Average Speed Enforcement and its Potential Application on New Brunswick Roads

by

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Bachelor of Science in Civil Engineering, University of New Brunswick, 2017

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

Master of Engineering

in the Graduate Academic Unit of Civil Engineering

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This report is accepted by the
Dean of Graduate Studies

THE UNIVERSITY OF NEW BRUNSWICK

March 2021

Abstract

Average Speed Enforcement (ASE) is a is a relatively new approach that can be used to enforce speed limits. ASE determines a vehicle's mean speed over an extended length of road by recording the time a motorist took to drive between two set points. Reducing the speed of motorists over a longer section of roadway yields benefits such as fewer collisions and a reduction in fuel consumption. This study investigated the findings of the effectiveness of average speed enforcement among those jurisdictions that have adopted it. It was found that ASE reduces collisions by 30-40% and that it lowers carbon emissions by roughly 15% on a 100 km/h road. These findings were then applied to a local road to determine if an economic case could be made for its use in New Brunswick. Route 7 between Oromocto and Saint John was chosen as a test site. A field study found that the average space mean speed on this facility was 107 km/h and the 85th percentile speed was 114 km/h despite the posted speed limit being only 100 km/h. The potential benefits of ASE were estimated and an economic evaluation found that its deployment would yield a benefit-cost ratio of approximately 15.6.

Acknowledgements

I wanted to get a worldwide perspective of average speed enforcement and its use in different countries so this project would not have been as successful without the help of many people. I spent a lot of time researching where average speed enforcement has been used permanently or on a trial basis. This led to a lot of emails going unanswered except for a select few people that took the time to respond with whatever info that they thought could be useful for me. I'd like to thank the following people who provided a lot of useful information:

Carol Nightingale, Department for Infrastructure and Transport in South Australia
Charlotte Bradford, Road User Licensing, Insurance and Safety Division in the United Kingdom
Dr. Lutz Gaspers and Michael Heller, HFT Stuttgart, Germany
Mavis Johnson, Canadian Traffic Safety Institute
Lex Jansen, Citizen Correspondence Cluster Ministry of Justice and Security, The Netherlands

I'd also like to thank my supervisor Dr. Eric Hildebrand. The way he teaches and willing ness to help was a big factor in me wanting to pursue Transportation Engineering as a career and my decision to return to UNB for my graduate studies.

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Chapter 1: Introduction

Average Speed Enforcement (ASE), also known as Point-to-Point Enforcement or Section Speed Enforcement, is one of the many tools that can be used by governing bodies to reduce the number of speeding motorists. It is one of the newer methods and is beginning to gain more popularity. While not yet used in North America, it has been employed in various countries such as Australia, England, Scotland, The Netherlands, Austria, Italy, France, Czechia and South Korea (Shim *et al*., 2020; Walker *et al*., 2012). First used in the Netherlands in 1997, it quickly spread to other European countries in the following years (Fletcher, 2018). ASE has become quite popular in the United Kingdom, with approximately 410 kilometres of roadway being regulated using ASE by the year 2015 (Fletcher, 2018; Owen *et al*., 2016).

ASE has become an ideal way of policing speeding as it is beneficial and favored by motorists and groups looking to enforce speeds. For enforcement groups, average speed is favored as a tool because it successfully lowers speeds over a long distance. This provides an advantage over speed cameras that only measure "spot" speeds instantaneously at one location. Motorists have been known to only temporarily lower their speeds when in the presence of spot cameras only to resume speeding shortly afterwards, a concept sometimes referred to as *speed surfing*. While ASE similarly has issues enforcing speeds outside its enforcement zone, they still lower speeds over a much larger area compared to spot cameras. By reducing the speeds of vehicles throughout an extended length of roadway, average speed cameras provide a wide array of benefits including a reduction in collisions, fuel usage and noise pollution. Many jurisdictions have reported a public acceptance of ASE as motorists perceive that it is the fairest way to enforce speeds. When caught speeding from a device that measures speeds at a single location, motorists may argue that the instant they were recorded was not representative of their driving behaviour as a whole.

ASE is also generally combined with favorable policy decisions that encourage acceptance by motorists. Cameras generally have warning signs preceding them and are painted in bright colours. Cameras are usually only able to be placed at locations with a history of collisions, and any fines revenue from the cameras can only be used for roadway maintenance or safety improvements and not general government revenue.

Past methods of speed enforcement have largely included using technologies like radar/lidar to determine the speed of a vehicle instantaneously at one particular location. The way ASE differs is that it utilizes multiple cameras located a large distance apart. In the UK the shortest enforcement zone is 390 metres with the longest being 46 kilometres (Owen *et al*., 2016). Rather than record the speed of a vehicle at each location, like other automated speed enforcement methods, the cameras record a picture of the license plate of each vehicle along with a timestamp of when the vehicle passed by the camera. The speed of the vehicle between the two cameras is determined by taking the known distance between the two cameras and dividing by the amount of time taken to traverse this distance. The time taken to traverse the distance is known by taking the difference in the timestamps recorded in the pictures at each of the camera locations; because of this ASE is ideal for locations where there are few spots drivers can stop. If there was a business such as a gas station between two camera stations, drivers could theoretically speed to the gas station, pause to refuel or take a break of some kind, then continue speeding to the following camera. Depending on the time spent at a gas station and the amount the driver was exceeding the speed limit, the cameras likely would not detect a speeding driver as the time between the two stations might be greater than the limit.

1.1 Background

Speeding and the dangers it poses have been an important topic for the past few decades. ASE is one of the many strategies that are available to those wishing to improve speed limit compliance. These tools can vary from active enforcement such as police officers or spot speed cameras to more passive forms that control speed such as speed bumps or humps or other traffic calming practices such as chicanes. For the purposes of this study, ASE was compared to enforcement from police officers and spot cameras as this study is more focused on curbing highway speeding and these are the forms of enforcement most widely seen on highways.

One of the most common methods of speeding enforcement used throughout North America is enforcement by police officers in person with radar/lidar devices. Some motorists may prefer the human element of traditional enforcement and may believe that when pulled over for speeding or other driving offenses, there is a chance, they will be given some leniency as a police officer can judge each offense on a case-by-case basis. This can also be a problem as it can lead to the limits being inconsistently enforced.

While police enforcement is one of the most widely used techniques, it is not ideal to solely rely on this method alone. Of all the methods discussed it is the most labour intensive. Police officers have many different duties they do daily that provide a lot of value to society as a whole. It could be debated that sitting in one location for the sole purpose of catching speeding motorists could be one of the least efficient uses of their time. For a country such as Canada this is a major issue. Canada is among the largest countries in the world, geographically, so it is difficult to enforce speed using only police officers with such large areas to cover.

Since it is nearly impossible to solve the issues of speeding by increasing the manpower of police forces a lot of effort has been spent on looking for solutions that are not labor intensive. One of the most common methods for this has been through the use of spot speed cameras. When a speeding driver is detected by a camera a picture of the vehicle is taken, this picture would include the license plate of the vehicle and sometimes a picture of the driver. With the picture, the system can automatically send a fine in the mail to the owner of the vehicle with the registration details.

The benefits of spot speed cameras include the reduction in labour for the officers issuing the tickets and also safety for the officers as they no longer have to pull over vehicles on busy highways. These cameras have issues for people who typically do or do not speed.

For motorists who are typically compliant, being caught by a spot speed camera can be frustrating as some may feel the infraction is not a reflection of their overall driving behaviour. For people that typically speed, these cameras are often easy to spot or are identified by GPS-based Apps. This can lead to ‘camera surfing’ where a speeding motorist can brake right before a camera to give the semblance of adhering to the speed limit for the brief moment they are being recorded.

Traffic cameras also automatically issue speeding tickets. This gives an added bonus of safety as it is not required for police officers to pull over drivers on crowded roadways. While this billing system is quite efficient for a governing body to issue tickets in this way motorists feel it has some issues. Since receiving a ticket in the mail has some delay it could take weeks for the driver to receive it. In the weeks that passed since the incident, they could incur other fines and not change their behavior at all.

ASE has many of the same positives and negatives of spot cameras but with some extra advantages. For drivers that do not typically speed, it gives them an opportunity to correct their speed so that their average speed over the enforcement zone does not exceed the limit. For drivers that do consistently speed, it virtually eliminates the camera surfing that can occur. In Figure 1-1, it is illustrated that speed compliance tends to be more effective and consistent when using an average speed technique. With fewer camera installations, the average speed cameras can get a much larger area where speed limits are followed compared to many spot speed cameras.

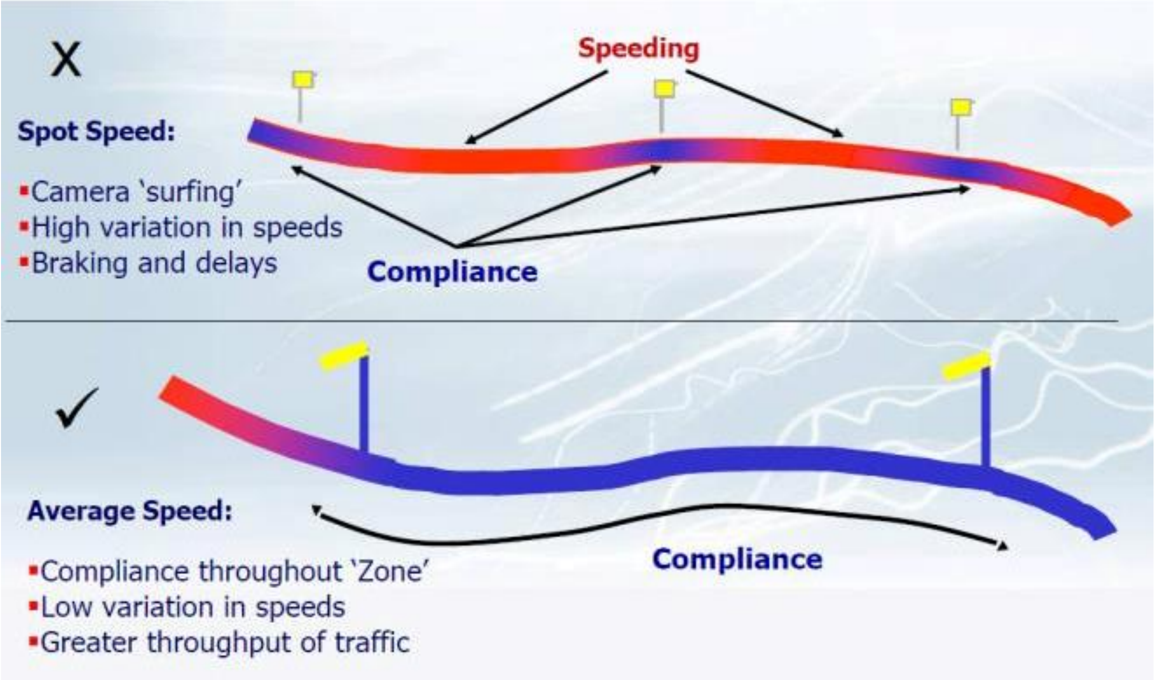

Figure 1-1 Comparison of Spot Speed and ASE

(Source: Ilgaz & Saltan, 2017)

1.2 Study Goal

The main goal of this research was to study the benefits of ASE and determine if it would be beneficial to implement on New Brunswick roadways. In order to complete this research, the following steps were undertaken:

- Investigate experiences with ASE worldwide
- Investigate and quantify speed profiles throughout a study area
- Determine the amount and severity of collision history within the study area
- Investigate collision modification factors for highways with ASE

- Determine the installation costs of average speed cameras
- Determine yearly maintenance and operation costs of ASE
- Determine yearly savings of benefits such as collision reduction, carbon emission reduction and speeding fines
- Compare benefits and costs while accounting for interest over the estimated life cycle

1.3 Scope

To determine if there would be some benefit to ASE, Route 7 between Oromocto and Saint John was chosen as a test case location. This section was chosen because the 70 kilometre stretch of roadway offers a large quantity of variability with stretches where the roadway has different lane configurations while the posted speed limit remains constant at 100km/h throughout. An additional benefit of this location is that there are few opportunities for motorists to enter/exit the route or stop. While performing a study tracking the movement of vehicles along the route, there is a lower chance a vehicle leaves the study area without first being tracked throughout. Some of this variability includes areas where the highway is twinned or sections where it is undivided with one lane in each direction or locations where it is not twinned but one direction has passing or a climbing lane. Figure 1-2 shows the study area along with approximate observation locations (stations A to D).

Figure 1-2 NB Route 7 Study Area

(Source: Google maps)

This section of arterial highway was used to study driver behavior on the road, such as the typical speeds driven by motorists, as well as the collision history of the road. With these data, a determination was whether ASE would be beneficial at this location.

Chapter 2: Literature Review and Scan of Experiences

The following sections provide a review of previous studies identifying the benefits of ASE and of lowering speeding in general. It also discusses the general effectiveness in terms of the rate of compliance that this strategy has as well as the dangers of speeding and the related costs of collisions.

2.1 Costs of Speeding

Speeding has been a known issue that many transportation professionals have spent a lot of time trying to remedy. The connection between speeding and collisions has been studied at length. In Australia between 2013 and 2017, speeding was identified as a contributing factor in 20% of all serious injury collisions and in 30% of all fatal collisions (Government of South Australia, n.d.). Speeding increases the likelihood and severity of a collision as it reduces the amount of time that a driver has to react to oncoming danger and, should a collision occur, increases the kinetic energy that a driver may be exposed.

Any achievable reduction in vehicle operating speeds can be beneficial from a safety perspective. For example, driving 10 km/h over the speed limit in a zone with a posted speed limit of 60 km/h is equivalent to driving with a blood alcohol concentration of 0.1g/100ml, which is above the 0.08g/100ml Canadian limit (Government of South Australia, n.d.). Driving 10km/h above a posted speed limit of 60km/h would also mean the driver is four times more likely to be involved in a collision involving a fatality (Government of South Australia, n.d.).

In 2018, 26% of all fatal collisions involved at least one speeding vehicle in the United States (NHTSA, 2020). The data in Figure 2-1 show that when comparing speeding and non-speeding drivers involved in a fatal collision, the speeding drivers were more likely to have been involved in other dangerous activities in the five years prior to their fatal collision.

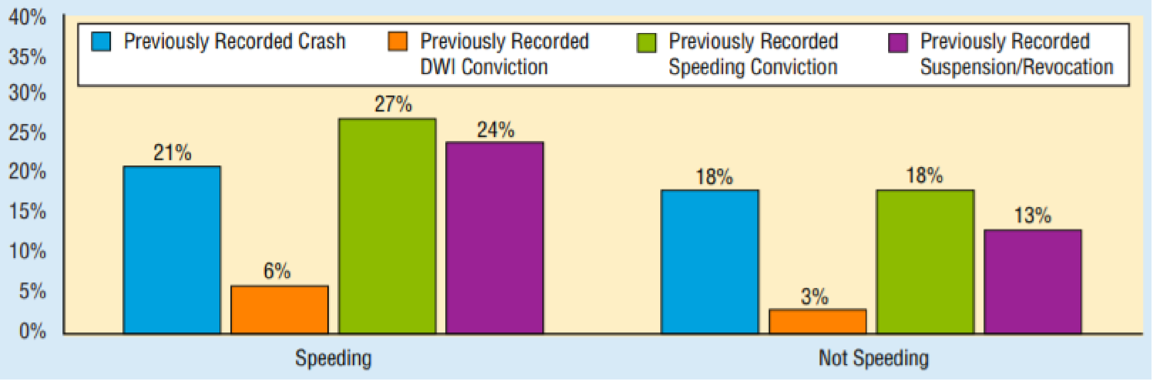

Figure 2-1 Previous 5-Year Driving Records of Drivers Involved in Fatal Traffic Crashes

(Source: NHTSA, 2020)

To help quantify the negative impact of roadway collisions many studies have tried to quantify the outcomes of various collision severities. One of the ways studies tend to delineate collision severities is using the categories of Property Damage Only (PDO), Injury and Fatal. Collisions that are classified as PDOs are generally fairly minor and can easily be quantified monetarily based on the amount it costs to repair any vehicles or other objects involved in the collision. Injury and fatal collisions are generally more difficult to quantify as they involve human elements such as pain, suffering and social implications that are difficult to quantify and could vary from person to person. While they also may include the costs of property damage, they mainly take into account the time someone involved in a collision takes to recover from it with their lost time at work or medical fees they may have incurred. They can also include a ‘willingness to pay’ economic element of how much someone would be willing to pay to avoid a potential collision. The following table provides the findings of a recent Canadian study that looked at the impacts of collisions on New Brunswick highways (Lougheed, 2016).

Table 2-1 Collision Costs Based on Severity (in 2021 dollars)

Collision Severity	Collision Cost
PDO	$16,700
Injury	$166,800
Fatal	$6,115,000

2.2 International Average Speed Enforcement Experiences

When discussing areas that experience high numbers of speeding vehicles, a large emphasis is placed on reducing the 85th percentile speed and, to a lesser degree, the average speed. ASE has been shown to be particularly effective in combating extreme or excessive speeding behavior (Soole *et al*., 2013). Typically speed profiles on most roadways will resemble a normal distribution curve. Depending on the road, these normal distribution curves may stretch over a large range of speeds with large standard deviations or may have a smaller spread and lower standard deviation. Since average speed enforcement is effective against aggressive speeding, it effectively removes one of the tails in a normal distribution curve that would represent the population of road users that speed excessively compared to the rest of the population. By forcing motorists, who previously would have exceeded the speed limit, to lower their speeds, it decreases the standard deviation of speeds along a roadway. When the drivers that typically speed are forced to drive at or below the speed limit, it creates a number of benefits that will be discussed in the following sections.

Some of the more notable studies showing the reduction in speeding resulting from ASE strategies are identified in Table 2-2.

Table 2-2 Impact of Average Speed Enforcement on Speed

Location	Impact on location or key findings	Source
A90 Highway in Scotland	Prior to installation of cameras, 60% of motorists were observed exceeding speed limits. After cameras introduced, percentage reduced to 1%.	(Fletcher, 2018)
A13 Highway in the Netherlands	After installation, only 0.5% of motorists found speeding	(Wegman & Goldenbeld, 2006)
UK Motorways	On an unenforced section of the M4 highway, 60% of motorists seen driving within a 15 mph range. On an enforced section of A77, 60% of people observed driving within a 5 mph range.	(Thornton, 2010)
A610 and A6514 highways in Nottingham, England	At both sites, 85th percentile speeds were lowered to posted speed limits (44 mph to 40 mph and 39 mph to 30 mph).	(Soole *et al.*, 2013)

The reductions in speed that are seen with the installation of ASE, lower collisions in several different ways. ASE is effective in reducing the speeds of motorists that are exceeding the speed limit and this, in turn, lowers the standard deviation of highway speeds. Collisions become increasingly frequent as a motorist increases their speed beyond the average speed of other motorists (SWOV, 2012). With all motorists driving relatively the same speed, it creates fewer situations where a motorist may approach a vehicle traveling in the same direction. These scenarios present potentially dangerous situations such as the possibility of a rear-end collision or a dangerous passing situation.

The following table outlines some before and after studies that have taken place studying the effects of ASE on various locations.

Table 2-3 Impact of Average Speed Enforcement on Collisions

Location	**Impact on location or key findings**	**Source**
A77 Highway in Scotland	Fatalities and serious injuries declined by 74%.	(Fletcher, 2018)
Great Britain	Fatal and serious collisions fell by 36.4% (25-46% 95% confidence interval). Personal injury fell by 16% (9-22% 95% confidence interval)	(Owen *et al*., 2016)
A610 and A6514 highways in Nottingham, England	Fatalities or significant injury collisions reduced by 65%	(Soole *et al*., 2013)

Although all of these results seem to suggest a strong relationship between ASE and lowering collisions, some have argued that these types of studies are not robust enough or explanatory (Owen *et al*., 2016). The argument against average speed cameras and other measures that reduce speed is that the results from research might be misleading or overexaggerated.

Many of the studies listed previously do not account for things like the 'background trend' in collision reductions, the influence of site-selection bias and/or a regression to the mean (Owen *et al*., 2016). The background trend refers to collisions reducing nationwide through other means, these can include the constant safety improvements to cars themselves or other infrastructure upgrades. Sites that have had ASE introduced generally have seen high numbers of collisions. In all the studies previously noted, it was not clear if the collisions experienced prior to enforcement were part of a long-term trend or an abnormality. Often it is difficult to have extensive collision history data. Some of the studies provided examined three years prior to camera installation and three years after installation. It is unknown if these 3-year samples are representative of a trend in collisions or an abnormality. There is a chance that after speed enforcement cameras are installed, collisions could return to normal or 'regress to the mean' and are not actually influenced by the cameras. This regression to the mean is also sometimes quite large as the sites selected for ASE see abnormally large amounts of collisions. Site-selection bias can come into play with ASE as the sites chosen typically see lots of collisions which means they would be more likely to improve. With all of these reasons why collisions may vary from year-to-year naysayers argue that the collision benefits seen at average speed sites have been overstated at the very least.

To combat the perception that ASE cameras might have received more credit than they deserve for preventing collisions, studies have been undertaken using empirical Bayes methodology in order to isolate the average speed cameras as a variable. One such study in South Korea noted a 43% reduction in collisions which was estimated to be 5.6 times greater than the collision reduction expected from cameras that record spot speeds at one location (Shim *et al*., 2020). Two other studies using empirical Bayes methodology were done in Italy which showed an expected collision reduction of 31-32% (Montella *et al*., 2012, 2015). This study also showed what scenarios ASE could be most beneficial as the 31.2% collision reduction was broken down for different collision severities and scenarios, which can be seen in Table 2-4.

Table 2-4 Notable Findings on Collision Reductions Using Empirical Bayes

Type of Collision	Reduction in Collisions
Severe Collisions	55.6%
Non-severe Collisions	26.6%
Collisions on Curves	43.4% to 48.8%
Nighttime Collisions	38.1%
Daytime Collisions	26.3%
Single Vehicle Collisions	43.7%
Rainy Weather	57.3%
Wet Pavement	50.9%

(Montella *et al*., 2012, 2015)

While a reduction in speed variance is ideal for reducing collisions, it is also a benefit for reducing travel times. Other forms of speed enforcement, such as spot speed cameras can create bottle-necks that lower journey times for the motoring public as a whole. A speeding motorist may brake suddenly upon seeing a speed camera to lower their speed to the posted speed limit. This may cause a situation where motorists following closely behind are forced to react to the vehicle in front of them, forcing them to slow down; they may also slow down even more aggressively as they are not sure why the previous motorist was braking. This scenario can lead to chain braking (or shockwave) due to the initial vehicle in front braking. This is avoided with ASE as it can create a “factory conveyor belt” type flow of vehicles (Collins & McConnell, 2008). With vehicles travelling similar speeds, it creates larger headways that are more likely to be maintained. With vehicles more evenly spaced out, it can help avoid congestion in areas that were previously bottlenecks along the road network (Collins & McConnell, 2008).

Chapter 3: New Brunswick Case Study

This chapter summarizes an evaluation of whether ASE might be beneficial within the New Brunswick context. The study used AADT traffic volumes along Route 7 in addition to speed and collision data to provide baseline data that allowed an estimate of ASE benefits to be determined. The cost of a collision was then studied to determine the monetary impacts of a collision. With the collision costs known, they were then compared with other benefit and cost factors such as carbon reductions and life cycle costs of ASE zones to determine if ASE would provide a net benefit.

3.1 Methodology

Speed data were collected using two methods. The first was by using radar guns at stations A and D in Figure 1.2. This was done to mimic the most commonly used method of speed detection currently used by police and to compare with speeds collected within the ASE zone. To collect these data, vehicles were stationed at each of these locations with radar detecting speed guns. Field personnel were instructed to park a safe distance away from the roadway, to remain in the vehicles for safety purposes and to remain somewhat hidden so as not to influence the speeds of passing motorists. Fifty vehicles were recorded at each station for a total of 100 sampled spot speeds.

To begin collecting average speed data, the field personnel started by synchronizing their timing devices and then placed themselves at their respective stations. Personnel were instructed to park their vehicles to the side of the route a safe distance away from the roadway and were instructed to park perpendicular to the road facing the road. This was done because some New Brunswick registered vehicles still have license plates on the front and rear of the vehicle, and positioning the parked vehicle to see both ends of the vehicle gives the field personnel two chances to record vehicle identifiers. The vehicle identifiers that were collected were the time the vehicle passed the station, the last three digits of a license plate, the type of vehicle, the colour of the vehicle and any other identifier the data collector thought was noteworthy. These identifiers were logged into the Data Collection sheet, which can be found in Appendix A. At a minimum, the field personnel attempted to collect the time the vehicle passed and the last three digits of the license plate. The other identifiers were largely used to distinguish between multiple vehicles with the same last three digits on their plate that passed by a station at similar times. The type of vehicle, colour and other identifiers would also be used to identify vehicles with no plate or a plate that is obstructed by dirt or other accessories.

For large commercial trucks with trailers, field personnel attempted to record both the front and rear plates if possible and to note which plate was the rear plate and which was the front plate. This is because for large commercial trucks with trailers, the truck can have a different plate compared to the trailer. If Station A was only able to record the front plate and then Station B only has the opportunity to record the rear plate, the only way the movement of this vehicle can be tracked is if Station C is able to catch both the front and rear plates to link the plates recorded by Stations A and B.

For the type of vehicle and colour identifiers, field personnel were to keep these attributes as simple as possible. For the type of vehicle, field personnel were limited to the categories of motorcycle, car, pickup truck, van and truck for anything larger than a standard passenger vehicle. Field personnel only used simple primary or secondary colours (such as red, yellow, blue, orange, green, violet) and avoided shades of colours to ensure consistency. If necessary, they used the other identifier category to identify a particular shade of colour or combination of colours.

The initial goal of the study was to collect average speed data from Station A all the way to Station D, with Stations B and C also being included to provide shorter section length speeds. This would mean the study area of the average speed data collected would be roughly 70 km long. On the day data were to be collected, construction had begun on a stretch of roadway between Stations A and B. This construction led to significant delays for motorists that would have altered the average speed of vehicles travelling from Station A to D, so the section of roadway between Stations A and B had to be removed from the average speed data collection. The length of the study area from Stations B to D was 34.2 km, the approximate locations of the stations and construction zone can be seen in Figure 3-1.

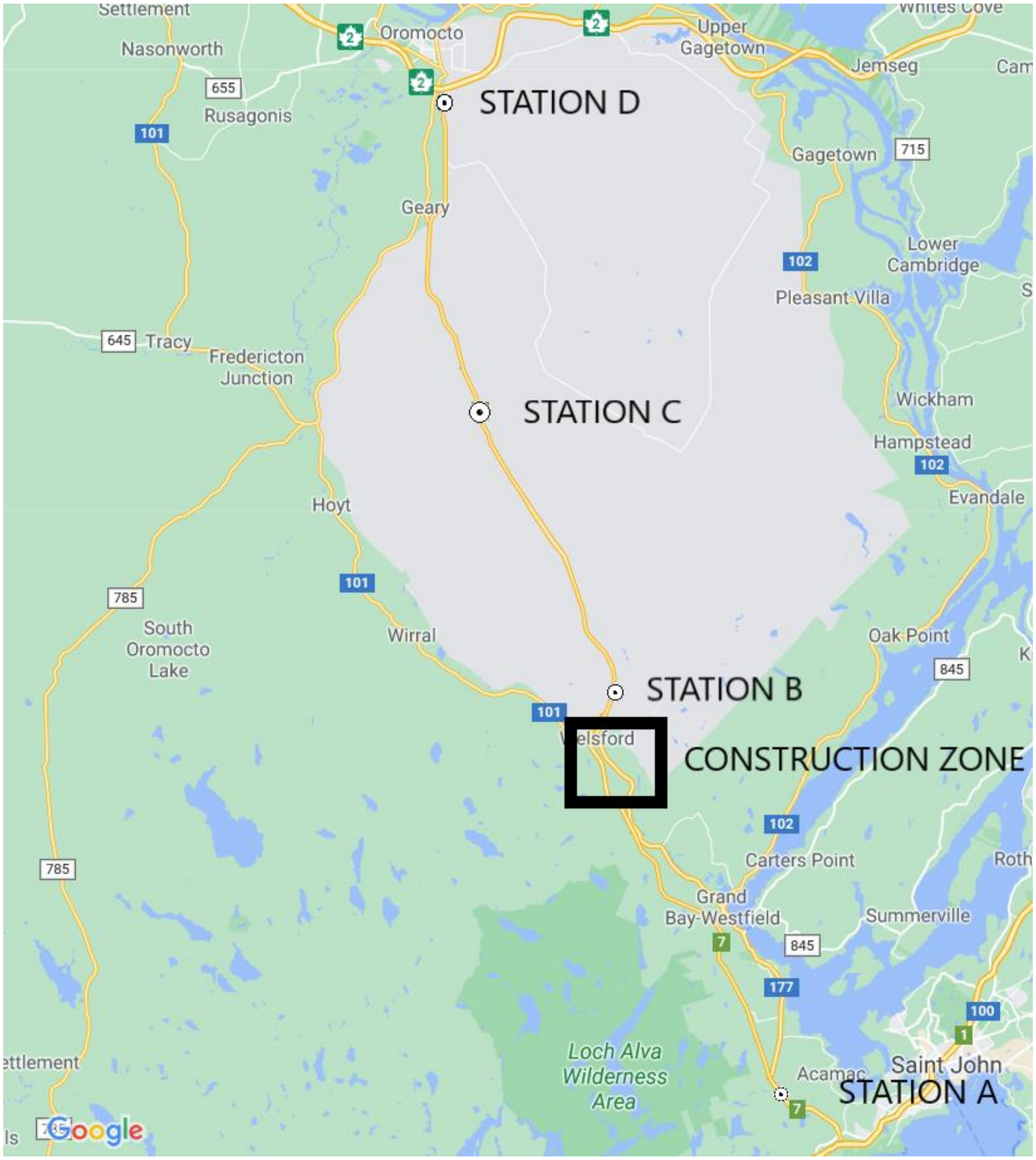

Figure 3-1 NB Route 7 Study Area With Construction Zone

(Source: Google maps)

Since the times of vehicles passing were recorded to the minute and not the exact second, this led to some additional source of error when shortening the study section length.

There was potential for a vehicle to arrive at the starting station right as a clock changes minutes and then arrives at the final station right before it changes to the next minute. This might lead the data to show the vehicle took 30 minutes to pass through the stations when it really took 30 minutes and 59 seconds. When taking this potential +/- 1-minute error across the 70 km of the planned study area, it led to a maximum variance increase or decrease of approximately 3 km/h in vehicle speeds; however, this margin of error increases as the distance of the total study area shortens. With the large sample size of vehicles studied, this error is not of huge concern as it was expected to average out but is worth noting. It was most evident when comparing the average speeds of vehicles travelling the length of the study area compared to the speeds of vehicles between each of the individual stations, there was more variance and spikes in data of low or high speeds when looking at speeds between individual stations. It was not possible to record times at a higher accuracy as this would put too much strain on the field personnel in how much information they had to record in a short amount of time.

3.2 Analysis

Using the data generated from the speeds that were collected, it was possible to determine if a speeding problem exists on this route and whether there would be a benefit in using an enforcement tool such as ASE to lower speeds. From the speed data collected, cumulative frequency diagrams were plotted in order to determine the 85th percentile speed.

In order to determine if ASE is a viable technique to reduce speeds in this area, a benefit-cost analysis was performed to determine if it makes sense financially for the government to make an investment to install infrastructure for ASE. ASE offers a wide variety of benefits that can be quantified into a monetary value.

One of the most important factors was safety improvements with ASEs potential for reducing collisions. Using collision data from 2016-2017 an estimation of the number of collisions that occurred within the study area was determined. Since the collision data included severity of injury it was possible to attribute a cost to having a collision, it can then be determined the approximate savings to society that a reduction in collisions would bring (Lougheed, 2016). Since it is also known that drivers also use less fuel while driving through an ASE zone, due to driving at a constant and slower speed, there is also a benefit to society with the savings in fuel. Not only do the drivers save money on their own personal fuel costs, but society also sees a benefit with less carbon emissions being produced by passing vehicles. With an estimation on the number of vehicles and the amount their speed would be reduced by, along with current estimations of the indirect costs per ton of the carbon pollution, a savings for society was also produced.

Potential fines revenue generated by the ASE cameras was also included into the benefits as the funds would offset the costs of the infrastructure that would need to be installed and maintained. Knowing the current driving patterns along the route as well as compliance rates seen in other areas that use ASE, a rough estimate of the number of offenders that will continue to speed can be determined. These fines revenue would likely be used to offset some of the maintenance and operational costs should the cameras be put in place.

All of the benefits listed previously were compared with the installation, maintenance and operational costs of the cameras for the ASE. The installation costs are the initial costs of purchasing the necessary equipment and potentially software needed and the installation of that equipment along the roadway in order to start using ASE. Maintenance costs included things like replacing some of the hardware, such as the camera itself or the structure it is attached to. It could also include washing off debris from the camera lens so that it can clearly see vehicles passing by. Operational costs included things like the amount of electricity needed to run the cameras as well as back office operations for ticket processing. While the entire system can be automated, if it were to be used in NB there would likely be someone tasked with verifying that the images of a vehicle being caught speeding are in fact legitimate in the early stages of the ASE program. Knowing the amount of offenders that are likely to be seen at this location, a number of images needing to be reviewed can be estimated, and if we assume a couple of minutes are needed to verify a speeding offense, the number of hours required to complete this role along with its wages can be estimated to get a yearly cost. While adding jobs to the province, such as the person required to verify the images and any persons needed for maintenance, could be seen as a positive for the provincial economy; for the purposes of this report they were seen as a cost.

The benefits and costs were tabulated in monetary terms and a benefit-cost analysis was performed. All annual values were calculated to their present worth, factoring in the time value of money, and were then compared to one-time investments such as the installation costs. A 15-year period was chosen for the benefit-cost analysis. This was done for two reasons. The first being that perhaps at some point, the entire system may need to be replaced and further maintenance would be inefficient. The second being that ASE could also become obsolete in 15 years because new technologies may become more prevalent. Car technologies are constantly evolving, and a popular topic today involves speculation over when technologies will permit autonomous operations. One study noted that by 2040 mode share of manually driven vehicles will have gone from 85% today to 35% as autonomous technologies penetrate the vehicle fleet (Simons & Malkin, 2020).

3.3 Results

The following subsections present a summary of all results developed from this test case study. Speed profiles generated from spot speed surveys are presented, average speed observations throughout the study length are shown, and an estimation of all benefits and costs associated with a potential installation of average speed cameras was synthesized.

3.3.1 Speed

Speed data were collected using two different methods at various locations along the study area. One method involved getting spot speeds at one location using a radar gun. These spot speeds were collected at two locations within the study area, at Station A and at Station D. The second method being the speeds collected time stamping vehicles to get an average speed throughout the zone. These spot speeds were taken and compared with each other as well as with the speed data generated with the average speed method.

The first spot speeds were taken at the south end of the study area at Station A and included 50 samples, results can be seen in Figure 3-2 below.

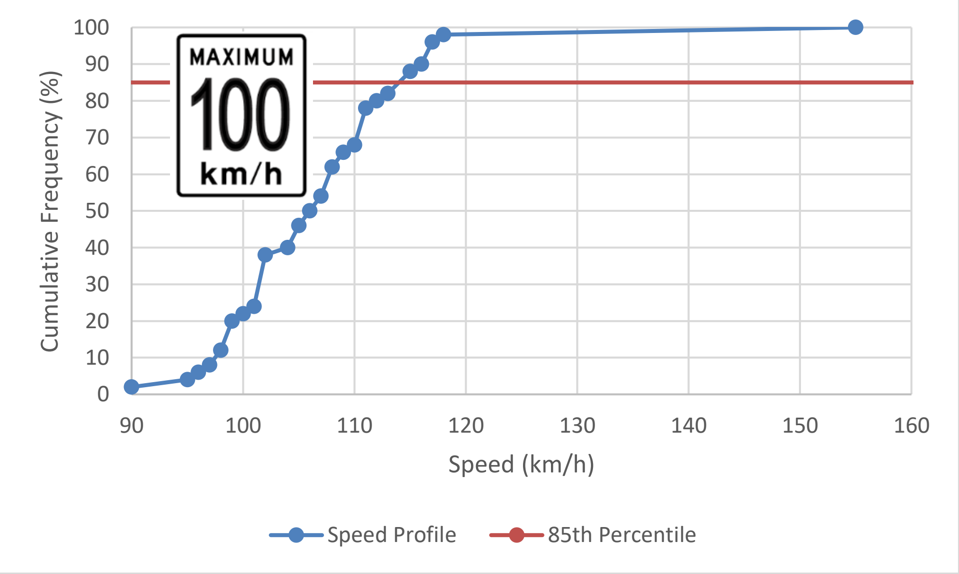

Figure 3-2 Station A Spot Speed Samples

This was then compared to the speeds generated at Station D where 50 spot speed samples were also collected. The results of this can be seen in the figure below.

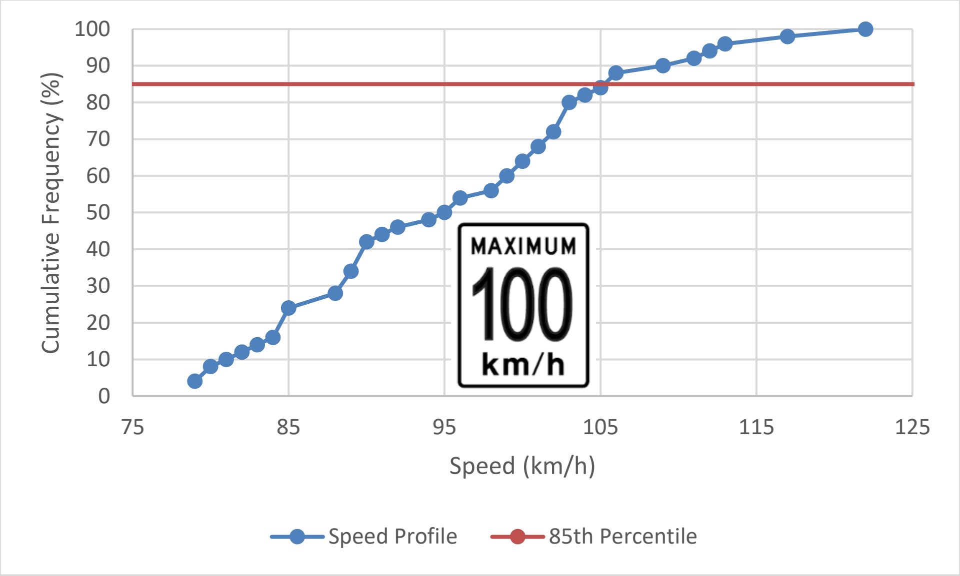

Figure 3-3 Station D Spot Speed Samples

While both locations have the same posted speed limit of 100 km/h and are on the same route, it is apparent both locations experienced different levels of speeding. The 85th percentile speed at Station A was found to be 114 km/h while it was 105 km/h at Station D.

With the average speed data collection effort 252 vehicles were observed and time stamped at each of observation stations B, C and D. The results of the data can be seen in Figure 3-4. The 85th percentile speed was 114km/h while the mean speed was 107km/h.

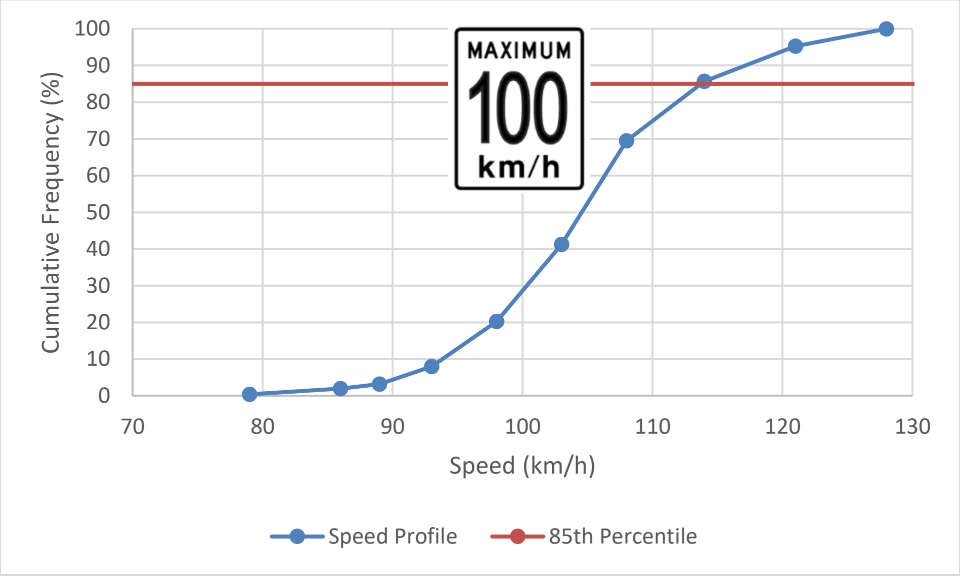

Figure 3-4 Average Speeds Through Study Area (Station B to D)

While the data obtained from the average speed study provided a similar 85th percentile to the speed that was recorded at Station A, this graph showed that there is a larger portion of people who were obeying the speed limit compared to Station A. Similar to data recorded at Station D, the average speed data shows there was a small portion of drivers that drove below 90 km/h, which was not seen in data recorded at Station A.

3.3.2 Collisions

Using the collision dataset provided by the New Brunswick Department of Transportation and Infrastructure, it was possible to isolate collisions that only occurred within the study area. To do this, data were filtered to include collisions that only occurred on Route 7. Since Route 7 is a very long arterial, additional filters also needed to be applied to locate collisions more precisely. For example, if a collision was located on Route 7 but near Kimble Drive, it was eliminated from the analysis since Kimble Drive is not close enough to the study area. Following this process, it was possible to summarize the collision data in Table 3-1.

Table 3-1 Collisions Within Study Area

Year	PDO Collisions	Injury Collisions	Fatality Collisions	Total
2016	26	17	0	43
2017	28	10	1	39

Using the collision data and the costs of collisions identified previously, it was possible to estimate how much these collisions cost society in each of these years. By multiplying the number of collisions by the cost of that severity of collisions, a value can be calculated which is shown in the table below (Lougheed, 2016).

Table 3-2 Costs of Collisions (in 2021 Dollars)

Year	PDO Collisions	Injury Collisions	Fatality Collisions	Total
2016	$433,600	$2,835,200	$0	$3,268,800
2017	$467,000	$1,667,800	$6,115,000	$8,249,800

Over a two-year period, this study area has seen accidents that have costed roughly $11,518,600 in damages or $5,759,300 per year. ASE has shown to have a crash reduction effect of slightly over 30%, with Montella *et al.* (Montella *et al*., 2012) estimating it to be 32%. If ASE were installed within this study area, it could be expected that 32% of all collisions could be avoided. Applying this 32% collision modification factor would bring down the yearly costs of collisions to $3,916,300, or an annual savings of $1,843,000, which was found by subtracting the expected yearly costs from the current yearly costs of collisions. The $1,843,000 savings was used as a benefit that was applied yearly in the benefit-cost analysis.

3.3.3 Fuel and Carbon Emissions

The study area in question sees an average of 4,800 vehicles every day according to NBDTI and is roughly 70 kilometres (43.5 miles) long from Stations A to D. Multiplying the number of vehicles by the length of the study section gave the number of total miles driven by all vehicles which was 208,800 vehicle-miles. On average, vehicles operate at approximately 25 miles per gallon (United States Environmental Protection Agency, 2020). With the number of vehicle-miles driven on this road daily at the assumed efficiency of the vehicles on the road it was estimated that approximately 8,352 gallons or 31,615 litres of fuel were consumed on this section of highway daily. Each litre of fuel consumed produces roughly 2.36kg of CO2 emissions which meant this route produced 74,612 kg of CO2 every day (Thornton, 2010). Current estimates of the social costs of CO2 emissions placed it at a cost of roughly $50 CAD per tonne of CO2, which meant based on the emissions seen on this route, a yearly social cost of CO2 emissions was estimated to be roughly $3,730,600 every year. When ASE was applied to a 50 mph road, a decrease of 29.5% was seen in the yearly costs of fuel and CO2 emissions and on

70 mph roads, a decrease of 11.3% can be expected (Thornton, 2010). Since a speed limit of 100 km/h equates to 62 mph and the benefits of enforcing 60 mph speed limit was not studied by Thornton it was conservatively assumed that enforcing a 100 km/h speed limit with ASE would produce a 11.3% decrease in CO2 emissions. This assumption was necessary as the correlation between speed and fuel efficiency is not linear, and the benefits of enforcing 100 km/h were not studied (Thornton, 2010). When the 11.3% savings was applied on costs of CO2 emissions the yearly CO2 costs of this route dropped to $3,309,000. Subtracting the $3,309,000 from the current costs of $3,730,600 gave a yearly benefit estimate of $421,600 in favor of using ASE.

3.3.4 Fines Revenue

ASE is seen as highly effective at lowering speeds. In places where ASE was studied, between 0.5% to 7% of drivers were seen disregarding the speed limit once the cameras had been put in place (Soole *et al*., 2013). For the purposes of getting an estimate on the amount of fines revenue that was expected, a conservative estimate of 0.5% was used. It was calculated that of the 4,800 vehicles that use this road daily, it can be expected that roughly 24 vehicles will disregard the average speed cameras every day. Currently, fines in New Brunswick range from $140-$570 for exceeding the posted speed limit by less than 25km/h or $240-$2,260 when exceeding the speed limit by more than 25km/h. Assuming the average speed cameras observe 24 vehicles per day and that only the lowest fine of $140 was given to each of the offenders, the province could expect $1,226,400 in fines yearly from this roadway.

3.3.5 Installation, Maintenance and Operation Costs

The largest cost for this project was the upfront construction cost. Initial estimates on installation costs were seen to be $75,000-$300,000 per camera in Australian Dollars (Cameron, 2008). Installation costs vary depending on the lane configuration at the enforcement site and proximity to a power source. Prices are anticipated to continue to drop as the technology advances (Soole *et al*., 2013). For the purposes of this report, a conservative estimate of $300,000 CAD was used and the installation of four cameras was assumed, two cameras being placed at each the beginning and end of the enforcement zone to track vehicles in both directions. While the installation costs are anticipated to drop overseas for the purposes of this report, an additional 10% was added to this estimate. This was to ensure a conservative assumption that hopefully covers any unforeseen costs or shipping fees from overseas companies. For the 70km stretch of Route 7 in the study area, it was estimated to cost $1,320,000 for the installation of the cameras in the enforcement zone.

It was assumed that it may be recommended to have someone assigned to verify speeding infringements detected by the cameras as well as someone to maintain and ensure the accuracy of the cameras, which will create some costs incurred for paying wages. The cameras, once installed, should identify roughly 24 vehicles speeding daily. It was assumed that it would take roughly 5 minutes in order to confirm or reject a speeding violation identified by the ASE cameras. The main duties of this position would be to ensure that the same vehicle appeared in each of the pictures generated by the cameras and that the time registered between cameras was logical. If this person spent on average 5 minutes for each of the 24 offences anticipated each day, this would equate to 1 hour of work per day. Another source of somewhat regular labour that can be anticipated is for maintenance purposes. Maintenance would not be needed very often, so it is somewhat difficult to estimate, common maintenance tasks would be cleaning the lens to ensure picture quality or replacing pieces of damaged hardware. For the purposes of this report, an average of 3 hours of labour was estimated per day for the average enforcement zone, which included time checking images as well as maintenance. This gave some extra time to complete inspections of images if the 5-minute estimation was too short and would leave time to complete any maintenance duties once they arise. It is assumed someone will be paid roughly $20 per hour, labour costs were estimated at $21,900 each year.

While an estimate for labour costs towards maintenance duties has been generated, this does not include the costs of materials. Some pieces of hardware may need to be replaced due to use or vandalism. An estimate of operational costs has also not been generated at this point. Both the maintenance costs and operational costs were difficult to estimate as it does not seem they have been published. For the purposes of this study, these costs were estimated to be $66,000 a year which was roughly 5% of the installation costs.

3.4 Benefit to Cost Analysis

The benefits and costs that were estimated previously and that were used in the benefit-cost analysis are summarized in the following table; all costs were yearly costs with the exception of the one-time installation costs. The values for installation and maintenance and operation have been adjusted for inflation to bring their value into 2021 dollars.

Table 3-3 Potential Benefits and Costs (2021 Dollars)

Benefits		Costs	
Collisions	$1,843,000	Installation	$1,612,500
Carbon Emissions	$421,600	Back Office Labour	$21,900
Fine Income	$1,226,400	Maintenance and Operation	$80,600

To compare the annual benefits and costs to the installation costs, each was brought to their present value while adjusting for the time value of money. To get the present values of the annuities the following formula was used.

$$PV = A\left[\frac{1-(1+r)^{-n}}{r}\right]$$

Where:

PV = Present Value ($)

A = Value of the annuity ($)

r = Discount rate (%)

n = Term length

For the calculations, a discount rate of 1.5% was chosen as it is the current 10 Year Canadian Savings Bond interest rate (Bank of Canada, 2021). The term length was assumed to be 15 years. When converting the previously calculated annuities into their present worth the following values were determined and are presented in Table 3-4.

Table 3-4 Total Benefits and Costs Over 15-Year Period

Benefits		Costs	
Collisions	$24,591,600	Installation	$1,612,500
Carbon Emissions	$5,625,500	Labour	$292,200
Fine Income	$16,364,100	Maintenance and Operation	$1,075,500
Total Benefits	**$46,581,200**	**Total Costs**	**$2,980,200**

Based on these totals, a benefit to cost ratio (BCR) of approximately 15.6 was found based on all benefits and costs analyzed. Some ASE benefit-cost analyses omit fines revenue from their benefits total as one of the main goals of ASE is to increase safety and not just to give out additional speeding tickets. If fines revenue were removed from the benefits, the BCR would be 10.1. It is also worth noting that the fines revenue alone would cover the real-world installation and maintenance costs associated with the lifespan of this project. In the first year of the project the fine income would come close to covering all of the installation costs.

A sensitivity analysis was also performed to analyze how changes to the interest rate and collision costs impacted the BCR. The costs of a collision involving a fatality or injury have been difficult to analyze with many different studies having different results. To combat this, the previously shown collision costs were increased or decreased by 20% and resulted in a range of BCRs. This process was also applied to the discount rate. The results of this can be seen in the following table; shaded in grey are the baseline results and factors that have been previously discussed. The data in Table 3-5 illustrate that the BCR ranges from 11.6 to 18.0 depending on the assumed discount rate and collision cost estimates. Regardless of the assumed input parameters, the benefits heavily outweigh the costs.

Table 3-5 Benefit to Cost Ratio Sensitivity

		Discount Rate Applied			
		0.5%	1.5%	3%	6%
Factor Applied to Collision Costs	80%	14.6	14.0	13.1	11.6
	100%	16.3	15.6	14.7	13.0
	120%	18.0	17.3	16.2	14.4

Chapter 4: Potential for Application on Route 7 and Other NB Roads

While the analyses previously presented and the BCR of 15.6 were specific to this location, more research could be done to better understand how ASE could impact this area. This chapter further explores how likely ASE would be a benefit for this area and what other factors should be investigated to develop a more robust evaluation for a particular jurisdiction.

4.1 Potential for Speed Decreases

On the A43 in Northampton, England, the 85th percentile speed decreased from 58 mph to 45 mph, or a 22.4% decrease, once ASE was introduced to enforce the 50 mph speed limit (Soole *et al*., 2013). Other studies have noted that, on average the 85th percentile has been shown to decrease by 14.4% (Soole *et al*., 2013). If the 85th percentile speed were to decrease by 14.4% on NB Route 7, it would fall from 114 km/h to 98 km/h, which is just below the 100 km/h posted speed limit. It was believed that this decrease was plausible for this area given the number of speeding vehicles seen at this location. Of the 252 samples recorded, 148 of them were observed to be going at least 5 km/h over the posted speed limit. Given how effective ASE is for preventing excessive speeding, it is expected nearly all of these 148 samples will drive at or below the posted speed limit if ASE were present. As stated earlier, it was estimated that should an ASE system be installed at this location, it would only observe approximately 24 speeding offences daily.

4.2 Improvements on the Benefit-Cost Analysis

The benefit-cost analysis presented in this paper focused on the benefits of reducing the number of collisions, reducing emissions from vehicles, and income from fines, as well as the costs associated with installing and operating the system. This led to a BCR of 15.6 (or 10.1 if fines revenue was excluded as a benefit). These BCRs are similar to what other studies have found (Soole *et al*., 2013). One study that evaluated average speed enforcement on roads throughout the Western Australia road network found the BCR could vary from 9.74 to 49.15 due to different traffic and collision statistics (Cameron, 2008).

With more collision data, a different approach towards generating potential savings in collision costs could be undertaken. Montella *et al*. estimated that a 32% reduction in all collision types could be expected after average speed was enforced; however, he also noted how different scenarios experienced higher rates of collision reduction *(Montella et al.*, 2012, 2015). Some of the greatest crash reductions were in rainy weather (57%), on wet pavement (51%), on curves (49%) and single vehicle crashes (44%) (Montella *et al*., 2012, 2015). These studies also noted that there was a 46% reduction in fatal collisions (Montella *et al*., 2012, 2015). Previously in this benefit-cost analysis, a 32% reduction in collisions was applied to all types of collisions. With this 32% reduction applied to the annual fatal collision costs of $3,057,500 a yearly savings of $978,400 was achieved. When applying the 46% reduction, a yearly savings of $1,406,500 is found. This difference between applying a 32% reduction in fatal collisions and 46% is enough to boost the BCR from 15.6 to 17.5.

Additional gains in collision savings could also be realized if some of the collision modifications factors for things like collisions during rainy weather, wet pavement and curves that were previously identified were used. For this location in particular, the savings would have increased if the single vehicle collision modification factor was applied. As seen in Table 4-1 nearly 82% of all collisions seen in the two-year period were single vehicle collisions.

Table 4-1 Collision Type Breakdown

Year	Single Vehicle Collisions	Two Vehicle Collisions	Three or More Vehicle Collisions
2016	36	7	0
2017	31	6	2

Another situation where ASE is particularly effective is in preventing collisions where the pavement is wet or slippery. In the collision data for this location, 16 of the 82 collisions (19.5%) were noted to be on slippery pavement.

It would be possible to develop a more accurate collision costs savings estimate using the collision modification factors among the others that were identified; however, given the data available, it was decided to take a more general and conservative approach. Given that only one fatal collision occurred in one of the two years of data available, it was difficult to determine how frequent they are and if the one collision that happened in the data was statistically significant.

Even if there are areas where the analysis could be improved upon and refined, the sensitivity analysis showed that when adjusting for some of the important factors, there is still a lot of benefit in installing ASE cameras at this location. The savings from collision costs was the largest benefit in the analysis. The sensitivity analysis showed that, even if these savings were overstated or the discount rate was not aggressive enough, at a minimum this location would see a benefit to cost ratio of 11.6. The collision costs and the discount rate were chosen as factors for the sensitivity analysis as they were two of the factors with the most uncertainty and were two of the more impactful variables in the benefit-cost analysis. Collision costs is a variable that can widely vary as collisions are somewhat random and difficult to predict on a year to year basis, and the assumed costs to society of a collision vary greatly from study to study. It was also important to study the change in discount rate in a long-term project such as this; the economy could change at any moment over the 15-year period, which would impact the appropriate discount rate. The other variables studied had less variance as most of them had a linear relationship with traffic volumes which are more stable and predictable from year to year.

Chapter 5: Conclusions and Recommendations

The previously presented data analysis indicates that ASE would be useful for this location and likely other New Brunswick highways. The spot speed data, as well as the average speed data showed a clear trend of speeding throughout the study area. It is also worth noting the differences in the spot speed samples at Station A and D as well. These differences showed that there are perhaps hot zones throughout the study area where speeding was more prevalent, and these sections of high speeds may or may not have been correlated with large collision black spots. Employing ASE would encourage a more uniform driving speed throughout the area and help eliminate these changes in driving speeds from one area to the next and maintain more constant headways between vehicles.

For most roadway designs, the goal is to have the posted speed limit match the eventual 85th percentile speed. While this was not the case in this location, based on the current research on ASE, trends have shown that it is possible that enforcement of average speed could bring the 85th percentile speed down to the posted speed limit.

It is also likely that ASE would also have a positive impact on collisions. Two of the scenarios where average speed is most effective in reducing collisions is with single vehicle collisions and collisions with adverse road conditions such as slippery or wet pavement.

5.1 Future Research

Public consultation should be initiated between any governing body that is considering using ASE. With some projects in Canada aimed at lowering roadway speeds through the use of various types of spot speed cameras, at times these can be seen as unpopular with some North American road users. This lack of popularity can lead to some road safety programs ending prematurely due to pressure on local governments to end the programs. In other countries around the world, public approval has been achieved by creating an understanding of why ASE is being used.

Some studies have shown that forcing speeding motorists to reduce their speeds had an impact on non-speeding motorists to also lower their speeds (Fleiter *et al*., 2010). Some non-speeding motorists may feel societal pressures to increase their speeds when faster motorists approach from behind. It has not been studied thoroughly whether this effect happens once ASE was implemented, as much of the research on ASE has been on speeding motorists and how collisions on the route were impacted.

5.2 Research Limitations

If another similar study were to be carried out, it would be beneficial to have cameras that provide enough resolution to see license plates and are able to synchronize to the nearest second. The benefits to this are two-fold. As mentioned previously, this would eliminate the error that comes from recording times to only the nearest 1-minute accuracy. More importantly, it would allow for a greater number of vehicles to be included in the data set. Given the traffic levels experienced at this location, it was difficult for field personnel to identify each vehicle that passed, especially if there were multiple passing vehicles spaced close together. This led to most field personnel estimating that they were only able to properly identify about two out of three vehicles or every three out four. If there is approximately a 70% chance of identifying a vehicle at any given station, this means there is only a 49% chance a particular vehicle is identified at two stations, and the chance that a vehicle is identified at each station decreases for each station added to the study area. By utilizing high definition video cameras, this would allow a more precise timing as well as the ability to identify most vehicles that pass by an observation point. For a road that has a higher AADT, it is recommended to use a camera system as it may not be possible to get every two out of three vehicles if there are more vehicles to view and less time in between vehicles for the data recorded to reset.

5.3 Recommendations

Based on the findings presented in this report, it is recommended the province of New Brunswick consider the use of ASE on their highways. Through this study, it has been shown that it can be beneficial to install ASE on Route 7 between Saint John and Oromocto. The Government of New Brunswick, as well as other governing bodies, may wish to perform similar studies to this one to analyze the benefits of other roadways. The area studied in this report sees roughly 4,000 vehicles per day, and there are many other stretches of roadway in New Brunswick that see double or even triple that amount of traffic daily. On a road with more traffic, the benefits such as reduced carbon emissions will increase at the same rate traffic increases while the cost of installation and maintenance will stay the same, assuming a similar enforcement zone area. While an increase in traffic and an increase in collisions are not a linear relationship, there are likely stretches of highways that could see higher benefits from collisions reduced through the use of ASE.

The province of New Brunswick has recently done or promised to do projects such as twinning or realigning highways with the aim of improving roadway safety. Recently the province has looked at making improvements to Route 11 that has been estimated to cost $500 million and include some twinning of that highway to improve safety and capacity of the route (NBDTI, n.d.). It is recommended that before undertaking large projects such as the project on Route 11 to consider using ASE as the $500 million anticipated for the Route 11 project far exceeds the $3 million anticipated for the lifecycle costs of an ASE zone. There may be other motivations in the situation of the Route 11 project to twin that route such as capacity and level of service, but if the main goal of the project is to improve safety, ASE may be able to provide similar benefits at a fraction of the costs in certain situations.

If ASE were to be adopted, the provincial government may wish to alter the penalty for being caught or clearly identify where fines revenue will go. Over a 15-year period, the yearly income of fines revenue on its own exceeds the entire lifecycle costs of the project by $13 million as seen in Table 3-4. Previous benefit-cost analysis research has been done on ASE, and some have purposely omitted fines revenue from their results as the intended goal of ASE is to improve road safety and not to turn a profit. To counter this, the province may alter the fine structure for speeding in an ASE zone, or they could reinvest the revenue into road maintenance or other road safety programs.

ASE is an emerging technology that will continue to grow in its usage as the price of installation continues to decline. It has been proven that it successfully does what it is designed to do, which is to slow speeding motorists and to prevent collisions. ASE also has other benefits such as reductions in fuel usage which also lowers carbon emissions and also creates larger headways between vehicles that lower travel times and increase travel time predictability. The way it enforces speed is generally endorsed by the general public, especially when combined with appropriate policy decisions, and it is seen as one of the fairer ways to enforce speeding.

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Appendix A

Data Collection Form

Sample Data Collection Form

Time	Plate	Type of Vehicle	Colour	Other Identifiers

Appendix B

Speed Data

Average Speed Data Samples

License Plate	Station B	Station C	Station D	Time B-D	Speed (km/h)
317	9:49	9:56	10:07	0:18	114
921	9:49	9:56	10:07	0:18	114
951	9:49	9:57	10:08	0:19	108
557	9:49	9:56	10:07	0:18	114
279	9:49	9:56	10:07	0:18	114
334	9:49	9:57	10:08	0:19	108
232	9:49	9:57	10:10	0:21	98
595	9:50	10:02	10:09	0:19	108
273	9:50	9:58	10:10	0:20	103
838	9:59	10:07	10:19	0:20	103
672	9:49	9:57	10:10	0:21	98
955	9:59	10:05	10:15	0:16	128
514	9:59	10:07	10:19	0:20	103
374	9:59	10:07	10:20	0:21	98
239	9:59	10:08	10:20	0:21	98
722	10:00	10:08	10:20	0:20	103
391	10:09	10:17	10:30	0:21	98
401	10:09	10:17	10:30	0:21	98
573	10:09	10:17	10:30	0:21	98
924	10:09	10:18	10:30	0:21	98
710	10:09	10:17	10:29	0:20	103
010	10:09	10:18	10:30	0:21	98
114	10:18	10:26	10:38	0:20	103
317	10:18	10:26	10:36	0:18	114
339	10:18	10:27	10:40	0:22	93
075	10:18	10:27	10:40	0:22	93
153	10:18	10:27	10:38	0:20	103
339	10:18	10:31	10:44	0:26	79
531	10:18	10:28	10:40	0:22	93
177	10:18	10:27	10:40	0:22	93
333	10:21	10:27	10:40	0:19	108
693	10:29	10:37	10:48	0:19	108
299	10:29	10:36	10:48	0:19	108
010	10:29	10:36	10:47	0:18	114
991	10:29	10:36	10:46	0:17	121
923	10:29	10:36	10:47	0:18	114

License Plate	Station B	Station C	Station D	Time B-D	Speed (km/h)
BPU	10:29	10:36	10:47	0:18	114
739	10:29	10:36	10:46	0:17	121
198	10:29	10:37	10:49	0:20	103
414	10:29	10:38	10:50	0:21	98
495	10:39	10:51	11:03	0:24	85
007	10:39	10:46	10:57	0:18	114
784	10:39	10:47	10:58	0:19	108
152	10:39	10:46	10:57	0:18	114
910	10:39	10:47	10:57	0:18	114
769	10:39	10:46	10:56	0:17	121
314	10:39	10:48	11:01	0:22	93
579	10:39	10:48	10:59	0:20	103
056	10:49	10:56	11:07	0:18	114
189/347	10:39	10:50	11:03	0:24	85
058	10:39	10:48	11:00	0:21	98
918	10:49	10:57	11:09	0:20	103
762	10:49	10:59	11:12	0:23	89
633	10:49	10:56	11:06	0:17	121
498	10:49	10:56	11:08	0:19	108
135	10:49	10:57	11:08	0:19	108
418	10:49	10:57	11:07	0:18	114
419	10:49	10:58	11:10	0:21	98
261	10:51	10:59	11:10	0:19	108
622	10:59	11:07	11:18	0:19	108
951	10:59	11:06	11:17	0:18	114
422	10:59	11:07	11:18	0:19	108
877	10:59	11:07	11:19	0:20	103
470/203	10:59	11:09	11:23	0:24	85
586	10:59	11:06	11:17	0:18	114
726	11:00	11:09	11:22	0:22	93
786	11:07	11:15	11:27	0:20	103
867	11:07	11:14	11:25	0:18	114
285	11:07	11:14	11:25	0:18	114
091	11:07	11:15	11:27	0:20	103
677	11:07	11:16	11:28	0:21	98
309	11:07	11:15	11:27	0:20	103
087	11:07	11:16	11:28	0:21	98
028	11:07	11:16	11:29	0:22	93

License Plate	Station B	Station C	Station D	Time B-D	Speed (km/h)
817	11:17	11:23	11:33	0:16	128
313	11:17	11:23	11:33	0:16	128
MAN	11:09	11:16	11:28	0:19	108
844	11:17	11:25	11:37	0:20	103
508	11:17	11:25	11:36	0:19	108
405	11:17	11:24	11:36	0:19	108
556	11:17	11:24	11:33	0:16	128
503	11:17	11:23	11:33	0:16	128
119	11:17	11:24	11:35	0:18	114
496	11:17	11:24	11:36	0:19	108
972	11:17	11:25	11:37	0:20	103
485	11:17	11:25	11:36	0:19	108
498	11:17	11:24	11:33	0:16	128
504	11:18	11:25	11:36	0:18	114
919	11:27	11:34	11:45	0:18	114
968	11:27	11:33	11:44	0:17	121
534	11:27	11:35	11:47	0:20	103
963	11:27	11:34	11:46	0:19	108
138	11:28	11:35	11:47	0:19	108
138	11:36	11:43	11:54	0:18	114
WSUV	11:28	11:35	11:45	0:17	121
RPU	11:35	11:42	11:53	0:18	114
818	11:35	11:43	11:55	0:20	103
030	11:37	11:44	11:55	0:18	114
047	11:36	11:44	11:54	0:18	114
960	11:44	11:51	12:02	0:18	114
756	11:44	11:51	12:01	0:17	121
272	11:44	11:51	12:01	0:17	121
871	11:44	11:51	12:02	0:18	114
441	11:44	11:51	12:03	0:19	108
831	11:44	11:51	12:01	0:17	121
398	11:44	11:51	12:02	0:18	114
886	11:50	11:57	12:06	0:16	128
175	11:50	11:59	12:11	0:21	98
308	11:50	11:58	12:09	0:19	108
220	11:50	11:57	12:09	0:19	108
715	11:50	11:58	12:09	0:19	108
849	11:50	11:58	12:10	0:20	103

License Plate	Station B	Station C	Station D	Time B-D	Speed (km/h)
427	11:50	11:58	12:09	0:19	108
067	11:50	11:58	12:10	0:20	103
46E	11:52	12:01	12:13	0:21	98
194/76L	11:52	12:02	12:14	0:22	93
167	11:52	12:00	12:12	0:20	103
392	11:52	12:00	12:12	0:20	103
806	11:57	12:04	12:15	0:18	114
860	11:57	12:05	12:17	0:20	103
168	11:57	12:04	12:14	0:17	121
036	11:57	12:04	12:15	0:18	114
786	11:57	12:05	12:16	0:19	108
367	11:57	12:04	12:14	0:17	121
901	11:57	12:05	12:15	0:18	114
664	12:04	12:11	12:23	0:19	108
103	12:04	12:12	12:23	0:19	108
380	12:04	12:12	12:25	0:21	98
264	12:11	12:18	12:31	0:20	103
550	12:11	12:18	12:28	0:17	121
595	12:11	12:19	12:30	0:19	108
205/581	12:11	12:21	12:33	0:22	93
091	12:11	12:19	12:31	0:20	103
942	12:11	12:19	12:30	0:19	108
854/157	12:11	12:19	12:31	0:20	103
732	12:12	12:19	12:31	0:19	108
127	12:19	12:26	12:37	0:18	114
740	12:19	12:27	12:38	0:19	108
082	12:19	12:27	12:38	0:19	108
912	12:19	12:27	12:37	0:18	114
212	12:19	12:27	12:39	0:20	103
197	12:19	12:27	12:38	0:19	108
342	12:19	12:27	12:38	0:19	108
570	12:19	12:27	12:38	0:19	108
449/80C	12:19	12:29	12:41	0:22	93
994	12:19	12:29	12:41	0:22	93
176	12:19	12:29	12:41	0:22	93
963	12:28	12:36	12:48	0:20	103
674	12:28	12:36	12:48	0:20	103
794	12:28	12:36	12:47	0:19	108

License Plate	Station B	Station C	Station D	Time B-D	Speed (km/h)
353	12:28	12:36	12:47	0:19	108
149	12:29	12:37	12:48	0:19	108
503	12:30	12:37	12:48	0:18	114
741	12:29	12:36	12:48	0:19	108
210	12:37	12:44	12:56	0:19	108
224	12:37	12:44	12:54	0:17	121
010	12:37	12:43	12:54	0:17	121
406	12:37	12:44	12:56	0:19	108
602	12:37	12:44	12:56	0:19	108
648	12:37	12:45	12:55	0:18	114
127	12:37	12:44	12:55	0:18	114
857	12:37	12:46	12:57	0:20	103
501	12:37	12:45	12:57	0:20	103
799	12:37	12:45	12:56	0:19	108
515	12:45	12:52	13:04	0:19	108
265	12:45	12:51	13:01	0:16	128
327	12:45	12:52	13:03	0:18	114
201	12:45	12:52	13:04	0:19	108
337	12:45	12:53	13:04	0:19	108
640	12:46	12:53	13:04	0:18	114
117	12:53	13:01	13:12	0:19	108
639	12:53	13:01	13:13	0:20	103
313	12:53	13:02	13:14	0:21	98
021	12:53	13:01	13:13	0:20	103
960	12:54	13:00	13:11	0:17	121
851	12:54	13:02	13:13	0:19	108
366	12:54	13:02	13:14	0:20	103
773	12:54	13:03	13:15	0:21	98
342	12:54	13:02	13:14	0:20	103
827	12:54	13:02	13:14	0:20	103
554	12:54	13:02	13:14	0:20	103
850	1:02	1:11	1:23	0:21	98
974	1:02	1:09	1:18	0:16	128
738	1:02	1:10	1:22	0:20	103
960	1:02	1:09	1:19	0:17	121
295	1:02	1:10	1:21	0:19	108
907	1:03	1:10	1:22	0:19	108
171	1:03	1:12	1:23	0:20	103

License Plate	**Station B**	**Station C**	**Station D**	**Time B-D**	**Speed (km/h)**
357	1:03	1:12	1:23	0:20	103
466	1:03	1:12	1:24	0:21	98
764	1:04	1:12	1:24	0:20	103
063	1:04	1:12	1:23	0:19	108
578	1:11	1:18	1:28	0:17	121
849	1:11	1:19	1:30	0:19	108
703	1:11	1:18	1:28	0:17	121
733	1:11	1:18	1:28	0:17	121
355	1:12	1:18	1:29	0:17	121
640	1:12	1:19	1:30	0:18	114
276	1:12	1:19	1:29	0:17	121
556	1:12	1:20	1:31	0:19	108
269	1:12	1:21	1:32	0:20	103
807	1:13	1:20	1:32	0:19	108
709	1:13	1:20	1:32	0:19	108
898	1:13	1:21	1:32	0:19	108
953	1:21	1:28	1:38	0:17	121
640	1:21	1:28	1:40	0:19	108
630	1:21	1:29	1:41	0:20	103
171	1:21	1:29	1:44	0:23	89
736	1:21	1:28	1:40	0:19	108
830	1:21	1:28	1:38	0:17	121
137	1:21	1:29	1:41	0:20	103
869	1:21	1:30	1:42	0:21	98
271	1:21	1:29	1:40	0:19	108
657	1:21	1:30	1:42	0:21	98
453	1:22	1:29	1:42	0:20	103
313	1:29	1:37	1:48	0:19	108
212	1:29	1:37	1:49	0:20	103
975	1:30	1:38	1:50	0:20	103
335	1:30	1:38	1:50	0:20	103
893	1:30	1:37	1:50	0:20	103
988	1:38	1:45	1:57	0:19	108
420	1:38	1:46	1:54	0:16	128
3VX	1:38	1:45	1:56	0:18	114
697	1:39	1:45	1:58	0:19	108
042	1:39	1:45	1:55	0:16	128
308	1:39	1:46	1:58	0:19	108

License Plate	Station B	Station C	Station D	Time B-D	Speed (km/h)
477	1:39	1:46	1:58	0:19	108
212	1:49	1:56	2:07	0:18	114
120	1:49	1:57	2:07	0:18	114
327	1:49	1:58	2:10	0:21	98
146	1:49	1:57	2:08	0:19	108
846	1:49	1:57	2:08	0:19	108
630	1:49	1:58	2:09	0:20	103
720	1:49	1:59	2:12	0:23	89
245	1:49	1:57	2:08	0:19	108
114	1:49	1:57	2:13	0:24	85
852	1:49	1:58	2:10	0:21	98
596	1:51	1:57	2:08	0:17	121
582	1:51	1:58	2:10	0:19	108
355	1:51	1:58	2:10	0:19	108
114	2:03	2:11	2:24	0:21	98
JMJ	2:03	2:11	2:22	0:19	108
418	2:03	2:11	2:24	0:21	98
914	2:03	2:10	2:19	0:16	128
579/914	2:04	2:12	2:25	0:21	98
109	2:04	2:11	2:24	0:20	103
243	2:04	2:11	2:24	0:20	103
048	2:04	2:12	2:24	0:20	103
221	2:04	2:12	2:25	0:21	98
295	2:04	2:12	2:25	0:21	98
763	2:04	2:13	2:25	0:21	98
202	2:06	2:13	2:25	0:19	108

Spot Speed Samples Collected

Station A Speeds (km/h)	Station D Speeds (km/h)
111	102
113	85
102	106
108	111
107	112
116	117
99	89
98	90
101	79
90	92
99	88
100	90
96	83
109	79
111	101
111	91
99	85
106	80
105	96
111	85
102	94
155	109
115	106
117	105
105	96
99	100
98	103
117	122
108	103
118	103
97	82
115	81
102	102
104	89
102	84
109	80
112	99
108	99

Station A Speeds (km/h)	**Station D Speeds (km/h)**
105	100
108	104
111	113
115	103
117	95
102	85
102	88
107	90
106	98
110	101
95	90
102	89
106	76
108	80
109	83
119	85
108	96
105	89
105	79
117	105
103	94
107	106
108	86
99	85
102	88
98	86
96	95
94	77
96	76
102	78

Curriculum Vitae

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2012-2017

Publications: None

Conference Presentations: None