presence of an unsignalized intersection, average speed, classification, and presence of a crosswalk all with location (either urban or rural). This strongly supports the decision to model urban and rural schools together. Correlation coefficients indicate that the majority of rural schools within the sample are all located on roadways with few intersections or crosswalks and higher speeds. For this reason all data were modelled together using the variable for the presence of an unsignalized intersection and/or crosswalk and the variable for average speed. The variable for location was excluded because of the strong correlation to included variables. Average speed was expected to be correlated with classification because a “zone” indicates a lowered speed limit (30 km/h in Canada); the classification variable was, therefore, excluded from the model as well.

Variables were modelled using SAS (a statistical software program). The SAS output from the final, most significant regression model is outlined in Table 4.9. Observed and predicted annual collisions were plotted to assess the goodness-of-fit of the model. Results for model fit can be found in Figure 4.2.

Results from indicate that the variables significantly affecting collision frequencies that follow a regular negative binomial distribution include total road volume (measured in average vehicles per day), the presence of a 4-leg or 3-leg signalized intersection, the number of unsignalized intersections present (0, 1, or <1), and the number of through lanes.

Table 4.9 – SAS Regression Model Output (final)

Analysis of Maximum Likelihood Parameter Estimates					
Parameter	**Coefficient**	**Standard Error**	**Wald 95% Confidence Limits**		**p-value**
Intercept	-5.4986	2.1340	-9.6812	-1.3161	0.0100
Road Vol. (Natural Log)	0.4069	0.2462	-0.0756	0.8894	0.0984
4-leg Signalized Intersection Present	2.1058	0.2764	1.5640	2.6476	<.0001
3-leg Signalized Intersection Present	1.6708	0.3366	1.0110	2.3306	<.0001
1 Unsignalized Intersection Present	0.7087	0.2937	0.1330	1.2844	0.0158
>1 Unsignalized Intersection Present	0.9534	0.2367	0.4894	1.4175	<.0001
Number of Through Lanes	0.7445	0.3519	0.0547	1.4343	0.0344
Dispersion	0.1761	0.1370	0.0383	0.8092	
Analysis of Maximum Likelihood Zero Inflation Parameter Estimates					
Parameter	**Coefficient**	**Standard Error**	**Wald 95% Confidence Limits**		**p-value**
Intercept	12.6341	4.1749	4.4513	20.8168	0.0025
Road Volume (Natural Log)	-1.5342	0.5049	-2.5237	-0.5447	0.0024
Length	-0.0059	0.0031	-0.0119	0.0001	0.0536

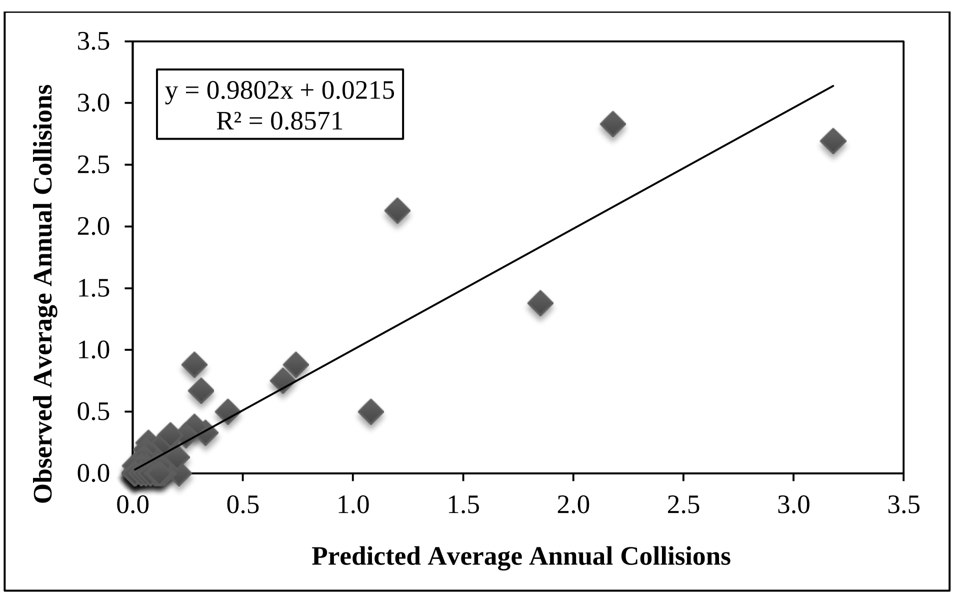

Figure 4.2 – Goodness-of-Fit (Final Model)

Table 4.10 – Summary of Statistical Analysis for Goodness-of-Fit

SUMMARY OUTPUT						
Regression Statistics						
Multiple R	0.92579264					
R Square	0.85709201					
Adjusted R Square	0.85428989					
Standard Error	0.23826148					
Observations	53					
ANOVA						
	df	*SS*	*MS*	*F*	*Significance F*	
Regression	1	17.363960	17.36396	305.87297	3.4048E-23	
Residual	51	2.8951951	0.056769			
Total	52	20.259155				
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0.021451	0.0368277	0.58248	0.56280913	-0.05248	0.095386
X Variable 1	0.980155	0.0560434	17.4892	3.4048E-23	0.86764	1.092666

The predictors selected to inflate the zero counts in the data was the natural logarithm of total road volume (AADT) as well as total length. This is because of the known relationship between road volume and collisions where roads with very low traffic volumes are less likely to experience a collision within the few years of collision history being analyzed (i.e., a zero collision count from the second process). Total length was used in the zero-inflated model to account for the difference in lengths (without normalizing data for length). This indicates that shorter school zones/areas would likely result in fewer collisions. Both variables were significant in the zero inflated model.

The goodness-of-fit was assessed by plotting the average observed annual collisions versus the predicted annual collisions for each school. The result is illustrated in Figure

4.2. The observed slope for the final model was 0.98 with an intercept of 0.02. These values were found to not be statistically different than 1.0 for the slope and not statistically different than zero for the intercept at a 95% confidence level, which indicates that the R-squared value for the line of best fit could be used to evaluate the goodness-of-fit of the model. Statistical results for the slope and intercept can be found in Table 4.10. The resulting R-squared value was 0.857 indicating a fairly solid model. It is also notable that the dispersion factor shown in the SAS output (Table 4.9) is greater than zero (0.1761), indicating that the zero-inflated negative binomial distribution was the correct functional model to use.

A number of trial models were run in order to select the most appropriate solution. The first trial model resulting in all significant variables, substituted the variable of number of lanes and unsignalized intersections with a single variable for the presence of an unsignalized intersection and/or crosswalk. The second trial model resulting in all significant variables, removed the variables for lanes and unsignalized intersections and included signalized and unsignalized crosswalks. Output results can be found in Tables D.1 and D.2 in Appendix D. Changes did not affect goodness-of-fit results significantly.

The resulting SPFs based on the final model are as follows:

$$a_1 = ({x_1}^{0.4069}) \times (e^{-5.4986+2.1058x_2+1.6708x_3+0.7087x_4+0.9534x_5+0.7445x_6}) \quad \text{[E. 4.1]}$$

$$a_2 = (e^{12.6341-0.0059x_7}) \times ((x_1)^{-1.5342}) \quad \text{[E. 4.2]}$$

$$p(ZI) = \frac{a_2}{1+ a_2} \quad \text{[E. 4.3]}$$

$$y = a_1 * (1 - p(ZI)) \quad \text{[E. 4.4]}$$

Where:

- $a1$ is the prediction established from the negative binomial model;
- $a2$ is the prediction established from the zero inflated model;
- x_1 is total road volume in average vehicles per day (AADT);
- x_2 is 1 for a 4-leg signalized intersection present or 0 for no 4-leg signalized intersection present;
- x_3 is 1 for a 3-leg signalized intersection present or 0 for no 3-leg signalized intersection present;
- x_4 is 1 for one unsignalized intersection or 0 for greater than one or no unsignalized intersection present;
- x_5 is 1 for greater than one unsignalized intersection or 0 for one or no unsignalized intersection present;
- x_6 is 1 for two through lanes present (in one direction) or 0 for one through lane present (in one direction);
- x_7 is the length of the school zone/area in metres
- $p(ZI)$ is the probability of the predicted collision following the zero inflated process (i.e. only resulting in a zero count); and
- y is the final predicted number of annual collisions in school locations **during school operating times only** (Monday-Friday, September 01-June 30, 7:30 a.m.-4:30 p.m.) based on both processes.

4.3.2.1 SPF-based Warrant System

SPF equations can be used to evaluate the performance of schools by computing the PFI for each school under analysis. This would be done by following the methodology described in sections 3.1.2 and 3.2.2. Schools delineated for safety counter-measures should be ranked by the road authority based on highest to lowest PFI. Schools performing the worst (corresponding with the highest PFI) might be selected as candidates for the installation of radar speed display devices.

4.3.2.2 Worksheet-based Warrant System

A warrant worksheet to be used as a guideline by road authorities to decide whether a radar speed display is justified was developed to provide a simpler decision tool. The product of the maximum value of a variable and its corresponding coefficient were calculated for all independent variables to determine the importance of each factor. The maximum value of binary variables was 1; for continuous variables the maximum value was determined as the average value of the largest bin. Relative weights of the product of the maximum value and coefficients for each variable were calculated which represent the Maximum Point Value (MPV) for each independent variable in the final worksheet. Results are indicated in Table 4.11, below.

Table 4.11 – Maximum Point Values

Explanatory Variable	Max. Value × Coefficient	Relative Weight (MPV)
Road Vol. (AADT)	3.68 (0.4069*ln(8593))	39
4-leg Signalized Intersection	2.1058	23
3-leg Signalized Intersection	1.6708	19
Unsignalized Intersection	0.9534	11
Number of Through Lanes	0.7445	8
Total	9.04	100

Weighting factors for each variable are based on the percentage of the product of the maximum value and its coefficient that corresponded with each bin value within a variable. Categorical range values were selected for each of the variables; for continuous variables the category ranges corresponded approximately with the four quartile values, for binary variables the categories were either present or not present (1 or 0). The weighted factors for the different categories of an independent variable were determined by calculating the percentage of the maximum coefficient that corresponded with each bin value within a variable. For binary variables, the coefficients were all or nothing. For continuous variables the average value corresponding to the category under analysis were multiplied by the coefficients for the variable in the SPF equations (Equations 4.1-4.4) including the zero-inflated model and compared to the maximum value. Results for weighted factors are displayed in Table 4.12, below.

Table 4.12 – Weighted Factors

Variable	Bin Ranges	Average	Coef.×Avg.	ZI	%	WF
Road Volume **(AADT)**	<800	700	2.67	1.03	0.28	**0.30**
	800-3000	2000	3.09	2.35	0.64	**0.66**
	3001-5000	4000	3.37	3.04	0.83	**0.85**
	5001-8000	6500	3.57	3.40	0.92	**0.95**
	>8000	8593	3.69	3.57	0.97	**1.00**
4-leg Signalized Intersection	Not Present	0	0	-	0.00	**0.00**
	Present	1	2.11	-	1.00	**1.00**
3-leg Signalized Intersection	Not Present	0	0	-	0.00	**0.00**
	Present	1	1.67	-	1.00	**1.00**
Unsignalized Intersection	Not Present	0	0	-	0.00	**0.00**
	1 Present	1	0.71	-	0.74	**0.74**
	>1 Present	1	0.95	-	1.00	**1.00**
Number of Through Lanes (per direction)	1	0	0	-	0.00	**0.00**
	>1	1	0.74	-	1.00	**1.00**

All collisions occurring in both urban and rural schools were categorized by severity to determine the distribution of each; severity levels included property damage only (PDO), injury, and fatality. The total cost of a collision based on severity level was taken as an average of the two sources found in the literature. Total cost of a collision occurring within school zones/areas was calculated as the sum of the collision severity distribution and the corresponding collision cost. Results are indicated in Table 4.13, below. It is notable that with no observed fatalities, the total weighted cost is significantly lower as a consequence.

Table 4.13 – Cost of Collision Based on Collision Type Distribution (normalized to 2015 Canadian Dollars)

	Collision Type		
	PDO	Injury	Fatality
Distribution (%)	0.68	0.32	0
Cost	$9,890	$105,200	$5,036,158
Weighted Cost	$6,725	$33,664	$0.00
			Total Cost: $40,390

The cost of a set of radar speed display boards (one for each end of a designated school zone) was obtained through discussion with the City of Fredericton Engineering Department. The total cost can range from $10,000 to $12,000 per unit (City of Fredericton, personal communication, October 2014). The average value of $11,000 per unit (multiplied by two units per school zone) was used. Lifespan of the display units can vary depending on location, however, given the harsh climate experienced in New Brunswick, the lifespan was estimated at 15 years.

A Collision Modification Factor (CMF) of 0.88 was estimated using the before and after collision data of schools within the sample that had radar speed displays installed within the years e`valuated. Results are indicated in Table 4.14, below. This value, although estimated using a small sample and not statistically proven, is reasonably close to the values of 0.93-0.95 found in the literature (Hallmark *et al.* 2015).

Table 4.14 – Collision Reduction Factor for Speed Display Devices in School Zones

School (year installed)	Avg. Collisions Before	Avg. Collisions After
Devon Middle (2010)	0.08	0.20
Beaverbrook (2010)	0.85	1.00
Hillcrest (2010)	0.85	0.50
Forest Hill (2010)	0.25	0.25
Alexander Gibson (2010)	0.00	0.00
Na'sis Memorial (2011)	0.40	0.33
Canterbury (2011)	0.00	0.00
Park St. (2012)	0.00	0.00
FHS/Priestman (2012)	1.15	1.00
Liverpool (2013)	0.00	0.00
Barkers Point (2013)	0.00	0.00
Montgomery (2013)	0.17	0.00
TOTAL	3.74	3.28
CMF	**0.88**	

Comparing the distribution of cost per collision in a school zone/area ($40,390) and the total cost of two display boards ($22,000), a total of 0.54 collisions would be required to be prevented over the 15-year life of the unit in order for the benefit of collisions reduced to cover the cost of the units. With a CMF of 0.88, a total of 4.54 collisions would need to occur within the lifespan of a radar speed display board to achieve a reduction of 0.54 collisions. At an estimated 15 year average life expectancy, this would result in a required 0.30 collisions per year. The threshold value was determined by plotting all possible scenarios and determining the volume that would yield a collision rate of the critical value of 0.30 collisions per year. Finally, the corresponding total score for each scenario was calculated, which represent the score at which the number of collisions occurring would warrant radar speed display installation, with the lowest score corresponding with the threshold value. The resulting threshold value is 42, however, maximum point values were scaled to represent a threshold value of 100. The plotted scenarios can be found in Figures D.3 to D.14 in Appendix D.

The final warrant sheet developed as a usage guideline for radar speed display devices in school zones is displayed in Table 4.15. The general design of the worksheet is based on the guideline for establishment of school zones and area from TAC (2006); however, as discussed above, the maximum point values and weighting factors have been developed empirically rather than relying on subjectivity and engineering judgement. The procedure to employ the worksheet is as follows (similar to procedure described in the TAC guideline):

1. Determine the appropriate description for each of the criterion in the worksheet for the school zone/area under analysis.
2. Multiply the corresponding weighted factor (WF) of the appropriate description with the maximum point value (MPV) for the respective criterion. Place this value in the score box.
3. Repeat for each criterion.
4. Sum all criterion scores for a final score and insert it in the respective box (bottom right corner).
5. If the score is greater than the threshold value (100) then a radar speed display board is justified based on cost-recovery.
6. Use engineering judgement and consider location specific conditions and usage guidelines (described below the warrant table) along with results of the worksheet to determine if a speed display unit should be installed.

Table 4.15 – Usage Guideline Worksheet for Radar Speed Displays in School Zones

INSTALLATION CRITERION	MAXIMUM POINT VALUE (MPV)	DESCRIPTION	WEIGHTING FACTOR (WF)	SCORE (MPV* WF)
Road Volume (AADT)	94	<800	0.30	
		800-3000	0.66	
		3001-5000	0.85	
		5001-8000	0.95	
		>8000	1.00	**RV=**
Signalized Intersection (4-leg)	55	Not Present	0.00	
		Present	1.00	**SI4 =**
Signalized Intersection (3-leg)	46	Not Present	0.00	
		Present	1.00	**SI3 =**
Unsignalized Intersection	26	Not Present	0.00	
		1 Present	0.74	
		>1 Present	1.00	**UI =**
Number of Through Lanes (one direction)	19	1	0.00	
		>1	1.00	**NTL =**
TOTAL SCORE (sum of RV, SI4, SI3, UI, NTL)				

If Total Score >100, Radar Speed Display Board is Warranted

Usage Guidelines:

- If school zone **EXCEEDS 350 metres** it should be given stronger consideration.
- A school zone with a **CROSSWALK** present should be given stronger consideration.
- Warrant is based on a **TWO-UNIT** installation per school zone.

It is important to emphasize that the threshold value for school zones warranting radar speed display installation is highly dependent on a number of different variables including the cost of collisions, the service life of radar speed displays, and the CMF of radar speed displays. The threshold value, as well as the weighting factors and maximum point values should continue to be updated as further research efforts are made to determine more statistically proven values for these variables. Variables could also change between jurisdictions and should be updated to reflect local conditions. It is important that engineering judgement be an included factor in the decision of whether or not a radar speed display is warranted.

4.3.2.3 Warrant System Application

The two approaches of the radar speed display warrant system were tested by applying the methods to all schools within the study samples. Results are synthesized in Tables 4.16 and 4.17 for the SPF-based approach for urban and rural schools, respectively; and Tables 4.18 and 4.19 for the worksheet approach for urban and rural schools, respectively.

After employing the first method, schools were ranked from highest PFI to lowest PFI. Schools with high PFIs would be prioritized for speed display installation. Results from the second approach were also ranked from highest to lowest total score. Schools with scores above the threshold value warrant radar speed display installation in terms of economic justification. It is important to note that because the threshold value depends on highly changeable variables that schools approaching the threshold value (values highlighted in grey) should not necessarily be disregarded. Other factors not included in the worksheet such as zone length and whether a crosswalk is present should also be considered.

It is also notable that the worksheet approach can be used to estimate which schools are likely to experience a greatest number of collisions, where a higher expected collision rate corresponds with a higher total score. This could be beneficial because it provides a more efficient method for comparing likely collision experiences between different candidate roadways. Total scores should be used along with results from the SPF-based warrant approach and engineering judgement to determine appropriate locations for radar speed display installation.

Results indicate that 50% of the urban schools and 25% of rural schools in New Brunswick are performing worse than expected according to the newly developed SPF models. Results from the worksheet approach indicate that of the urban schools performing worse than expected, 38% also had total scores that economically warranted radar speed displays. Many urban schools had total scores approaching 100 and should also be considered, particularly if they are also performing worse than expected. Results for rural schools indicate that none met the criteria for economically warranting radar speed display installation. This is not a surprise given that the majority of rural school zones/areas do not include intersections, particularly signalized, which is a major explanatory variable incorporated in the worksheet.

Table 4.16 – SPF-based Warrant Approach Trial (Urban)

School	Actual Col/Yr	Expected Col/Yr (E. 4.1-4.4)	PFI	
Bayview	2.83	2.18	0.65	↑ Performing Worse than Expected
George St	2.13	1.20	0.93	
Garden Creek	0.88	0.28	0.60	
Loc Lomond	0.67	0.31	0.36	
Devon Middle	0.25	0.07	0.18	
Beaverbrook	0.88	0.74	0.14	
Ecole Champlain	0.31	0.17	0.14	
Forest Hill	0.25	0.14	0.11	
Nashwaaksis Middle	0.25	0.14	0.11	
Nashwaaksis Memorial	0.38	0.28	0.10	
Harrison Trimble	0.13	0.05	0.08	
Kingsclear	0.50	0.43	0.07	
Bessborough	0.31	0.24	0.07	
Hillcrest	0.75	0.68	0.07	
Bliss Carman	0.20	0.15	0.05	
Ecole Sainte-Bernadette	0.06	0.02	0.04	
Montgomery	0.13	0.12	0.01	
Champlain	0.33	0.34	-0.01	↓ Performing Better than Expected
Evergreen Park	0.00	0.01	-0.01	
Arnold H. McLeod	0.00	0.01	-0.01	
Lewisville	0.00	0.01	-0.01	
Park St	0.00	0.04	-0.04	
Forest Glen	0.00	0.04	-0.04	
Connaught St	0.00	0.06	-0.06	
Birchmount	0.13	0.20	-0.07	
Sunny Brae Middle	0.06	0.13	-0.07	
Barker's Point	0.00	0.08	-0.08	
Royal Road	0.00	0.12	-0.12	
Edith Cavell	0.00	0.13	-0.13	
Northrup Frye	0.00	0.14	-0.14	
Liverpool St	0.00	0.21	-0.21	
FHS/Priestman	1.38	1.85	-0.47	
Moncton High	2.69	3.18	-0.49	
Prince Charles	0.50	1.08	-0.58	

Table 4.17 – SPF-based Warrant Approach Trial (Rural)

School	Actual Col/Yr	Expected Col/Yr (E. 4.1-4.4)	PFI	
Belleisle Regional High	0.19	0.06	0.13	**Performing ↑ Worse than Expected**
Millville Elementary	0.13	0.05	0.08	
Riverside Consolidated	0.06	0.01	0.05	
Stanley High	0.06	0.04	0.02	
Harvey High	0.06	0.04	0.02	
Lawrence Station Elementary	0.06	0.06	0.00	
Minto Elementary-Middle	0.00	0.01	-0.01	**Performing Better than Expected ↓**
Brown's Flat Elementary	0.00	0.01	-0.01	
Janeville Elementary	0.00	0.01	-0.01	
Pennfield Elementary	0.00	0.01	-0.01	
Millerton School	0.00	0.04	-0.04	
Blacks Harbour	0.06	0.11	-0.05	
Ecole La Villa-Des-Amis	0.06	0.11	-0.05	
Miramichi Rural School	0.00	0.06	-0.06	
Ecole Notre-Dame	0.06	0.12	-0.06	
Upper Miramichi Elementary	0.00	0.08	-0.08	
Ecole La Decouverte-De-Saint-Sauveur	0.00	0.10	-0.10	
Back Bay Elementary	0.00	0.11	-0.11	
Bonar Law Memorial High	0.00	0.12	-0.12	

Table 4.18 – Worksheet-based Warrant Approach Trial (Urban)

School	Total Score	
Moncton High	170	→ Meets Threshold
Bayview	166	
Fredericton High School/Priestman	159	
George St	149	
Prince Charles	139	
Beaverbrook	132	
Hillcrest	132	
Kingsclear	120	
Champlain	113	
Nashwaaksis Memorial	109	
Loc Lomond	109	
Garden Creek	106	
Birchmount	106	
Nashwaaksis Middle	99	Does Not Meet Threshold ←
Bliss Carman	94	
Forest Hill	94	
Ecole Champlain	94	
Montgomery	89	
Royal Road	89	
Sunny Brae	89	
Connaught St	88	
Liverpool	88	
Harrison Trimble	88	
Bessborough	88	
Barkers Point	81	
Northrop Frye	81	
Edith Cavell	81	
Lewisville	62	
Park St	54	
Ecole Sainte-Bernadette	54	
Arnold H. McLeod	54	
Devon Middle	54	
Forest Glen	47	
Evergreen Park	28	

*Schools with crosswalks present and/or longer lengths should be given stronger consideration

Table 4.19 – Worksheet-based Warrant Approach Trial (Rural)

School	Total Score	
Ecole Notre-Dame	80	Does Not Meet Threshold ↓
Ecole La Villa-Des-Amis	80	
Bonar Law Memorial High	80	
Blacks Harbour	80	
Ecole La Decouverte-De-Saint-Sauveur	80	
Back Bay Elementary	80	
Belleisle Regional High	62	
Lawrence Station Elementary	62	
Upper Miramichi Elementary	62	
Stanley High	62	
Miramichi Rural School	62	
Harvey High	28	
Millerton School	28	
Riverside Consolidated	28	
Brown's Flat Elementary	28	
Pennfield Elementary	28	
Minto Elementary-Middle	28	
Janeville Elementary	28	
Millville Elementary	28	

*Rural schools tended to be longer than average and should be given stronger consideration

It is clear based on the variation in results that the two methods for warranting radar speed displays are not comparable. This is because of the difference in theory used in the two approaches. The SPF-based approach takes into consideration both the observed and expected collisions and compares the two values to determine how a specific school location is performing (worse or better than expected). Alternatively, the worksheet-based approach only accounts for the expected collisions and compares to a threshold value where a speed display unit would be cost-effective. The SPF-based warrant approach is useful for determining the most appropriate locations to use a radar speed display device in terms of improving safety; it does not, however, ensure it is a cost-effective solution. The worksheet-based approach would be appropriate where robust collision data are not available or where a quick estimate of whether or not a radar speed display unit would be economically justified is adequate (or a quick estimate of expected annual collisions). Ideally, the two methods would be used in conjunction to determine the most appropriate candidate school zones for radar speed display installation. In either case, the warrant system should be used as a guide along with engineering judgement.

4.4 Summary

A sample of urban and rural schools in New Brunswick were evaluated first in terms of classification procedures. No significant difference was found between the collision performance of schools within different jurisdictions despite the differences in classification approaches. This suggests that consistent classification of schools as either zones or areas does not significantly affect performance from a safety aspect. The sample of schools was then evaluated in terms of safety performance. It was determined that schools in both urban and rural areas are performing better than expected on average as well as on an individual yearly basis (compared to similar road facilities outside of the influence of a school).

Radar speed displays, a supplemental safety countermeasure used in many urban New Brunswick schools, were re-evaluated to determine if they are still effective at reducing motorists' speeds even after an increase in the number of devices have been installed at schools within the same network. Statistically significant speed reductions were still existent at two test locations six years after the initial boards were installed. Within the six year time period, 10 additional devices were installed at other schools within the City of Fredericton. Results can conclude that radar speed displays are still effective at reducing speeds long-term even with additional boards added to the network.

Collision count data for each of the urban and rural schools were modelled together to determine school zone/area characteristics that had the best predictive ability of collisions occurring in school zones/areas within school operating times. Results indicate that the presence of a signalized intersection (3-leg or 4-leg), the number of unsignalized intersections present (0, 1, >1), the number of through lanes, and the road volume all had a significant positive effect on collision rate. The model produced a set of equations that represent SPFs specifically for school zones/areas that were used to develop a warrant system for radar speed display usage using two separate approaches. The first is an SPF-based warrant system: SPF equations can be used by road authorities to calculate the PFI of candidate schools for radar speed displays. Schools selected for radar speed display installation should correspond with those performing the worst with respect to safety. The second approach is a traditional worksheet-based warrant system: road authorities can use the worksheet developed to determine a final score for candidate schools. Schools resulting in a total score greater than the threshold value would warrant radar speed display installation on the basis of cost-effectiveness.

The two approaches yield non-comparable results because of difference in theoretical framework of the two. The first approach compares observed school zone collisions with predicted school zone collisions while the second approach uses school zone characteristics to estimate if the cost of radar speed displays would be covered by the resulting collision reduction. Ideally, the two approaches would be used collectively along with engineering judgement to determine the most appropriate locations for radar speed displays in school zones.

5 Conclusions and Recommendations

A sample of school zones/areas from urban and rural locations in New Brunswick was selected to assess their performance with respect to safety. The urban school sample included all public schools within the City of Fredericton, the City of Moncton, and a portion of schools within the City of Saint John. The rural school sample was selected at random to provide a geographical representation of all rural schools in New Brunswick. Research included three related areas that included school zone and area establishment practices, collision data analysis, and the overall goal of developing a radar speed display warrant system for use in school zones.

5.1 Conclusions

School establishment was evaluated first to determine if the consistent classification of schools as either zones or areas had an effect on the overall safety performance. The *School and Playground Areas and Zones: Guidelines for Application and Implementation* was used as a reference guide (TAC 2006). Results indicate that 24% of the urban schools and 32% of the rural schools had at least one adjacent roadway that was not in compliance with the TAC guideline. No statistical difference was found between the PFI values for schools properly classified according to TAC and those that were not for both urban and rural locations. This suggests that there is no statistical differences in performance from a safety perspective despite the various approaches New Brunswick municipalities employ for school classification.

Collision history data were used to evaluate whether or not safety was real or perceived concern for school zones/areas. Results indicate that on average, only 21% of urban schools and 29% of rural schools were performing statistically worse than the group as a whole. Alternatively, 53% of urban schools and 33% of rural schools were performing better on average than the group as a whole. Comparing yearly PFI values for schools separately indicated that only 3% of urban schools and 0% of rural schools had a PFI statistically greater than the base value of zero (i.e. performing statistically worse). Similarly, 38% of urban schools and 54% of rural schools had a PFI value statistically less than the base value of zero (i.e. performing statistically better). Overall, results indicate that schools in New Brunswick are performing better than expected.

A comparison of the PFI values for school zones, areas, and zones/areas for urban schools showed no statistical difference with respect to collision rates. A similar comparison for rural schools with reduced speed zones established within close proximity of a school versus schools with no change in speed limit found there to be no statistical difference in their collision performance. Most collision types were either rear-end, right-angle or single vehicle. Only a small percentage of collisions (6% overall) involved pedestrians. It is notable that both rural and urban schools are experiencing a higher percentage of right-angle and rear-ended collisions, however, only rural schools also had a high percentage of single-vehicle collisions.

Radar speed display devices were evaluated in terms of their long-term effectiveness to determine if addition deployments of devices within a network had a negative effect. Statistical analyses indicate that the average speed of drivers through school zones equipped with radar speed display devices continue to be significantly lower than before the devices were installed even with additional sets of devices installed at other schools within a network.

The overall research goal involved the development of a radar speed display warrant system for use in school zones. Two different approaches were taken that included an SPF-based warrant system and a traditional worksheet-based warrant system. Both approaches required an appropriate regression model relating predictive variables to annual collision rates in school zones/areas; the selected model format was a zero-inflated negative binomial because of its ability to appropriately model collision count data with excess zeros. The most significant model included road volume (AADT), the presence of a signalized intersection (3-leg or 4-leg), the number of unsignalized intersections present (0, 1, <1), and the number of through lanes. Resulting equations essentially provide SPF models with fairly strong predictive abilities relating specifically to school zones/areas.

The first warrant approach developed involves using the developed SPF equations to determine the PFI for candidate roadways, which are then ranked from highest to lowest. Schools that would be most appropriate for radar speed display installation would correspond with the highest PFI (performing the worst in terms of safety). The second approach uses the worksheet presented in Table 4.14. A road authority would complete the worksheet for each candidate roadway to get a total score for each. If the total score meets or exceeds the threshold limit then a radar speed display installation would be warranted. Ideally a road authority would use the two approaches in conjunction, where the most appropriate locations for radar speed display installation would be those that meet the minimum threshold value for cost recovery and are performing worse than expected in terms of safety.

5.2 Recommendations

The following section summarizes recommendations for using the warrants developed through this research as well as for future research.

- Schools involved in this study should be analyzed further by performing before and after studies of collision data for the urban school zones that use different safety countermeasures. For example, this could determine if the use of flashing beacons to indicate a reduced speed limit throughout a school zone during peak periods (Moncton) is more effective at reducing collision frequency than radar speed display units (Fredericton).

- Schools currently using radar speed displays should be analyzed with before and after studies of collision data for the urban school zones that had radar speed display devices installed. This would determine the effectiveness of radar speed display devices on collision frequency and ultimately determine a more accurate CMF for radar speed displays.

- A more robust study could include more diverse rural school locations that include a wider range of rural school facility types (i.e. include rural school locations with signalized, unsignalized intersections, and/or crosswalks). This would allow urban and rural schools to be modelled separately with higher accuracy.

- Further research is recommended to determine the maximum number of radar speed displays that should be used within a city so that effectiveness is not compromised. Empirical-Bayesian analyses are recommended to determine if safety is compromised with the increase deployments of radar speed displays at school zones in New Brunswick. It is unclear whether there might be a dilution of their impact as they become common place (novelty effect) or if there are any spillover benefits to schools not treated (halo effect).

- This research assumed that independent predictive variables remained constant throughout each of the years of collision count data included. It is recommended that these variables be adjusted to reflect each year, though it is likely that minimal change will be present for most variables. This particularly applies to AADT values that could change yearly, as SPF equations rely heavily on this variable.

- The traditional warrant worksheet developed through this research was based on SPF equations that related collision count data to characteristics of schools found to have the greatest predictive abilities of collision frequency. It is recommended to develop a warrant system built on site characteristics of schools determined to be performing worse than expected. This would result in radar speed displays being warranted for locations with a high potential for improvement rather than solely based on economic justification.

- The SPF equations were developed based on New Brunswick schools and their characteristics. It is recommended that any jurisdiction using these equations to predict collisions at schools within their respective location first calibrate the models to reflect local conditions. The calibration process should follow that described in the Highway Safety Manual Volume 1 Appendix A1 (AASHTO 2010).

- Future research involving SPF models for school zones/areas should normalize school zone/areas by length first to include only collisions occurring within a predetermined length. Data should be run through the regression model with the collisions occurring within the normalized length only.

- The threshold value for schools warranting radar speed display installation is heavily dependent on a CMF value and service life of radar speed displays as well as the assumed cost of collision. It is recommended to perform a sensitivity analysis on variables that make up the threshold value (CMF of radar speed displays, cost of collision, and service life of radar speed displays). Values should be updated as future research relating to these variables is made available.

6 References

Alberta Infrastructure and Transportation. 2007. Guidelines for School and Playground Zones and Areas. Technical Standards Branch, Alberta Infrastructure and Transportation, Edmonton, Alberta.

Al-Dulaimi, M. 2015. A Method to Calibrate Roadway Lighting Warrants and Levels with Crash-History. Ph.D. thesis, Department of Civil, Building and Environmental, Concordia University, Montreal, Quebec.

American Association of State Highway and Transportation Officials (AASHTO). 2010. "Highway Safety Manual Volume 1 and 2, 1st ed". The American Association of State Highway and Transportation Officials. Washington, D.C.

Armstrong, J., Petch, Z. 2013. School Walking Hazard Guidelines. Proceeding of the 2013 Transportation Association of Canada Conference. Winnipeg, MB, 22-25 September, 2013.

D'Amours Ouellet, A., Cloutier, M. 2014. School Environment and Road Traffic Conflicts Involving Child Pedestrians: Preliminary Results. Presentation: 24th Canadian Multidisciplinary Road Safety Conference. Vancouver, BC, 1-4 June, 2014.

Devore, J.L. 2008. Probability and Statistics for Engineers and the Sciences. Thomson Higher Education, Belmont, CA.

Federal Highway Administration (FHWA). 2005. Crash Cost Estimates by Maximum Police-Reported Injury Severity Within Selected Crash Geometries. GHWAY-HRT-05-051. Available from http://www.fhwa.dot.gov/publications/research /safety/05051/03.cfm#cra [accessed 24 November 2015].

Federal Highway Administration (FHWA). 2009. Manual on Uniform Traffic Control Devices. U.S. Department of Transportation. Transportation Research Board. Washington, D.C.

Gunter, C., Hildebrand, E. 2008. Quantifying the Benefits of Road Safety Audits. Proceedings of the 18th Canadian Multidisciplinary Road Safety Conference, Whistler, BC. June 8-11, 2008.

Hallmark, S.L., Qiu, Y., Hawkins, N., Smadi, O. 2015. Crash Modification Factors for Dynamic Speed Feedback Signs on Rural Curves. Journal of Transportation Technologies, 5, 9-23.

Hawkins, G.H. 2007. Rear-Facing School Speed Limit Beacons. ITE Journal, **77**(6): 18-23.

Irwin, G.B., Faulks, J.D., Chekaluk, E. 2014. Do motorists really intend to speed in school zones? Road safety issues raised by Gregory *et al.* (2014) paper reporting speeding can be attributed to a failure in prospective memory. Proceedings of the 2014 Australasian Road Safety Research, Policing & Education Conference 12 – 14 November, Grand Hyatt Melbourne.

Kattan, L., Tay, R., & Acharjee, S. 2011. Managing speed at school and playground zones. Accident Analysis & Prevention, **43**(5), 1887-1891.

Lawrence, B., Miller, T.R., Zaloshnja, E., Lawrence, B.A. 2014. The Economic and Societal Impact of Motor Vehicle Crashes, 2010. Report No. DOT HS 812 013. Washington, DC:National Highway Traffic Safety Administration

Lazic, G. 2003. School Speed Zones: Before and After Study City of Saskatoon. Proceedings of the 2003 Annual Conference of the Transportation Association of Canada, St. John's, Newfoundland and Labrador.

National Cooperative Highway Research Program. 1974. Warrants for Highway Lighting. Transportation Research Board. National Research Council. Washington, D.C.

National Safety Council (NSC). 2012. Estimating the Costs of Unintentional Injuries. Illinois, 2014.

O'Brien, S. W., Simpson, C.L. 2012. Use of "Your Speed" Changeable Message Signs in School Zones: Experience from North Carolina Safe Routes to School Program. Transportation Research Record: Journal of the Transportation Research Board, **1981**(2318), 128-136. doi: 10.3141/2318-15.

Schroeder, P., Kostyniuk, L., & Mack, M. 2013. 2011 National Survey of Speeding Attitudes and Behaviors. (Report No. DOT HS 811 865). Washington, DC: National Highway Traffic Safety Administration.

Schwebel, D.C., Davis, A.L., O'Neal, E.E. 2011. Child Pedestrian Injury: A Review of Behavioural Risks and Preventive Strategies. American Journal of Lifestyle Medicine, **6**(4): 292-302. doi:10.1177/0885066611404876.

Simpson, C. 2008. Evaluation of Effectiveness of School Zone Flashers in North Carolina. Journal of the Transportation Research Board, **2074**: 21-28. doi: 10.3141/207403.

Strawderman, L., Zhang, L., Huang, Y. Nandi, A. 2013. Driver Speed Limit Compliance in School Zones: Assessing the Impact of Sign Saturation. Final Report No. FHWA/MS-DOT-RD-13-253. Mississippi Department of Transportation.

TAC. 1999. Geometric Design Guide for Canadian Roads. Transportation Association of Canada.

TAC. 2006. School and Playground Areas and Zones: Guidelines for Application and Implementation. Transportation Association of Canada.

Transport Canada. 2015. Canadian Motor Vehicle Traffic Collision Statistics 2013. Available from https://www.tc.gc.ca/media/documents/roadsafety/cmvtcs2013_eng.pdf [accessed 18 March 2016].

Veneziano, D., Hayden, L., Ye, J. 2010. Effective Deployment of Radar Speed Signs. Final report for California and Oregon Advanced Transportation Systems (COATS) Phase IV. State of California, Department of Transportation Division of Research and Innovation and U.S. Department of Transportation Research and Innovative Technology Administration.

Walsh, J., Rothman, L., Slater, M., Steverango, C., Howard, A. 2009. Are school zones effective? An examination of motor vehicle versus child pedestrian crashes near schools. Injury Prevention, **15**: 226-229. doi: 10.1136/ip.2008.020446.

Washington, S.P., Karlaftis, M.G. 2012. Statistical and Econometric Methods for Transportation Data Analysis, Second Edition. Taylor and Francis Group, Boca Raton, FL.

Appendix A – School Zone and Area Establishment

Table A.1 – TAC Guideline Scoring System (TAC, 2006)

TOTAL SCORE	AREA OR ZONE?
0-40	Nothing
41-64	SCHOOL AREA
65-80	SCHOOL AREA or SCHOOL ZONE
81-100	SCHOOL ZONE

Appendix B – Collision Data Analysis

Table B.1 – Model Calibration Factors

	Facility Type	HSM Model	BC Model
Fredericton	Urban Road Segments (2-lane)	0.94	0.59
	Urban Road Segments (4-lane)	n/a	n/a
	Urban 3-leg Unsignalized Intersection	0.92	0.96
	Urban 3-leg Signalized Intersection	0.51	0.50
	Urban 4-leg Unsignalized Intersection	0.77	0.90
	Urban 4-leg Signalized Intersection	1.08	1.03
Moncton	Urban Road Segments (2-lane)	0.94	0.59
	Urban Road Segments (4-lane)	1.31	1.45
	Urban 3-leg Unsignalized Intersection	0.56	0.78
	Urban 3-leg Signalized Intersection	n/a	n/a
	Urban 4-leg Unsignalized Intersection	1.31	1.73
	Urban 4-leg Signalized Intersection	1.37	1.31
Rural NB	Road Segment (2-lane)	0.83	0.45

Table B.2 – School Time Collision Distribution

City	Year	Total Collisions	Total Collisions (School Operating Times)	School Time Collision Factor
Fredericton	2012	1066	444	0.42
	2011	1230	462	0.38
	2010	1212	398	0.33
	2009	1334	464	0.35
	2008	1395	463	0.33
	2007	1315	480	0.37
			Average:	**0.36**
Moncton	2012	1855	630	0.34
	2011	2494	931	0.37
	2010	2637	930	0.35
	2009	2557	892	0.35
	2008	2357	815	0.35
	2007	2251	794	0.35
			Average:	**0.35**
Saint John	2012	776	254	0.33
	2011	813	250	0.31
	2010	864	223	0.26
	2009	1010	311	0.31
	2008	908	262	0.29
	2007	818	244	0.30
			Average:	**0.30**
Rural	2012	7957	2603	0.33
	2011	9506	3391	0.36
	2010	10096	3192	0.32
	2009	10648	3552	0.33
	2008	10238	3393	0.33
	2007	9796	3343	0.34
			Average:	**0.33**

Table B.3 – Urban School Collision Analysis Results – Stat. Test 1 (By Group)

School	Avg. Actual Cols/Yr	Expected Cols/Yr	Avg. PFI	z-stat*
Bayview	2.83	1.64	1.19	-15.68
George St	2.13	1.03	1.10	-14.35
Moncton High	2.69	1.60	1.09	-14.2
FHS/Priestman	1.38	0.64	0.73	-8.87
Garden Creek	0.88	0.27	0.61	-7.09
Hillcrest	0.75	0.38	0.37	-3.54
Loch Lomond	0.67	0.4	0.27	-2.06
Na’sis Memorial	0.38	0.13	0.24	-1.61
Ecole Champlain	0.31	0.08	0.23	-1.46
Beaverbrook	0.88	0.68	0.2	-1.02
Forest Hill	0.25	0.06	0.19	-0.87
Na’sis Middle	0.25	0.09	0.16	-0.43
Bliss Carman	0.25	0.11	0.09	0.61
Devon Middle	0.25	0.14	0.11	0.31
Harrison Trimble	0.13	0.04	0.09	0.61
Montgomery	0.13	0.09	0.04	1.35
Sunny Brae Middle	0.06	0.07	-0.01	2.09
Lewisville	0.00	0.02	-0.02	2.24
Evergreen Park	0.00	0.02	-0.02	2.24
Arnold H. McLeod	0.00	0.03	-0.03	2.39
Sainte-Bernadette	0.00	0.09	-0.03	2.39
Champlain Heights	0.33	0.05	-0.05	2.68
Barker's Point	0.00	0.05	-0.05	2.68
Forest Glen	0.00	0.06	-0.06	2.83
Park St	0.00	0.08	-0.08	3.13
Connaught St	0.00	0.08	-0.08	3.13
Northrup Frye	0.00	0.21	-0.08	3.13
Birchmount	0.13	0.36	-0.03	2.39
Royal Road	0.00	0.13	-0.13	3.87
Kingsclear	0.50	0.63	-0.13	3.87
Edith Cavell	0.00	0.16	-0.16	4.31
Liverpool St	0.00	0.34	-0.34	6.98
Bessborough	0.31	0.67	-0.36	7.27
Prince Charles	0.50	1.09	-0.59	10.68
		Avg:	**0.13**	
		St.Dev.:	**0.39**	

*Values highlighted in RED or GREEN are statistically significant compared to the group at a 5% level of Significance

Table B.4 – Urban Collision Analysis Results – Stat. Test 2 (By Year)

	Year	Actual Collisions	Expected Collisions	PFI	Avg PFI	St.Dev	t-stat*	t-crit
Bayview	2009	1	1.64	-0.64				
	2010	2	1.64	0.36				
	2011	2	1.64	0.36				
	2012	8	1.64	6.36				
	2013	2	1.64	0.36				
	2014	2	1.64	0.36	1.19	2.56	-1.14	±2.57
George	2005	4	1.03	2.97				
	2006	3	1.03	1.97				
	2007	2	1.03	0.97				
	2008	1	1.03	-0.03				
	2009	3	1.03	1.97				
	2010	3	1.03	1.97				
	2011	0	1.03	-1.03				
	2012	1	1.03	-0.03	1.10	1.36	-2.29	±2.37
Moncton	1997	1	1.60	-0.60				
	1998	6	1.60	4.40				
	1999	2	1.60	0.40				
	2000	1	1.60	-0.60				
	2001	3	1.60	1.40				
	2002	2	1.60	0.40				
	2003	1	1.60	-0.60				
	2004	6	1.60	4.40				
	2005	1	1.60	-0.60				
	2006	3	1.60	1.40				
	2007	3	1.60	1.40				
	2008	2	1.60	0.40				
	2009	6	1.60	4.40				
	2010	1	1.60	-0.60				
	2011	5	1.60	3.40				
	2012	0	1.60	-1.60	1.09	2.02	-2.16	±2.13
FHS/Priestman	2007	3	0.64	2.36				
	2008	4	0.64	3.36				
	2009	2	0.64	1.36				
	2010	0	0.64	-0.64				
	2011	0	0.64	-0.64				
	2012	0	0.64	-0.64				
	2013	1	0.64	0.36				
	2014	1	0.64	0.36	0.74	1.51	-1.39	±2.37
Garden Creek	2005	2	0.27	1.73				
	2006	1	0.27	0.73				

	2007	1	0.27	0.73				
	2008	0	0.27	-0.27				
	2009	0	0.27	-0.27				
	2010	2	0.27	1.73				
	2011	0	0.27	-0.27				
	2012	1	0.27	0.73	0.61	0.83	-2.08	±2.37
Hillcrest	1997	0	0.38	-0.38				
	1998	2	0.38	1.62				
	1999	1	0.38	0.62				
	2000	0	0.38	-0.38				
	2001	0	0.38	-0.38				
	2002	0	0.38	-0.38				
	2003	0	0.38	-0.38				
	2004	2	0.38	1.62				
	2005	0	0.38	-0.38				
	2006	3	0.38	2.62				
	2007	1	0.38	0.62				
	2008	1	0.38	0.62				
	2009	1	0.38	0.62				
	2010	1	0.38	0.62				
	2011	0	0.38	-0.38				
	2012	0	0.38	-0.38	0.37	0.93	-1.59	±2.13
Loch Lomond	2009	0	0.4	-0.4				
	2010	1	0.4	0.6				
	2011	2	0.4	1.6				
	2012	0	0.4	-0.4				
	2013	0	0.4	-0.4				
	2014	1	0.4	0.6	0.27	0.82	-0.81	±2.57
Na’sis Memorial	2007	2	0.13	1.87				
	2008	0	0.13	-0.13				
	2009	0	0.13	-0.13				
	2010	0	0.13	-0.13				
	2011	0	0.13	-0.13				
	2012	0	0.13	-0.13				
	2013	1	0.13	0.87				
	2014	0	0.13	-0.13	0.25	0.74	-0.96	±2.37
Ecole Champlain	1997	0	0.08	-0.08				
	1998	0	0.08	-0.08				
	1999	0	0.08	-0.08				
	2000	0	0.08	-0.08				
	2001	0	0.08	-0.08				
	2002	2	0.08	1.92				
	2003	1	0.08	0.92				

	2004	0	0.08	-0.08				
	2005	0	0.08	-0.08				
	2006	1	0.08	0.92				
	2007	0	0.08	-0.08				
	2008	0	0.08	-0.08				
	2009	0	0.08	-0.08				
	2010	1	0.08	0.92				
	2011	0	0.08	-0.08				
	2012	0	0.08	-0.08	0.23	0.60	-1.53	±2.13
Beaverbrook	1997	1	0.68	0.32				
	1998	0	0.68	-0.68				
	1999	2	0.68	1.32				
	2000	1	0.68	0.32				
	2001	0	0.68	-0.68				
	2002	0	0.68	-0.68				
	2003	1	0.68	0.32				
	2004	1	0.68	0.32				
	2005	1	0.68	0.32				
	2006	1	0.68	0.32				
	2007	0	0.68	-0.68				
	2008	3	0.68	2.32				
	2009	0	0.68	-0.68				
	2010	2	0.68	1.32				
	2011	1	0.68	0.32				
	2012	0	0.68	-0.68	0.20	0.89	-0.90	±2.13
Forest Hill	2007	1	0.06	0.94				
	2008	0	0.06	-0.06				
	2009	0	0.06	-0.06				
	2010	0	0.06	-0.06				
	2011	0	0.06	-0.06				
	2012	1	0.06	0.94				
	2013	0	0.06	-0.06				
	2014	0	0.06	-0.06	0.19	0.46	-1.16	±2.37
Na’sis Middle	2007	0	0.09	-0.09				
	2008	0	0.09	-0.09				
	2009	1	0.09	0.91				
	2010	1	0.09	0.91				
	2011	0	0.09	-0.09				
	2012	0	0.09	-0.09				
	2013	0	0.09	-0.09				
	2014	0	0.09	-0.09	0.16	0.46	-0.98	±2.37

Devon Middle	2007	1	0.14	0.86				
	2008	0	0.14	-0.14				
	2009	0	0.14	-0.14				
	2010	0	0.14	-0.14				
	2011	1	0.14	0.86				
	2012	0	0.14	-0.14				
	2013	0	0.14	-0.14				
	2014	0	0.14	-0.14	0.11	0.46	-0.68	±2.37
Bliss Carmen	2010	1	0.11	0.89				
	2011	0	0.11	-0.11				
	2012	0	0.11	-0.11				
	2013	0	0.11	-0.11				
	2014	0	0.11	-0.11	0.09	0.45	-0.45	±2.78
Harrison Trimble	1997	0	0.04	-0.04				
	1998	0	0.04	-0.04				
	1999	0	0.04	-0.04				
	2000	0	0.04	-0.04				
	2001	1	0.04	0.96				
	2002	0	0.04	-0.04				
	2003	0	0.04	-0.04				
	2004	0	0.04	-0.04				
	2005	0	0.04	-0.04				
	2006	0	0.04	-0.04				
	2007	0	0.04	-0.04				
	2008	1	0.04	0.96				
	2009	0	0.04	-0.04				
	2010	0	0.04	-0.04				
	2011	0	0.04	-0.04				
	2012	0	0.04	-0.04	0.09	0.34	-1.06	±2.13
Montgomery	2007	0	0.09	-0.09				
	2008	0	0.09	-0.09				
	2009	0	0.09	-0.09				
	2010	0	0.09	-0.09				
	2011	0	0.09	-0.09				
	2012	0	0.09	-0.09				
	2013	1	0.09	0.91				
	2014	0	0.09	-0.09	0.04	0.35	-0.32	±2.37
Sunny Brae	1997	0	0.07	-0.07				
	1998	0	0.07	-0.07				
	1999	0	0.07	-0.07				
	2000	0	0.07	-0.07				
	2001	0	0.07	-0.07				
	2002	0	0.07	-0.07				
	2003	0	0.07	-0.07				

	2004	0	0.07	-0.07				
	2005	0	0.07	-0.07				
	2006	1	0.07	0.93				
	2007	0	0.07	-0.07				
	2008	0	0.07	-0.07				
	2009	0	0.07	-0.07				
	2010	0	0.07	-0.07				
	2011	0	0.07	-0.07				
	2012	0	0.07	-0.07	-0.01	0.25	0.16	±2.13
Lewisville	1997	0	0.02	-0.02				
	1998	0	0.02	-0.02				
	1999	0	0.02	-0.02				
	2000	0	0.02	-0.02				
	2001	0	0.02	-0.02				
	2002	0	0.02	-0.02				
	2003	0	0.02	-0.02				
	2004	0	0.02	-0.02				
	2005	0	0.02	-0.02				
	2006	0	0.02	-0.02				
	2007	0	0.02	-0.02				
	2008	0	0.02	-0.02				
	2009	0	0.02	-0.02				
	2010	0	0.02	-0.02				
	2011	0	0.02	-0.02				
	2012	0	0.02	-0.02	-0.02	0.00	∞	±2.13
Evergreen	1997	0	0.02	-0.02				
	1998	0	0.02	-0.02				
	1999	0	0.02	-0.02				
	2000	0	0.02	-0.02				
	2001	0	0.02	-0.02				
	2002	0	0.02	-0.02				
	2003	0	0.02	-0.02				
	2004	0	0.02	-0.02				
	2005	0	0.02	-0.02				
	2006	0	0.02	-0.02				
	2007	0	0.02	-0.02				
	2008	0	0.02	-0.02				
	2009	0	0.02	-0.02				
	2010	0	0.02	-0.02				
	2011	0	0.02	-0.02				
	2012	0	0.02	-0.02	-0.02	0.00	∞	±2.13
Arnold	1997	0	0.03	-0.03				
	1998	0	0.03	-0.03				

	1999	0	0.03	-0.03				
	2000	0	0.03	-0.03				
	2001	0	0.03	-0.03				
	2002	0	0.03	-0.03				
	2003	0	0.03	-0.03				
	2004	0	0.03	-0.03				
	2005	0	0.03	-0.03				
	2006	0	0.03	-0.03				
	2007	0	0.03	-0.03				
	2008	0	0.03	-0.03				
	2009	0	0.03	-0.03				
	2010	0	0.03	-0.03				
	2011	0	0.03	-0.03				
	2012	0	0.03	-0.03	-0.03	0.00	∞	±2.13
Saint Bernadette	1997	0	0.09	-0.09				
	1998	1	0.09	0.91				
	1999	0	0.09	-0.09				
	2000	0	0.09	-0.09				
	2001	0	0.09	-0.09				
	2002	0	0.09	-0.09				
	2003	0	0.09	-0.09				
	2004	0	0.09	-0.09				
	2005	0	0.09	-0.09				
	2006	0	0.09	-0.09				
	2007	0	0.09	-0.09				
	2008	0	0.09	-0.09				
	2009	0	0.09	-0.09				
	2010	0	0.09	-0.09				
	2011	0	0.09	-0.09				
	2012	0	0.09	-0.09	-0.03	0.25	0.48	±2.13
Champlain Heights	2009	0	0.36	-0.36				
	2010	0	0.36	-0.36				
	2011	0	0.36	-0.36				
	2012	1	0.36	0.64				
	2013	1	0.36	0.64				
	2014	0	0.36	-0.36	-0.03	0.52	0.14	±2.57
Barkers Point	2007	0	0.05	-0.05				
	2008	0	0.05	-0.05				
	2009	0	0.05	-0.05				
	2010	0	0.05	-0.05				
	2011	0	0.05	-0.05				
	2012	0	0.05	-0.05				
	2013	0	0.05	-0.05				

	2014	0	0.05	-0.05	-0.05	0.00	∞	±2.37
Forest Glen	1997	0	0.05	-0.05				
	1998	0	0.05	-0.05				
	1999	0	0.05	-0.05				
	2000	0	0.05	-0.05				
	2001	0	0.05	-0.05				
	2002	0	0.05	-0.05				
	2003	0	0.05	-0.05				
	2004	0	0.05	-0.05				
	2005	0	0.05	-0.05				
	2006	0	0.05	-0.05				
	2007	0	0.05	-0.05				
	2008	0	0.05	-0.05				
	2009	0	0.05	-0.05				
	2010	0	0.05	-0.05				
	2011	0	0.05	-0.05				
	2012	0	0.05	-0.05	-0.05	0.00	∞	±2.13
Park St	2007	0	0.05	-0.05				
	2008	0	0.05	-0.05				
	2009	0	0.05	-0.05				
	2010	0	0.05	-0.05				
	2011	0	0.05	-0.05				
	2012	0	0.05	-0.05				
	2013	0	0.05	-0.05				
	2014	0	0.05	-0.05	-0.05	0.00	∞	±2.37
Connaught	2007	0	0.08	-0.08				
	2008	0	0.08	-0.08				
	2009	0	0.08	-0.08				
	2010	0	0.08	-0.08				
	2011	0	0.08	-0.08				
	2012	0	0.08	-0.08				
	2013	0	0.08	-0.08				
	2014	0	0.08	-0.08	-0.08	0.00	∞	±2.37
	2010	0	0.08	-0.08				
Northrop Frye	2011	0	0.08	-0.08				
	2012	0	0.08	-0.08	-0.08	0.00	∞	±4.03
Birchmount	1997	0	0.21	-0.21				
	1998	0	0.21	-0.21				
	1999	0	0.21	-0.21				
	2000	0	0.21	-0.21				
	2001	0	0.21	-0.21				
	2002	0	0.21	-0.21				
	2003	0	0.21	-0.21				

	2004	0	0.21	-0.21				
	2005	1	0.21	0.79				
	2006	0	0.21	-0.21				
	2007	0	0.21	-0.21				
	2008	0	0.21	-0.21				
	2009	1	0.21	0.79				
	2010	0	0.21	-0.21				
	2011	0	0.21	-0.21				
	2012	0	0.21	-0.21	-0.08	0.34	1.06	±2.13
Royal Road	2007	0	0.13	-0.13				
	2008	0	0.13	-0.13				
	2009	0	0.13	-0.13				
	2010	0	0.13	-0.13				
	2011	0	0.13	-0.13				
	2012	0	0.13	-0.13				
	2013	0	0.13	-0.13				
	2014	0	0.13	-0.13	-0.13	0.00	∞	±2.37
Kingsclear	2005	0	0.63	-0.63				
	2006	1	0.63	0.37				
	2007	0	0.63	-0.63				
	2008	1	0.63	0.37				
	2009	0	0.63	-0.63				
	2010	1	0.63	0.37				
	2011	0	0.63	-0.63				
	2012	1	0.63	0.37	-0.13	0.53	0.69	±2.37
Edith Cavell	1997	0	0.16	-0.16				
	1998	0	0.16	-0.16				
	1999	0	0.16	-0.16				
	2000	0	0.16	-0.16				
	2001	0	0.16	-0.16				
	2002	0	0.16	-0.16				
	2003	0	0.16	-0.16				
	2004	0	0.16	-0.16				
	2005	0	0.16	-0.16				
	2006	0	0.16	-0.16				
	2007	0	0.16	-0.16				
	2008	0	0.16	-0.16				
	2009	0	0.16	-0.16				
	2010	0	0.16	-0.16				
	2011	0	0.16	-0.16				
	2012	0	0.16	-0.16	-0.16	0.00	∞	±2.13
Liverpool	2007	0	0.34	-0.34				
	2008	0	0.34	-0.34				

	2009	0	0.34	-0.34				
	2010	0	0.34	-0.34				
	2011	0	0.34	-0.34				
	2012	0	0.34	-0.34				
	2013	0	0.34	-0.34				
	2014	0	0.34	-0.34	-0.34	0.00	∞	±2.37
Bessborough	1997	2	0.67	1.33				
	1998	0	0.67	-0.67				
	1999	0	0.67	-0.67				
	2000	1	0.67	0.33				
	2001	1	0.67	0.33				
	2002	0	0.67	-0.67				
	2003	0	0.67	-0.67				
	2004	0	0.67	-0.67				
	2005	0	0.67	-0.67				
	2006	0	0.67	-0.67				
	2007	1	0.67	0.33				
	2008	0	0.67	-0.67				
	2009	0	0.67	-0.67				
	2010	0	0.67	-0.67				
	2011	0	0.67	-0.67				
	2012	0	0.67	-0.67	-0.36	0.6	2.4	±2.13
	2009	0	1.09	-1.09				
Prince Charles	2010	1	1.09	-0.09				
	2011	1	1.09	-0.09				
	2012	0	1.09	-1.09				
	2013	0	1.09	-1.09				
	2014	1	1.09	-0.09	-0.59	0.55	2.63	±2.57

*Values highlighted in RED or GREEN are statistically significant compared separately by year at a 5% level of significance.

Table B.5 – Rural School Collision Analysis Results – Stat. Test 1 (By Group)

School	Actual Collisions/Yr	Expected Collisions/Yr	PFI	t-stat*
Belleisle Regional High	0.19	0.04	0.15	-13.34
Millville Elementary	0.13	0.04	0.09	-8.03
Lawrence Station Elem.	0.13	0.04	0.08	-8.03
Riverside Consolidated	0.06	0.01	0.05	-4.5
Stanley High	0.06	0.02	0.04	-3.61
Harvey High	0.06	0.03	0.03	-2.73
Juniper Elementary	0.06	0.03	0.01	-2.73
Central NB Academy	0.06	0.05	0.01	-0.96
Minto Elem.-Middle	0.00	0.01	-0.01	0.81
Blacks Harbour	0.06	0.07	-0.01	0.81
Dorchester Consolidated	0.00	0.01	-0.01	0.81
Brown's Flat Elementary	0.00	0.01	-0.01	0.81
Janeville Elementary	0.00	0.01	-0.01	0.81
Pennfield Elementary	0.00	0.01	-0.01	0.81
Ecole La Villa-Des-Amis	0.06	0.08	-0.02	1.69
Millerton	0.00	0.02	-0.02	1.69
Debec Elem.	0.00	0.03	-0.03	2.58
Cambridge-Narrows	0.00	0.03	-0.03	2.58
Miramichi Rural	0.00	0.03	-0.03	2.58
Ecole Notre-Dame	0.06	0.1	-0.04	3.46
Ecole La Decouverte-De-Saint-Sauveur	0.00	0.06	-0.06	5.23
Upper Miramichi Elem.	0.00	0.06	-0.06	5.23
Back Bay Elementary	0.00	0.07	-0.07	6.12
Bonar Law Mem. High	0.00	0.09	-0.09	7.89
		Avg.:	-0.001	
		St.Dev.:	0.055	

* Values highlighted in RED or GREEN are statistically significant compared to the group at a 5% level of significance.

Table B.6 – Rural Collision Analysis Results – Stat. Test 2 (By Year)

	Year	Actual Collisions	Expected Collisions	PFI	Avg. PFI	St. Dev	t-stat*	t-crit
Belleilse	1997	0	0.04	-0.04				
	1998	0	0.04	-0.04				
	1999	0	0.04	-0.04				
	2000	0	0.04	-0.04				
	2001	0	0.04	-0.04				
	2002	0	0.04	-0.04				
	2003	0	0.04	-0.04				
	2004	0	0.04	-0.04				
	2005	0	0.04	-0.04				
	2006	1	0.04	0.96				
	2007	0	0.04	-0.04				
	2008	0	0.04	-0.04				
	2009	0	0.04	-0.04				
	2010	0	0.04	-0.04				
	2011	2	0.04	1.96				
	2012	0	0.04	-0.04	0.15	0.54	-1.08	±2.13
Milleville	1997	0	0.04	-0.04				
	1998	0	0.04	-0.04				
	1999	0	0.04	-0.04				
	2000	0	0.04	-0.04				
	2001	2	0.04	1.96				
	2002	0	0.04	-0.04				
	2003	0	0.04	-0.04				
	2004	0	0.04	-0.04				
	2005	0	0.04	-0.04				
	2006	0	0.04	-0.04				
	2007	0	0.04	-0.04				
	2008	0	0.04	-0.04				
	2009	0	0.04	-0.04				
	2010	0	0.04	-0.04				
	2011	0	0.04	-0.04				
	2012	0	0.04	-0.04	0.09	0.50	-0.68	±2.13
Lawrence Station	1997	0	0.05	-0.05				
	1998	0	0.05	-0.05				
	1999	0	0.05	-0.05				
	2000	0	0.05	-0.05				
	2001	1	0.05	0.95				
	2002	0	0.05	-0.05				
	2003	0	0.05	-0.05				
	2004	0	0.05	-0.05				
	2005	1	0.05	0.95				
	2006	0	0.05	-0.05				

	2007	0	0.05	-0.05				
	2008	0	0.05	-0.05				
	2009	0	0.05	-0.05				
	2010	0	0.05	-0.05				
	2011	0	0.05	-0.05				
	2012	0	0.05	-0.05	0.08	0.34	-0.88	±2.13
Riverside	1997	0	0.01	-0.01				
	1998	0	0.01	-0.01				
	1999	0	0.01	-0.01				
	2000	0	0.01	-0.01				
	2001	0	0.01	-0.01				
	2002	0	0.01	-0.01				
	2003	0	0.01	-0.01				
	2004	1	0.01	0.99				
	2005	0	0.01	-0.01				
	2006	0	0.01	-0.01				
	2007	0	0.01	-0.01				
	2008	0	0.01	-0.01				
	2009	0	0.01	-0.01				
	2010	0	0.01	-0.01				
	2011	0	0.01	-0.01				
	2012	0	0.01	-0.01	0.05	0.25	-0.84	±2.13
Stanley	1997	1	0.02	0.98				
	1998	0	0.02	-0.02				
	1999	0	0.02	-0.02				
	2000	0	0.02	-0.02				
	2001	0	0.02	-0.02				
	2002	0	0.02	-0.02				
	2003	0	0.02	-0.02				
	2004	0	0.02	-0.02				
	2005	0	0.02	-0.02				
	2006	0	0.02	-0.02				
	2007	0	0.02	-0.02				
	2008	0	0.02	-0.02				
	2009	0	0.02	-0.02				
	2010	0	0.02	-0.02				
	2011	0	0.02	-0.02				
	2012	0	0.02	-0.02	0.04	0.25	-0.68	±2.13
Harvey	1997	0	0.03	-0.03				
	1998	0	0.03	-0.03				
	1999	0	0.03	-0.03				
	2000	1	0.03	0.97				
	2001	0	0.03	-0.03				
	2002	0	0.03	-0.03				
	2003	0	0.03	-0.03				

	2004	0	0.03	-0.03				
	2005	0	0.03	-0.03				
	2006	0	0.03	-0.03				
	2007	0	0.03	-0.03				
	2008	0	0.03	-0.03				
	2009	0	0.03	-0.03				
	2010	0	0.03	-0.03				
	2011	0	0.03	-0.03				
	2012	0	0.03	-0.03	0.03	0.25	-0.52	±2.13
Juniper	1997	0	0.03	-0.03				
	1998	0	0.03	-0.03				
	1999	0	0.03	-0.03				
	2000	1	0.03	0.97				
	2001	0	0.03	-0.03				
	2002	0	0.03	-0.03				
	2003	0	0.03	-0.03				
	2004	0	0.03	-0.03				
	2005	0	0.03	-0.03				
	2006	0	0.03	-0.03				
	2007	0	0.03	-0.03				
	2008	0	0.03	-0.03				
	2009	0	0.03	-0.03				
	2010	0	0.03	-0.03				
	2011	0	0.03	-0.03				
	2012	0	0.03	-0.03	0.03	0.25	-0.52	±2.13
Central NB Academy	1997	0	0.05	-0.05				
	1998	0	0.05	-0.05				
	1999	0	0.05	-0.05				
	2000	1	0.05	0.95				
	2001	0	0.05	-0.05				
	2002	0	0.05	-0.05				
	2003	0	0.05	-0.05				
	2004	0	0.05	-0.05				
	2005	0	0.05	-0.05				
	2006	0	0.05	-0.05				
	2007	0	0.05	-0.05				
	2008	0	0.05	-0.05				
	2009	0	0.05	-0.05				
	2010	0	0.05	-0.05				
	2011	0	0.05	-0.05				
	2012	0	0.05	-0.05	0.01	0.25	-0.20	±2.13
Minto	1997	0	0.01	-0.01				
	1998	0	0.01	-0.01				
	1999	0	0.01	-0.01				
	2000	0	0.01	-0.01				

	2001	0	0.01	-0.01				
	2002	0	0.01	-0.01				
	2003	0	0.01	-0.01				
	2004	0	0.01	-0.01				
	2005	0	0.01	-0.01				
	2006	0	0.01	-0.01				
	2007	0	0.01	-0.01				
	2008	0	0.01	-0.01				
	2009	0	0.01	-0.01				
	2010	0	0.01	-0.01				
	2011	0	0.01	-0.01				
	2012	0	0.01	-0.01	-0.01	0.00	∞	±2.13
Blacks Harbour	1997	0	0.07	-0.07				
	1998	0	0.07	-0.07				
	1999	1	0.07	0.93				
	2000	0	0.07	-0.07				
	2001	0	0.07	-0.07				
	2002	0	0.07	-0.07				
	2003	0	0.07	-0.07				
	2004	0	0.07	-0.07				
	2005	0	0.07	-0.07				
	2006	0	0.07	-0.07				
	2007	0	0.07	-0.07				
	2008	0	0.07	-0.07				
	2009	0	0.07	-0.07				
	2010	0	0.07	-0.07				
	2011	0	0.07	-0.07				
	2012	0	0.07	-0.07	-0.01	0.25	0.12	±2.13
Dorchester	1997	0	0.01	-0.01				
	1998	0	0.01	-0.01				
	1999	0	0.01	-0.01				
	2000	0	0.01	-0.01				
	2001	0	0.01	-0.01				
	2002	0	0.01	-0.01				
	2003	0	0.01	-0.01				
	2004	0	0.01	-0.01				
	2005	0	0.01	-0.01				
	2006	0	0.01	-0.01				
	2007	0	0.01	-0.01				
	2008	0	0.01	-0.01				
	2009	0	0.01	-0.01				
	2010	0	0.01	-0.01				
	2011	0	0.01	-0.01				
	2012	0	0.01	-0.01	-0.01	0.00	∞	±2.13

Brown's Flat	1997	0	0.01	-0.01				
	1998	0	0.01	-0.01				
	1999	0	0.01	-0.01				
	2000	0	0.01	-0.01				
	2001	0	0.01	-0.01				
	2002	0	0.01	-0.01				
	2003	0	0.01	-0.01				
	2004	0	0.01	-0.01				
	2005	0	0.01	-0.01				
	2006	0	0.01	-0.01				
	2007	0	0.01	-0.01				
	2008	0	0.01	-0.01				
	2009	0	0.01	-0.01				
	2010	0	0.01	-0.01				
	2011	0	0.01	-0.01				
	2012	0	0.01	-0.01	-0.01	0.00	∞	±2.13
Janeville	1997	0	0.01	-0.01				
	1998	0	0.01	-0.01				
	1999	0	0.01	-0.01				
	2000	0	0.01	-0.01				
	2001	0	0.01	-0.01				
	2002	0	0.01	-0.01				
	2003	0	0.01	-0.01				
	2004	0	0.01	-0.01				
	2005	0	0.01	-0.01				
	2006	0	0.01	-0.01				
	2007	0	0.01	-0.01				
	2008	0	0.01	-0.01				
	2009	0	0.01	-0.01				
	2010	0	0.01	-0.01				
	2011	0	0.01	-0.01				
	2012	0	0.01	-0.01	-0.01	0.00	∞	±2.13
Pennfield	1997	0	0.01	-0.01				
	1998	0	0.01	-0.01				
	1999	0	0.01	-0.01				
	2000	0	0.01	-0.01				
	2001	0	0.01	-0.01				
	2002	0	0.01	-0.01				
	2003	0	0.01	-0.01				
	2004	0	0.01	-0.01				
	2005	0	0.01	-0.01				
	2006	0	0.01	-0.01				
	2007	0	0.01	-0.01				
	2008	0	0.01	-0.01				
	2009	0	0.01	-0.01				

	2010	0	0.01	-0.01				
	2011	0	0.01	-0.01				
	2012	0	0.01	-0.01	-0.01	0.00	∞	±2.13
Ecole Villa-Des-Amis	1997	0	0.08	-0.08				
	1998	0	0.08	-0.08				
	1999	0	0.08	-0.08				
	2000	0	0.08	-0.08				
	2001	0	0.08	-0.08				
	2002	0	0.08	-0.08				
	2003	0	0.08	-0.08				
	2004	1	0.08	0.92				
	2005	0	0.08	-0.08				
	2006	0	0.08	-0.08				
	2007	0	0.08	-0.08				
	2008	0	0.08	-0.08				
	2009	0	0.08	-0.08				
	2010	0	0.08	-0.08				
	2011	0	0.08	-0.08				
	2012	0	0.08	-0.08	-0.02	0.25	0.28	±2.13
Millerton	1997	0	0.02	-0.02				
	1998	0	0.02	-0.02				
	1999	0	0.02	-0.02				
	2000	0	0.02	-0.02				
	2001	0	0.02	-0.02				
	2002	0	0.02	-0.02				
	2003	0	0.02	-0.02				
	2004	0	0.02	-0.02				
	2005	0	0.02	-0.02				
	2006	0	0.02	-0.02				
	2007	0	0.02	-0.02				
	2008	0	0.02	-0.02				
	2009	0	0.02	-0.02				
	2010	0	0.02	-0.02				
	2011	0	0.02	-0.02				
	2012	0	0.02	-0.02	-0.02	0.00	∞	±2.13
Debec	1997	0	0.03	-0.03				
	1998	0	0.03	-0.03				
	1999	0	0.03	-0.03				
	2000	0	0.03	-0.03				
	2001	0	0.03	-0.03				
	2002	0	0.03	-0.03				
	2003	0	0.03	-0.03				
	2004	0	0.03	-0.03				
	2005	0	0.03	-0.03				
	2006	0	0.03	-0.03				

	2007	0	0.03	-0.03				
	2008	0	0.03	-0.03				
	2009	0	0.03	-0.03				
	2010	0	0.03	-0.03				
	2011	0	0.03	-0.03				
	2012	0	0.03	-0.03	-0.03	0.00	∞	±2.13
Cambridge Narrows	1997	0	0.03	-0.03				
	1998	0	0.03	-0.03				
	1999	0	0.03	-0.03				
	2000	0	0.03	-0.03				
	2001	0	0.03	-0.03				
	2002	0	0.03	-0.03				
	2003	0	0.03	-0.03				
	2004	0	0.03	-0.03				
	2005	0	0.03	-0.03				
	2006	0	0.03	-0.03				
	2007	0	0.03	-0.03				
	2008	0	0.03	-0.03				
	2009	0	0.03	-0.03				
	2010	0	0.03	-0.03				
	2011	0	0.03	-0.03				
	2012	0	0.03	-0.03	-0.03	0.00	∞	±2.13
Miramichi Rural	1997	0	0.03	-0.03				
	1998	0	0.03	-0.03				
	1999	0	0.03	-0.03				
	2000	0	0.03	-0.03				
	2001	0	0.03	-0.03				
	2002	0	0.03	-0.03				
	2003	0	0.03	-0.03				
	2004	0	0.03	-0.03				
	2005	0	0.03	-0.03				
	2006	0	0.03	-0.03				
	2007	0	0.03	-0.03				
	2008	0	0.03	-0.03				
	2009	0	0.03	-0.03				
	2010	0	0.03	-0.03				
	2011	0	0.03	-0.03				
	2012	0	0.03	-0.03	-0.03	0.00	∞	±2.13
Ecole Notre-Dame	1997	0	0.1	-0.1				
	1998	0	0.1	-0.1				
	1999	0	0.1	-0.1				
	2000	1	0.1	0.9				
	2001	0	0.1	-0.1				
	2002	0	0.1	-0.1				
	2003	0	0.1	-0.1				

	2004	0	0.1	-0.1				
	2005	0	0.1	-0.1				
	2006	0	0.1	-0.1				
	2007	0	0.1	-0.1				
	2008	0	0.1	-0.1				
	2009	0	0.1	-0.1				
	2010	0	0.1	-0.1				
	2011	0	0.1	-0.1				
	2012	0	0.1	-0.1	-0.04	0.25	0.6	±2.13
Ecole Decouverte	1997	0	0.06	-0.06				
	1998	0	0.06	-0.06				
	1999	0	0.06	-0.06				
	2000	0	0.06	-0.06				
	2001	0	0.06	-0.06				
	2002	0	0.06	-0.06				
	2003	0	0.06	-0.06				
	2004	0	0.06	-0.06				
	2005	0	0.06	-0.06				
	2006	0	0.06	-0.06				
	2007	0	0.06	-0.06				
	2008	0	0.06	-0.06				
	2009	0	0.06	-0.06				
	2010	0	0.06	-0.06				
	2011	0	0.06	-0.06				
	2012	0	0.06	-0.06	-0.06	0	∞	±2.13
Upper Miramichi	1997	0	0.06	-0.06				
	1998	0	0.06	-0.06				
	1999	0	0.06	-0.06				
	2000	0	0.06	-0.06				
	2001	0	0.06	-0.06				
	2002	0	0.06	-0.06				
	2003	0	0.06	-0.06				
	2004	0	0.06	-0.06				
	2005	0	0.06	-0.06				
	2006	0	0.06	-0.06				
	2007	0	0.06	-0.06				
	2008	0	0.06	-0.06				
	2009	0	0.06	-0.06				
	2010	0	0.06	-0.06				
	2011	0	0.06	-0.06				
	2012	0	0.06	-0.06	-0.06	0	∞	±2.13
Back Bay	1997	0	0.07	-0.07				
	1998	0	0.07	-0.07				
	1999	0	0.07	-0.07				
	2000	0	0.07	-0.07				

	2001	0	0.07	-0.07				
	2002	0	0.07	-0.07				
	2003	0	0.07	-0.07				
	2004	0	0.07	-0.07				
	2005	0	0.07	-0.07				
	2006	0	0.07	-0.07				
	2007	0	0.07	-0.07				
	2008	0	0.07	-0.07				
	2009	0	0.07	-0.07				
	2010	0	0.07	-0.07				
	2011	0	0.07	-0.07				
	2012	0	0.07	-0.07	-0.07	0	∞	±2.13
Bonar Law	1997	0	0.09	-0.09				
	1998	0	0.09	-0.09				
	1999	0	0.09	-0.09				
	2000	0	0.09	-0.09				
	2001	0	0.09	-0.09				
	2002	0	0.09	-0.09				
	2003	0	0.09	-0.09				
	2004	0	0.09	-0.09				
	2005	0	0.09	-0.09				
	2006	0	0.09	-0.09				
	2007	0	0.09	-0.09				
	2008	0	0.09	-0.09				
	2009	0	0.09	-0.09				
	2010	0	0.09	-0.09				
	2011	0	0.09	-0.09				
	2012	0	0.09	-0.09	-0.09	0	∞	±2.13

*Values highlighted in RED or GREEN are statistically significant compared separately by year at a 5% level of Significance

Appendix C – Long-term Effectiveness of Radar Speed Display Boards

Table C.1 – Average Speeds (km/h) Bliss Carman Middle School – Peak Period

Location	Before	After 1-Week	After 2-Months	After 1-Year	After 4-Years	After 6-Years
A inbound	44.3	28.0	27.3	29.6	32.0	34.1
A outbound	44.1	35.9	33.2	35.8	35.4	39.5
B wb	45.4	31.1	35.2	33.0	34.1	34.9
B eb	47.1	36.0	41.2	37.5	33.4	37.0
C inbound	52.7	40.8	33.5	34.9	36.5	34.7
C outbound	54.7	42.1	42.1	40.6	37.2	38.5
Average:	**48.0**	**35.6**	**35.4**	**35.2**	**34.8**	**36.5**

	Before vs. 1-week	Before vs. 2-Months	Before vs. 1-Year	Before vs. 4-Years	Before vs. 6-Years	2-Months vs. 1-Year	1-Year vs. 4-Years	1-Year vs. 6-Years
t_{calc}*	**10.95**	**6.41**	**8.99**	**10.05**	**5.89**	0.17	0.42	-1.15

*Bold and underlined = statistically significant difference in means at 5% level of significance

Table C.2– Average Speeds (km/h) Bliss Carman Middle School – Non-Peak Period

Location	Before	After 1-Week	After 2-Months	After 1-Year	After 4-Years	After 6-Years
A inbound	47.2	33.3	27.0	30.7	33.1	34.9
A outbound	43.0	36.1	35.7	35.3	36.7	39.3
B wb	47.8	34.1	34.1	34.6	33.5	35.3
B eb	46.4	39.0	39.8	38.1	32.8	40.6
C inbound	55.4	46.1	36.7	35.8	37.0	36.2
C outbound	55.4	49.6	44.5	42.5	41.1	41.7
Average:	**49.2**	**39.7**	**36.3**	**36.2**	**35.7**	**38.0**

	Before vs. 1-week	Before vs. 2-Months	Before vs. 1-Year	Before vs. 4-Years	Before vs. 6-Years	2-Months vs. 1-Year	1-Year vs. 4-Years	1-Year vs. 6-Years
t_{calc}*	**6.61**	**5.54**	**6.93**	**8.40**	**4.87**	0.16	0.41	-2.19

*Bold and underlined = statistically significant difference in means at 5% level of significance

Table C.3 – Average Speeds (km/h) Devon Middle School – Peak Period

Location	Before	After 1-Week	After 2-Months	After 1-Year	After 4-Years	After 6-Years
A inbound	44.9	29.9	31.8	33.5	34.0	34.3
A outbound	42.8	40.5	38.9	33.1	39.2	36.9
B wb	40.6	30.3	30.1	35.6	36.3	36.5
B eb	39.5	40.0	36.0	37.4	34.6	36.6
C inbound	41.7	36.0	35.4	31.3	33.0	35.3
C outbound	42.1	45.1	39.2	37.8	39.1	41.7
Average:	**41.9**	**37.0**	**35.2**	**34.8**	**36.0**	**36.9**

	Before vs. 1-week	Before vs. 2-Months	Before vs. 1-Year	Before vs. 4-Years	Before vs. 6-Years	2-Months vs. 1-Year	1-Year vs. 4-Years	1-Year vs. 6-Years
t_{calc}*	1.79	**<u>3.91</u>**	**<u>4.57</u>**	**<u>4.57</u>**	**<u>3.56</u>**	0.27	-1.07	2.49

* **<u>Bold and underlined</u>** = statistically significant difference in means at 5% level of significance

Table C.4 – Average Speeds (km/h) Devon Middle School – Non-Peak Period

Location	Before	After 1-Week	After 2-Months	After 1-Year	After 4-Years	After 6-Years
A inbound	40.8	33.5	32.9	33.2	34.3	34.9
A outbound	41.8	40.1	38.2	39.3	39.5	36.3
B wb	39.7	30.1	32.2	34.0	38.5	34.2
B eb	43.2	42.9	37.2	38.0	35.0	37.7
C inbound	44.8	38.8	36.1	34.0	34.3	35.8
C outbound	44.5	45.9	42.7	39.6	40.7	40.5
Average:	**42.5**	**38.6**	**36.6**	**36.4**	**37.0**	**36.6**

	Before vs. 1-week	Before vs. 2-Months	Before vs. 1-Year	Before vs. 4-Years	Before vs. 6-Years	2-Months vs. 1-Year	1-Year vs. 4-Years	1-Year vs. 6-Years
t_{calc}*	**<u>2.21</u>**	**<u>5.36</u>**	**<u>5.32</u>**	**<u>3.68</u>**	**<u>8.73</u>**	0.25	-0.71	0.30

* **<u>Bold and underlined</u>** = statistically significant difference in means at 5% level of significance

Appendix D – Development of Speed Display Board Guidelines

Table D.1 – SAS Output Trial 2 (unsignalized intersection/crosswalk only variable)

Analysis of Maximum Likelihood Parameter Estimates					
Parameter	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**p-value**
Intercept	-6.8273	1.7986	-10.3524	-3.3022	0.0001
Road Vol. (AADT)	1.0361	0.5518	0.2047	0.1506	0.0070
4-leg Signalized Intersection	2.0868	0.2310	1.6339	2.5396	<.0001
3-leg Signalized Intersection	1.4814	0.2789	0.9349	2.0280	<.0001
Unsignalized Intersection and/or Crosswalk	1.0361	0.2454	0.5551	1.5171	<.0001
Dispersion	0.2154	0.1523	0.0539	0.8609	
Analysis Of Maximum Likelihood Zero Inflation Parameter Estimates					
Parameter	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**p-value**
Intercept	10.6608	3.9521	2.9149	18.4067	0.0070
Road Vol. (ln)	-1.2535	0.4653	-2.1654	-0.3415	0.0071
Length	-0.0062	0.0032	-0.0125	0.0000	0.0507

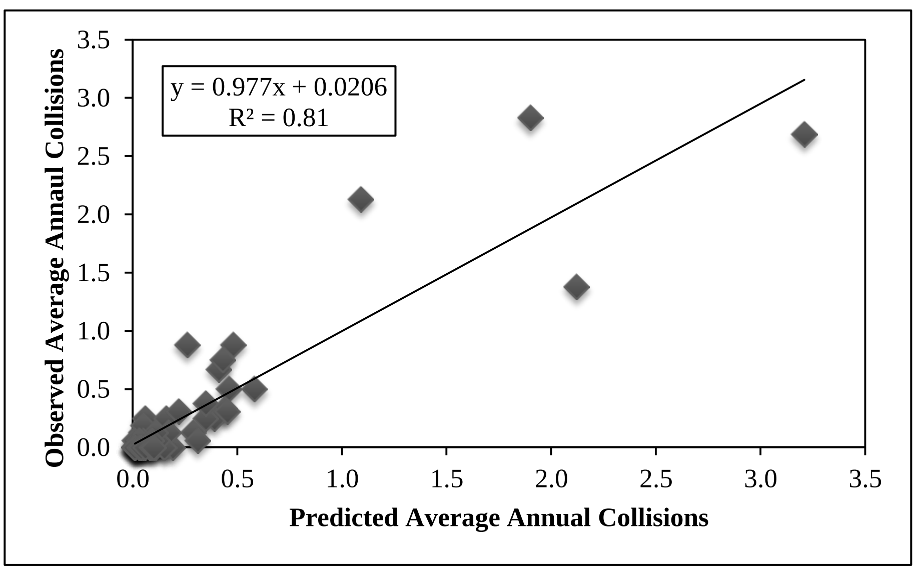

Figure D.1 – Model Fit for Trial 2

Table D.2 – SAS Output for Trial 3 (signalized/unsignalized crosswalk variables)

Analysis of Maximum Likelihood Parameter Estimates					
Parameter	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**p-value**
Intercept	-6.7833	2.0839	-10.8677	-2.6990	0.0011
Road Vol. (ln)	0.5646	0.2421	0.0900	1.0391	0.0197
Signalized Crosswalk	0.6227	0.2692	0.0951	1.1503	0.0207
Unsignalized Crosswalk	0.8784	0.1921	0.5019	1.2549	<.0001
4-leg Signalized Intersection	2.0437	0.2661	1.5222	2.5652	<.0001
3-leg Signalized Intersection	1.6090	0.2742	1.0715	2.1464	<.0001
Dispersion	0.1693	0.1383	0.0342	0.8390	
Analysis Of Maximum Likelihood Zero Inflation Parameter Estimates					
Parameter	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**p-value**
Intercept	10.5356	4.0157	2.6649	18.4062	0.0087
Road Vol. (ln)	-1.2576	0.4687	-2.1762	-0.3391	0.0073
Length	-0.0057	0.0030	-0.0115	0.0001	0.0532

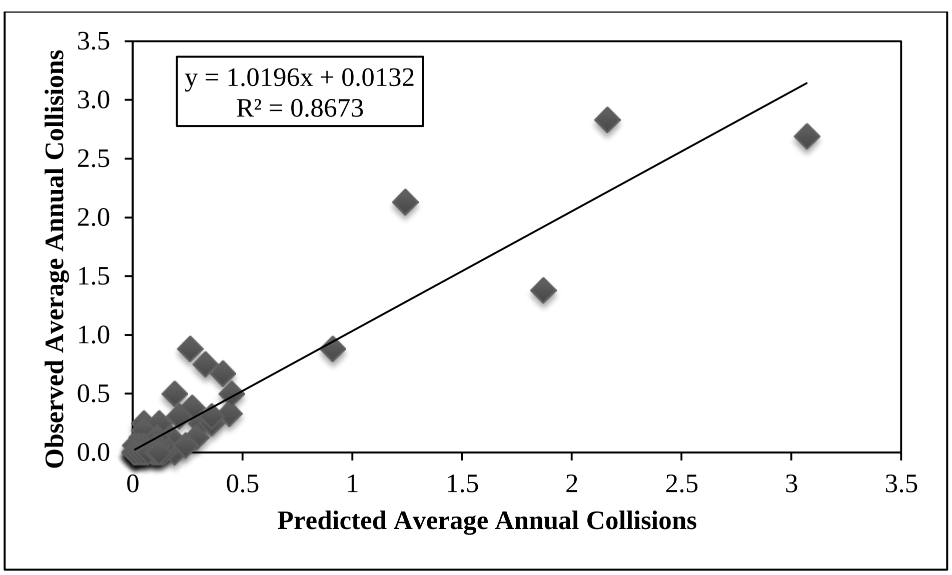

Figure D.2 – Model Fit for Trial 3

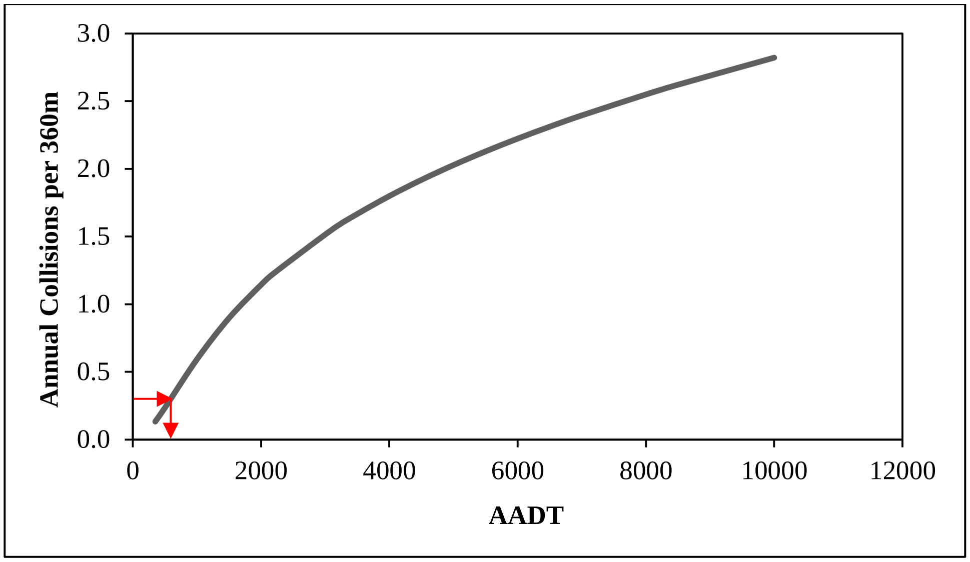

Figure D.3 – AADT, 4-leg Sig. Intersection, 1 Unsig. Intersection

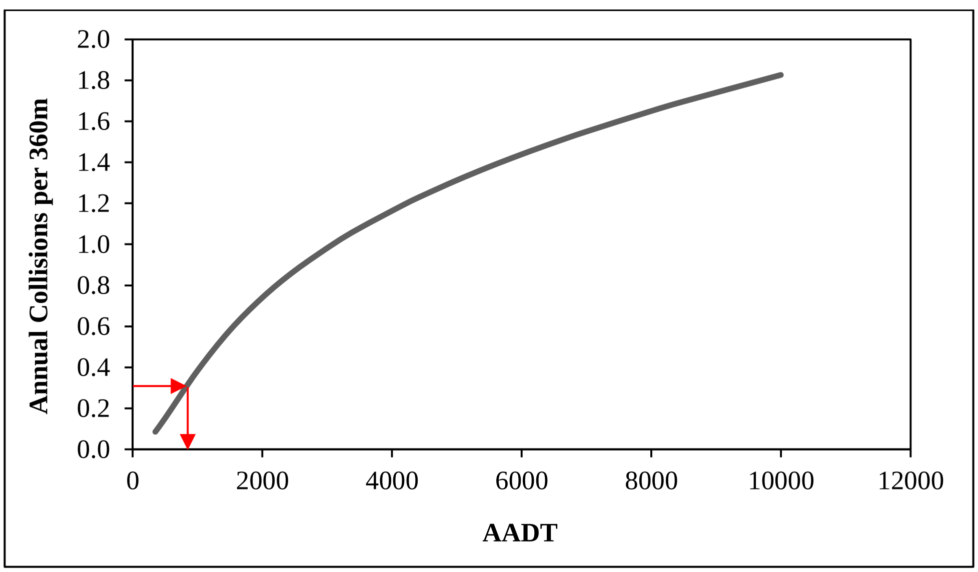

Figure D.4 – AADT, 3-leg Sig. Intersection, 1 Unsig. Intersection

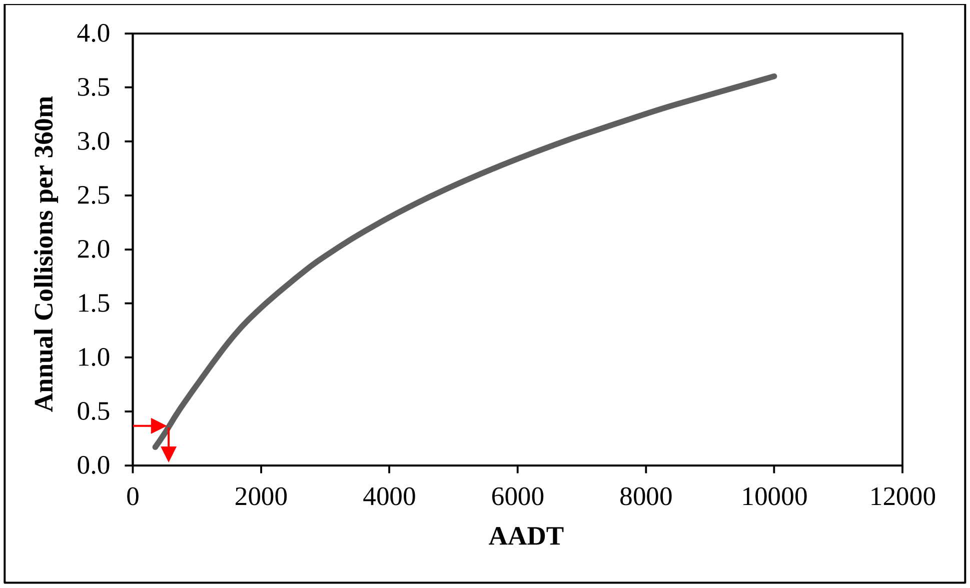

Figure D.5 – AADT, 4-leg Sig. Intersection, >1 Unsig. Intersection

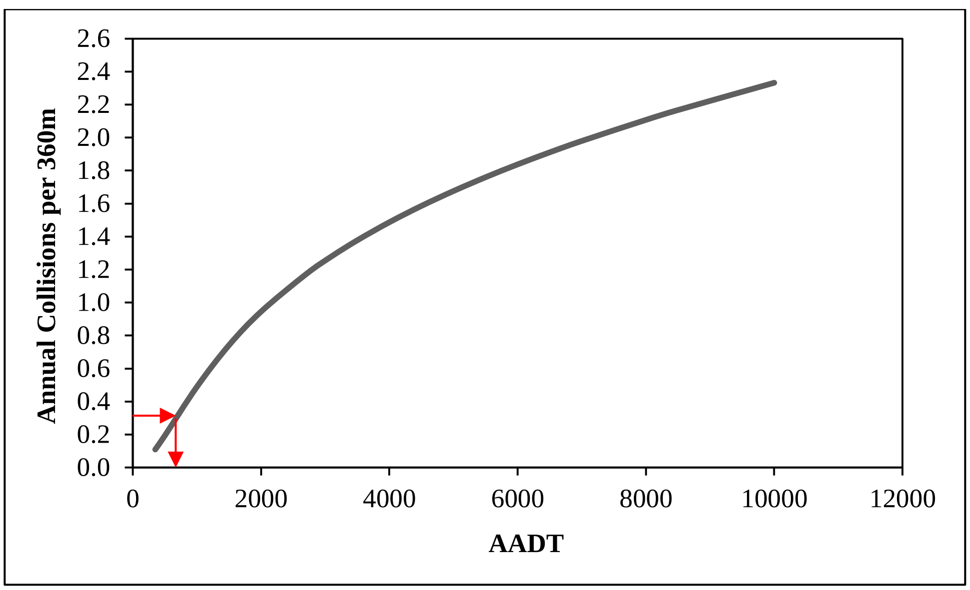

Figure D.6 – AADT, 3-leg Sig. Intersection, >1 Unsig. Intersection

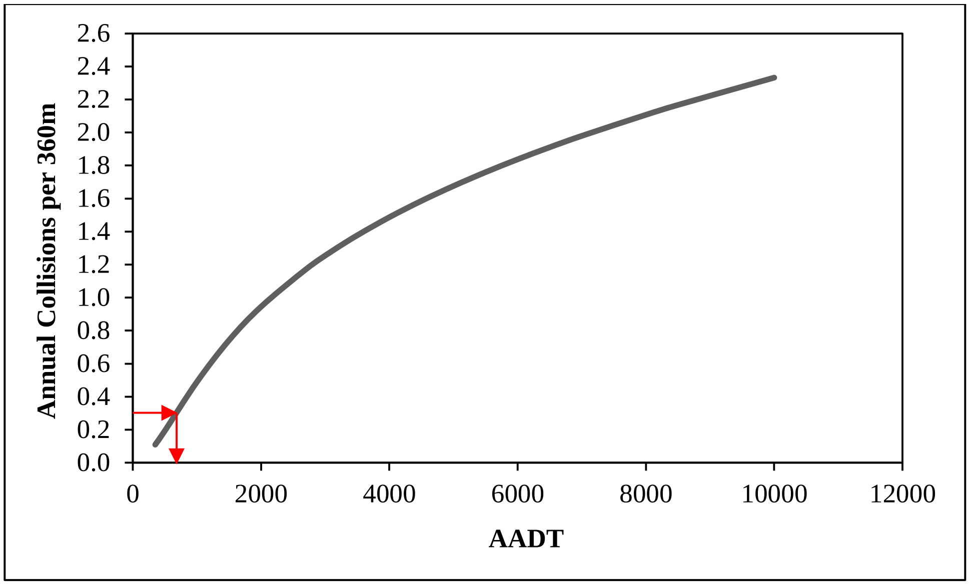

Figure D.7 – AADT, 4-leg Sig. Intersection, 2 Through Lanes

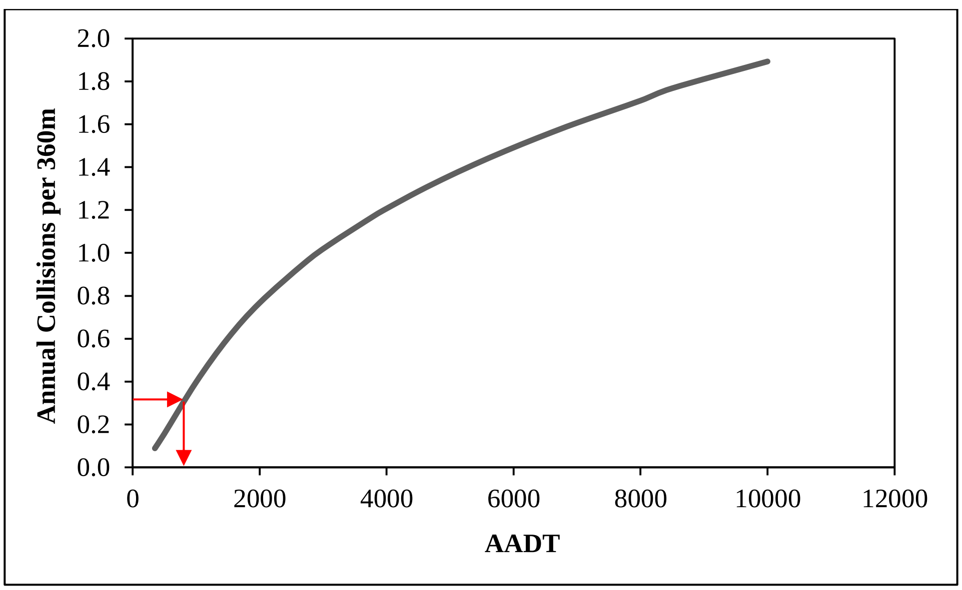

Figure D.8 – AADT, 3-leg Sig. Intersection, 2 Through Lanes

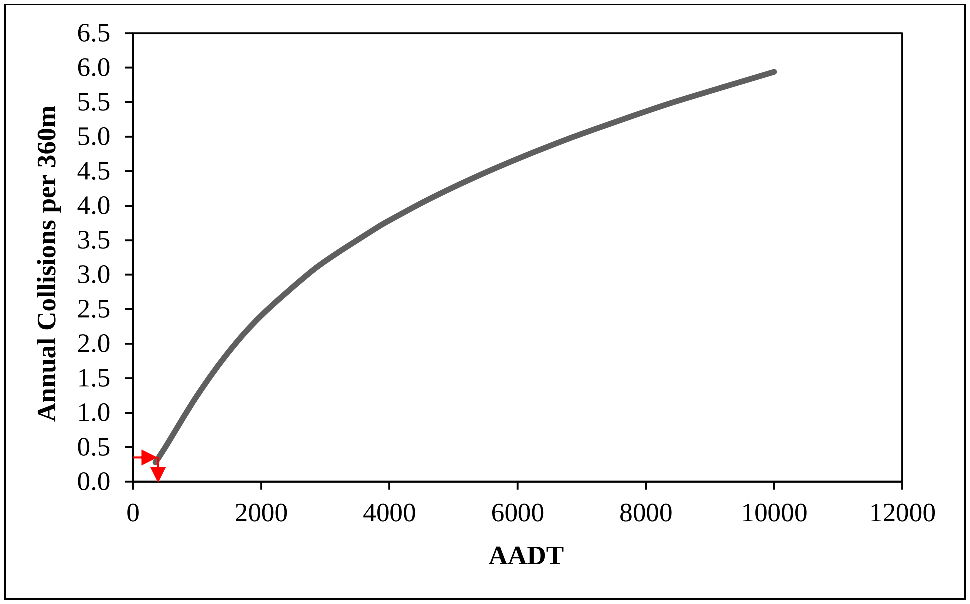

Figure D.9 – AADT, 4-leg Sig. Intersection, 1 Unsig. Intersection, 2 Through Lanes

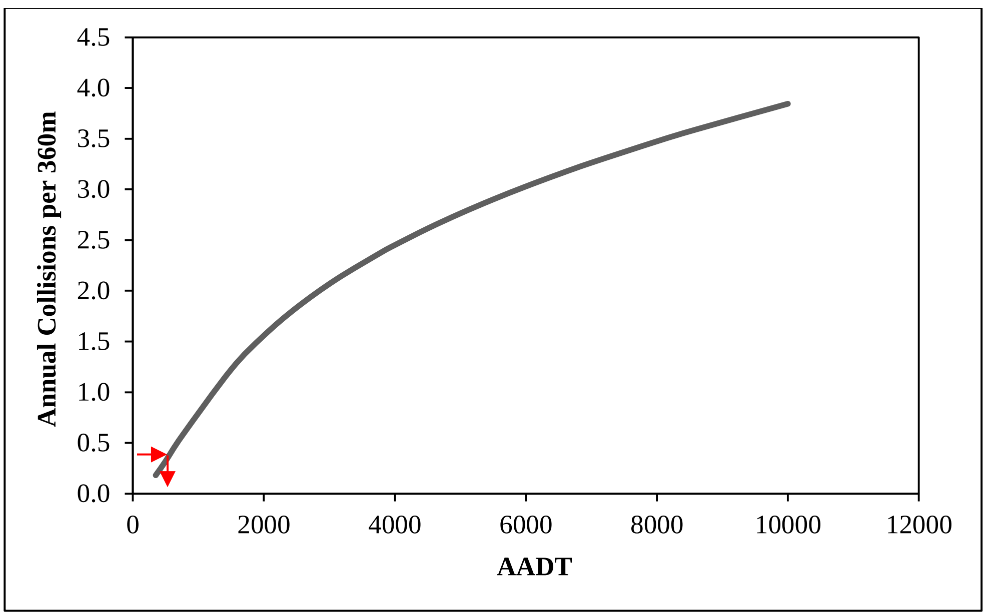

Figure D.10 – AADT, 3-leg Sig. Intersection, 1 Unsig. Intersection, 2 Through Lanes

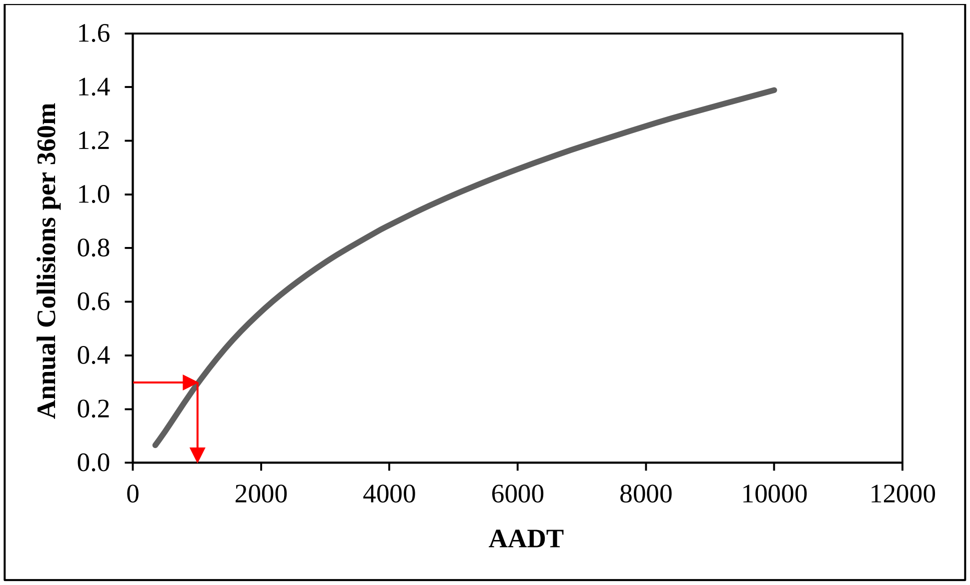

Figure D.11 - AADT, 4-leg Sig. Intersection

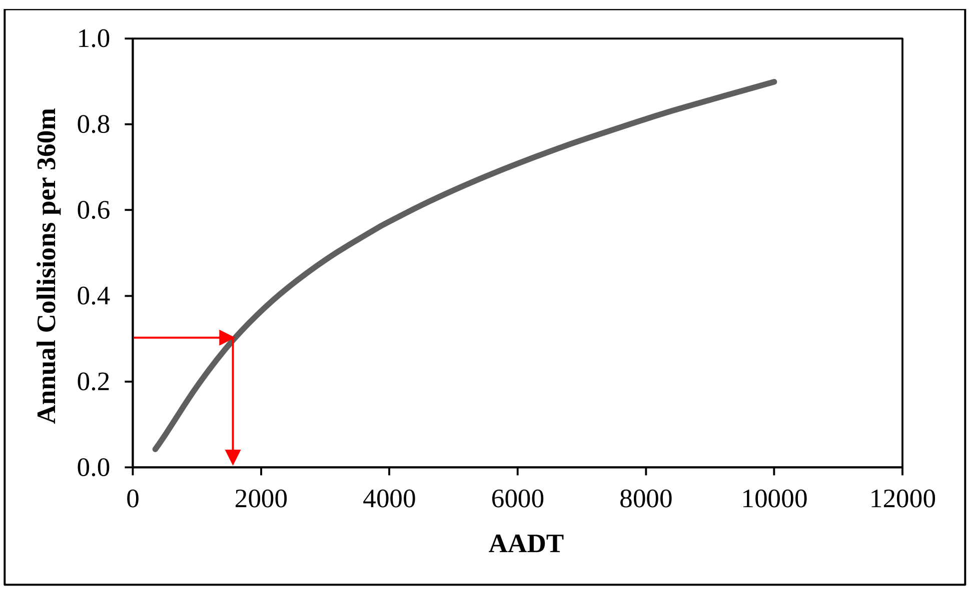

Figure D.12 – AADT, 3-leg Sig. Intersection

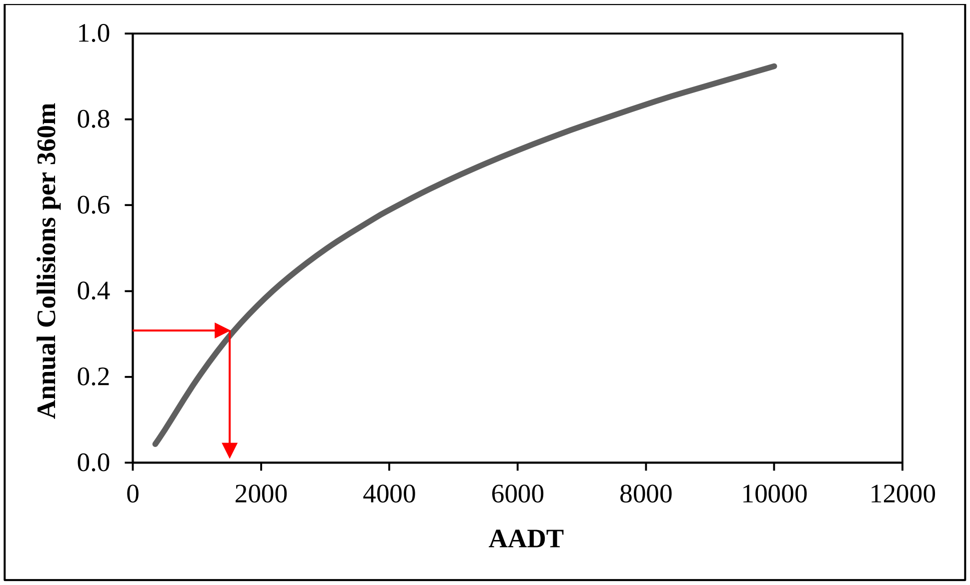

Figure D.13 – AADT, >1 Unsig. Intersection, 2 Through Lanes

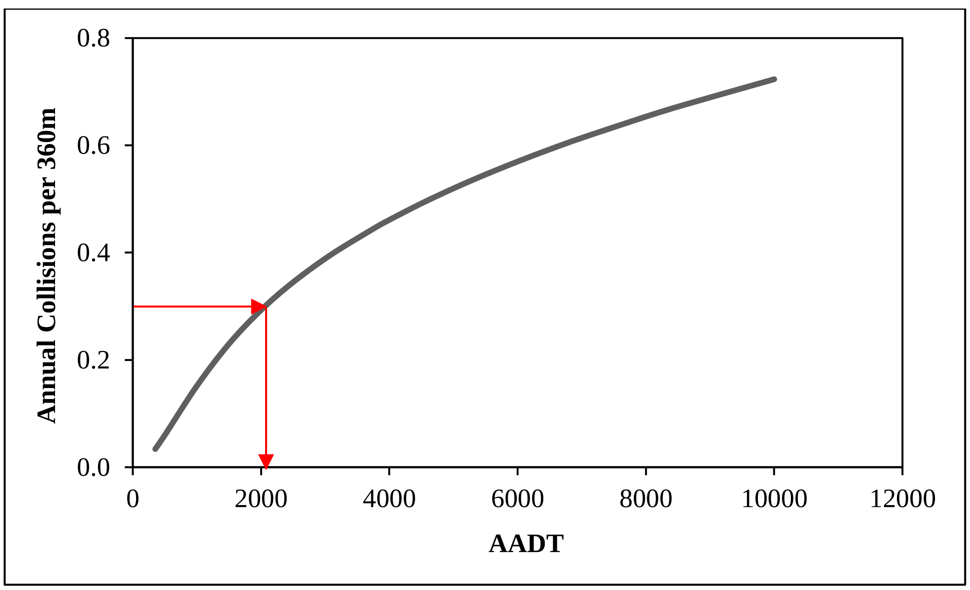

Figure D.14 – AADT, 1 Unsig. Intersection, 2 Through Lanes

Curriculum Vitae

Candidate's full name: Kaitlin E. Hazzard

Place and Date of Birth: Fredericton, New Brunswick, Canada
18 April 1992

Email: kaitlin.hazzard@unb.ca

Universities Attended: University of New Brunswick
Fredericton, New Brunswick
Bachelor of Science in Civil Engineering (First Division)

Publications:

Hazzard, K.E., Hildebrand, E.D., Christie, J.S. 2016. A Warrant System for the Use of Speed Display Signs in School Zones. To be published in the proceedings of the 2016 National Transportation Association of Canada Conference and Exhibition, Transportation Association of Canada, Toronto, ON, September 2016.

Hazzard, K.E., Hildebrand, E.D. 2015. School Zone Safety: Are We Pandering to Parents? Proceedings of the 2015 National Transportation Association of Canada Conference and Exhibition, Transportation Association of Canada, Charlottetown, PEI, September 2015.

Hildebrand, E.D., D.D. Mason, D.P. Paradis, and K.E. Hazzard. 2014. Long-Term Effectiveness of Radar Speed Display Boards in School Zones. Proceedings of the Canadian Multidisciplinary Road Safety Conference XXIV, Canadian Association of Road Safety Professionals, Vancouver, BC, June 2014.