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Frequency and Potential Severity of Red Light Running in Anchorage – Phase II

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Red light running (RLR) is among the leading causes of urban automobile crashes, and the rate of related crashes is increasing. Phase I of the Alaska RLR project was independently conducted by the UAA Civil Engineering Department (Abaza and Strait, 2014). The findings of the Phase I study warranted further investigation as part of this project (Phase II). The Alaska Department of Transportation and Public Facilities would like to better understand the problem so that it can design effective strategies for reducing severe crashes at signalized intersections. Policy and law makers need information as well to produce effective countermeasures as RLR often leads to severe crashes. Frequency of RLR was measured at six different intersections in Anchorage, Alaska. The highest RLR violations in through and right turning movements at all severity levels occur at C Street and 6th Avenue. RLR violations are highest at evening peak period for all pavement surface conditions, and violations generally increase as average daily traffic increases. Alertness during left turning promotes safety and reduces violations for the locations considered. Drivers tend not to stop on slippery pavement as the signal is turning red. Results show crash rates in the studied locations align well with the RLR violation. RLR violation and crashes are considered higher than other localities in the lower forty-eight with insignificant rate of fatalities in the studied locations. Prolonged green interval proved ineffective in limiting RLR violations, even at low traffic volume, and extending yellow interval by 1–2 seconds might not be sustainable in reducing RLR violation. The literature review supports the effectiveness of using advance warning signs as an effective tool to reduce RLR. ITS solutions, e.g., "blue confirmation light," and vehicle detection technology in signal programming can reduce RLR. Finally, awareness programs and enhanced drivers training manuals (DTM), in combination with the countermeasures mentioned, are effective ways to reduce RLR violations.

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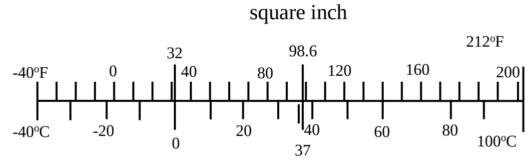
METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS					APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH					LENGTH		
in	inches	25.4		mm	mm	millimeters	0.039	inches	in
ft	feet	0.3048		m	m	Meters	3.28	feet	ft
yd	yards	0.914		m	m	Meters	1.09	yards	yd
mi	Miles (statute)	1.61		km	km	kilometers	0.621	Miles (statute)	mi
		AREA					AREA		
in^2	square inches	645.2	millimeters squared	cm^2	mm^2	millimeters squared	0.0016	square inches	in^2
ft^2	square feet	0.0929	meters squared	m^2	m^2	meters squared	10.764	square feet	ft^2
yd^2	square yards	0.836	meters squared	m^2	km^2	kilometers squared	0.39	square miles	mi^2
mi^2	square miles	2.59	kilometers squared	km^2	ha	hectares (10,000 m^2)	2.471	acres	ac
ac	acres	0.4046	hectares	ha					
		MASS (weight)					MASS (weight)		
oz	Ounces (avdp)	28.35	grams	g	g	Grams	0.0353	Ounces (avdp)	oz
lb	Pounds (avdp)	0.454	kilograms	kg	kg	kilograms	2.205	Pounds (avdp)	lb
T	Short tons (2000 lb)	0.907	megagrams	mg	mg	megagrams (1000 kg)	1.103	short tons	T
		VOLUME					VOLUME		
fl oz	fluid ounces (US)	29.57	milliliters	mL	mL	milliliters	0.034	fluid ounces (US)	fl oz
gal	Gallons (liq)	3.785	liters	liters	liters	Liters	0.264	Gallons (liq)	gal
ft^3	cubic feet	0.0283	meters cubed	m^3	m^3	meters cubed	35.315	cubic feet	ft^3
yd^3	cubic yards	0.765	meters cubed	m^3	m^3	meters cubed	1.308	cubic yards	yd^3
Note: Volumes greater than 1000 L shall be shown in m^3									
		TEMPERATURE (exact)					TEMPERATURE (exact)		
ºF	Fahrenheit temperature	5/9 (ºF-32)	Celsius temperature	ºC	ºC	Celsius temperature	9/5 ºC+32	Fahrenheit temperature	ºF
		ILLUMINATION					ILLUMINATION		
fc	Foot-candles	10.76	lux	lx	lx	Lux	0.0929	foot-candles	fc
fl	foot-lamberts	3.426	candela/m^2	cd/cm^2	cd/cm^2	candela/m^2	0.2919	foot-lamberts	fl
		FORCE and PRESSURE or STRESS					FORCE and PRESSURE or STRESS		
lbf	pound-force	4.45	newtons	N	N	newtons	0.225	pound-force	lbf
psi	pound-force per square inch	6.89	kilopascals	kPa	kPa	kilopascals	0.145	pound-force per square inch	psi

These factors conform to the requirement of FHWA Order 5190.1A *SI is the symbol for the International System of Measurements



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Abstract

Red light running (RLR) is among the leading causes of urban automobile crashes, and the rate of related crashes is increasing. Phase I of the Alaska RLR project was independently conducted by the UAA Civil Engineering Department (Abaza and Strait, 2014). The findings of the Phase I study warranted further investigation as part of this project (Phase II). The Alaska Department of Transportation and Public Facilities would like to better understand the problem so that it can design effective strategies for reducing severe crashes at signalized intersections. Policy and law makers need information as well to produce effective countermeasures as RLR often leads to severe crashes. Frequency of RLR was measured at six different intersections in Anchorage, Alaska. The highest RLR violations in through and right turning movements at all severity levels occur at C Street and 6^{th} Avenue. RLR violations are highest at evening peak period for all pavement surface conditions, and violations generally increase as average daily traffic increases. Alertness during left turning promotes safety and reduces violations for the locations considered. Drivers tend not to stop on slippery pavement as the signal is turning red. Results show crash rates in the studied locations align well with the RLR violation. RLR violation and crashes are considered higher than other localities in the lower forty-eight with insignificant rate of fatalities in the studied locations. Prolonged green interval proved ineffective in limiting RLR violations, even at low traffic volume, and extending yellow interval by 1–2 seconds might not be sustainable in reducing RLR violation. The literature review supports the effectiveness of using advance warning signs as an effective tool to reduce RLR. ITS solutions, e.g., "blue confirmation light," and vehicle detection technology in signal programming can reduce RLR. Finally, awareness programs and enhanced drivers training manuals (DTM), in combination with the countermeasures mentioned, are effective ways to reduce RLR violations.

Summary of Findings

Six signalized intersections in the Anchorage, Alaska, area were studied in analyzing the frequency and severity of red light running (RLR) violations. Five of the intersections were four-legged, and one was three-legged. With the exception of C Street and 6th Avenue, the intersections were chosen such that all types of movement at the intersection could be observed with proper sight distance. The COUNT Cam2000 camera was selected to record videos of vehicular movement at intersections. Twenty-four-hour video of a typical weekday was collected to analyze RLR in selected intersections. Four pavement conditions—dry, wet, snowy, and icy—were considered. At the C Street and 6th Avenue intersection, 25 RLR per 1000 entering vehicles were recorded or 250 per million entering vehicles (MEV), while at the other intersections, about 5 RLR violations were recorded. Of all six signalized intersections, the one at C Street and 6th Avenue had the highest rate of violations. The intersection at Boniface Parkway and Mountain View Drive, located at the end of a freeway ramp, had the highest rate of violation severity, defined as the depth of violation into the red light in seconds for the through movement. In general, through movements were the highest RLR violations compared with right and left turning movements. Though RLR violation severity of less than 1 second was predominant following the national trend, the presence of higher levels of severity makes RLR more complicated. Passenger vehicles violated the red light most frequently. An increase of traffic volume generally resulted in higher RLR violations in morning and afternoon peak hours. Considerably more violations were recorded during the late afternoon period into the nighttime hours, even though traffic volume decreased significantly. We found that green extension had no influence on reducing RLR violations for the locations and pavement surface conditions analyzed. Wet and icy conditions contributed significantly to the rate of RLR violation, compared with dry and snowy conditions, suggesting a forced condition of RLR. Particularly, for wet and icy road conditions, RLR violations occurred throughout the day to midnight. Thus, slippery wet or icy roadways at intersections were found to be likely conditions for through movement RLR. Drivers' fear of skidding through an intersection because of braking for a signal about to turn red was identified as the most likely reason for RLR. Afternoon was the most common time for RLR violations, and snowy pavement surface conditions were recorded during an appreciable number of RLR violations. The lowest number of RLR violations was recorded in dry pavement surface conditions. Red light running violations in wet conditions predominantly occurred in the through movement, with a severity level of less than 1 second; icy conditions were second in this regard. We analyzed a number of countermeasures for reducing RLR violations in the Anchorage area. An increase of the amber (yellow) interval by 1–2 seconds might technically result in a reduction in RLR violations for the through movement based on the measured violations but it was determined that this countermeasure is not sustainable. The literature review supports the notion that using advance flashing signs for the through movement, indicating a termination of the yellow interval, is an effective means of capturing a driver's attention before reaching the area of the intersection and consequently be able to avoid running the red-light. For a long-term strategy, the use of ITS solutions like a "blue confirmation light" and vehicle detection technology can effectively reduce RLR, even beyond 2-second violations. Finally, awareness programs and enhanced drivers training manuals (DTM), in combination with the countermeasures mentioned, are effective ways to reduce RLR violations.

CHAPTER 1 – INTRODUCTION AND RESEARCH APPROACH

Introduction

A traffic signal's function is to reduce traffic conflicts and eliminate major conflicts, improving the safety of motorists going through the intersection. A red light running (RLR) violation occurs when a motorist enters an intersection after the onset of a red signal light indicator. A report from a study conducted by the AAA Foundation for Traffic Safety (AAA Foundation for Traffic Safety, 2014) suggests that 93% of drivers believe that violating a red light is unacceptable behavior; however, one of three drivers admitted to running a red light in the past 30 days.

For many years, crashes due to RLR violators have been a serious threat to road safety at signalized intersections. In 2000, 106,000 crashes, 89,000 injuries, and approximately 1,036 fatalities directly attributed to RLR were reported (FHWA, 2002). According to the National Highway Traffic Safety Administration (NHTSA) and Fatality Analysis Reporting System (FARS) database, the RLR crashes caused 676 fatalities in 2009 (FHWA, 2010). Crashes due to RLR violations resulted in 8,845 fatalities from 2000–2009 throughout the U.S. (FHWA, 2010). According to the Insurance Institute of Highway Safety (IIHS, 2013), in 2012, RLR violations resulted in 683 fatalities and an estimated 133,000 injuries nationwide. In Anchorage Alaska, crash data in the period 2008-2014 for six intersections shows 5900 RLR crashes per MEV with 1 fatality and an average of 0.034 and 0.675 per MEV for incapacitating and non-capacitating injuries respectively.

Phase I of the Alaska RLR project was independently conducted by the UAA Civil Engineering Department (Abaza and Strait, 2014). Data collection took place from August 2011 to July 2012. Six intersections in Anchorage were chosen based on failure-to-stop citations, adequate traffic volumes, and geometry. The six intersections were recorded with ATD Northwest PATH cameras and a DVR system to capture RLR violations. The intersections were observed and recorded to identify how many violations occurred and their severity (how many seconds after the light turned red). The intersections studied were found to have an average violation rate of 1 per 1000 vehicles entering the intersection. The research team determined that when conditions were wet, 73% more RLR violations occurred than when conditions were dry. The findings of the Phase I study warranted further investigation as part of this project (Phase II).

In a cold region area like Anchorage, Alaska, diverse weather conditions trigger and/or increase weather-related crashes, such as RLR crashes. Phase I of this project showed significant differences in RLR violations in dry and wet pavement conditions. The RLR phenomenon highlights certain safety aspects at intersections in Anchorage under different weather conditions, especially during wintertime. Snowy and icy conditions in Alaska are possible contributing factors to RLR. Due to the serious consequences of RLR, most state and local governments throughout the U.S. have invested effort in exploring and implementing strategies to reduce RLR violations and their associated crashes. Effective implementation of countermeasures to reduce RLR in Alaska requires observation at a number of intersections throughout the year. This study took into consideration four pavement surface conditions—dry, wet, snowy, and icy—in the analysis of RLR violations.

Increase in vehicle miles traveled (VMT) per capita in the Alaska (2011-2014) is one of the highest nationwide (Megna, 2016) suggests the probability of more red light-related crashes in the coming years. Red light running is one of the leading causes of severe urban automobile collisions, with overall vehicular fatalities in Alaska at 30 per year in urban areas based on a three-year moving average, and overall (urban and rural), 84 per year as of 2016 with 21 fatalities per year in Anchorage alone or 7.04 per 100,000 populations (FARS, 2017). The rate at which these collisions occur rises with increasing VMT. One of the goals of this project is to identify countermeasures that would be applicable in Anchorage's physical environment, considering driver behavior, to reduce incidences of RLR. We analyzed countermeasures for relevance and applicability, and present them to the Alaska Department of Transportation and Public Facilities (DOT&PF) through this report. This study provides information that will help both the Municipality of Anchorage and DOT&PF in developing management and capital programs that address the "Four E's"—Engineering, Enforcement, Education and Emergency Services —as they relate to RLR issues in Alaska.

Problem Statement and Research Objective

Red light running violations pose a safety concern for motorists at intersections (FHWA, 2010; IIHS, 2013) as well as other roadway users. Moreover, violations that occur later in the red light cycle, while opposing traffic is flowing, stand a greater chance of causing serious crashes. In Phase I of this study, we found that pavement condition was an influencing factor in RLR violations, but only dry and wet pavement conditions had been considered. In a cold region such as Alaska, snow and ice on roadways may significantly affect RLR. Thus, contributory factors of different intersections and pavement conditions may have an influence on intersection crashes, especially in highly populated urban areas like Anchorage. Research on this topic will help develop appropriate countermeasures that help reduce RLR violations and minimize the number and severity of crashes at intersections.

This study had the following objectives:

- Identify the rate of RLR violations with respect to four pavement conditions—dry, wet, snowy, and icy—at six Anchorage intersections identified by DOT&PF, and highlight the most likely conditions for increased RLR violations.
- Provide a comparative analysis of RLR violations at the intersections.
- Identify the level of severity of RLR violations among the intersections.
- Propose effective countermeasures for limiting RLR violations in the Anchorage urban area with a priority on high crash sites.

Scope of Study

To analyze RLR violations in the selected six intersections of Anchorage, we collected and sorted 24 hours (Full day) of weekday videos recorded at each intersection in four pavement surface conditions. We analyzed RLR violations based on 1000 entering vehicles in selected approaches, the severity of violations, the type of movement, and the vehicle composition. Detailed fluctuations of RLR violations throughout a typical weekday, with green time phasing and ADT data, were analyzed to determine driver's vulnerability due to RLR violations with respect to these variables. To arrive at countermeasures, we considered the comparative analysis of RLR violations at the six intersections in four pavement conditions, and propose cost-effective and efficient methods to reduce RLR violations at the intersections in the Anchorage urban area.

Research Approach

To understand and address RLR within Anchorage, DOT&PF identified six intersections for study:

C Street and 6th Avenue (one-way vs. one-way)
Northern Lights Boulevard and UAA Drive (one way vs. two-way t-intersection)
15th Avenue and Ingra Street (one way vs. two-way intersection)
Spenard Road and Benson Boulevard (Two-way vs. one way)
C Street and Benson Boulevard (one-way vs. one-way)
Boniface Parkway and Mountain View Drive (two-wat vs. two-way)

Overview of the general geometrical characteristics of the studied intersections are addressed in Table B1 Appendix B. At these intersections, we observed and recorded RLR violations, noting intersections' general traffic and geometric characteristics and the characteristics associated with RLR violations. In Alaska, weather conditions influence RLR, because weather affects the pavement surface. Phase I of the project only captured summer season with dry and wet conditions. In this phase we analyzed four pavement surface conditions (wet, dry, snowy, and icy) throughout the year along with the rates of total violation, violations per movement type (through, right or left turns), severity of violations, violations by vehicle type, and the number of violations per green time intervals throughout a typical day of the week.

Throughout Phase I, we used an ATD Northwest camera with DVR system to record the data for analyzing. This camera system is technologically outdated for the needs and purposes of Phase II of the project. Numerous new camera recording systems would have been adequate for Phase II, but the most effective system for this research was the COUNTcam 200. Specifically, the COUNTcam 200 has a lens wide enough to capture traffic from one direction (stop line), along with the traffic signal heads. The COUNTcam 200 can store up to 200 hours of footage on a 64 GB SD card before the battery needs recharging. This system is a relatively inexpensive and practical way to capture data, and minimal effort is required to prepare the system in the field. The camera system setup is shown in Figure 1.1.

The rate of RLR violations with respect to 1000 entering vehicles and the rate of violations based on vehicle movement type (through, left, or right turning) for each pavement surface condition at each intersection studied are based on the video collected at each intersection. We note the severity of red light violations on a typical weekday for each intersection and the pavement conditions. Moreover, the composition of vehicle types over a one-day period for each of the pavement conditions is highlighted graphically.

Phasing is an important characteristic to address in RLR violations with respect to changes in green, yellow, or red timing. At the intersections studied, only green phasing was used, as red and yellow phasing was fixed throughout the day. For each intersection, traffic volume, green time phasing, and time of day data were collected. Afterwards, RLR violation data were introduced to provide stable ground for making valid comparisons. We studied 15-minute-interval data to further analyze RLR changes throughout the day. The research team encountered difficult circumstances in capturing pavement surface condition data for an entire day. Even so, it collected enough data for comparison and analysis of RLR violations at the intersections studied. Analysis details for each intersection can be found in Appendix B.

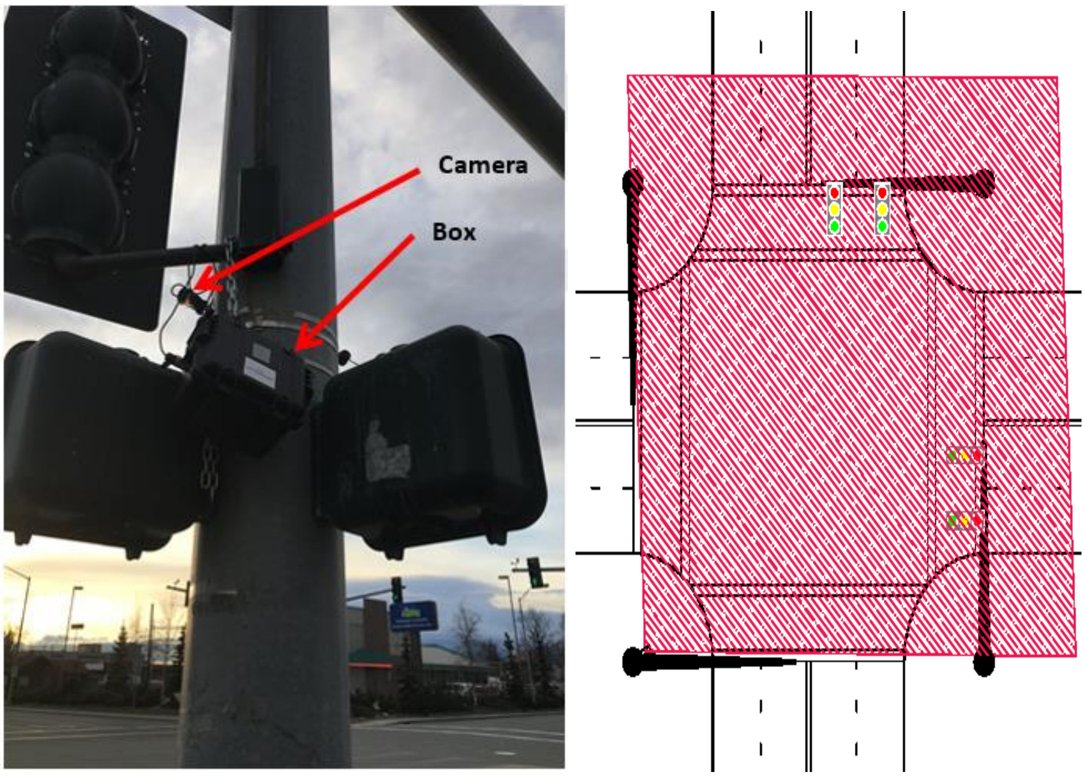

Figure 1.1: Phase II camera setup.

Literature Review

DOT&PF is interested in determining if RLR is a significant problem with the differing year-round road conditions, and how RLR in Alaska compares with the problem in the rest of the nation. Winter conditions in Alaska differ greatly from winter conditions in the rest of the United States. Snow and ice remain on roads for most of the winter, and majority of pavement markings are destroyed by snowplows and studded tires or covered by snow. Many newer technologies are available for obtaining accurate and consistent information. These newer technologies were used in Phase II data collection and analysis. Methodologies presented in the literature review varied. Some studies used sophisticated, complex, and expensive equipment that required signal communication with camera systems that were useful for RLR citations. Other studies used a simple camera setup with manual counts for RLR violations. RLR countermeasures currently in use are being researched to reduce the number of RLR incidents include speed pavement markings, increased yellow timing, signal visibility, red light cameras, pedestrian and signal countdowns, signal timing, and other engineering measures. Similar research studies have generally proved that countermeasures are effective in reducing violation rates of RLR, although some side effects were reported such as an increase in rear-end crashes, adaptation to an increase in yellow signal timing (Bonneson et al, 2004) and adaptation to green signal countdowns. Little was reported on the effects of pedestrian countdown timers on RLR, research in this field was split on this issue. According to Alaska RLR surveys in 2011, pedestrian countdown timers are specifically designed as an aid to pedestrians crossing the intersections. In case of some intersections, the timers coincide with the end of the green light cycle and drivers approaching those intersections can see how long before the light will change to yellow, which affects the rate of RLR, though many of the intersections showed no such correlation. In addition, little current research on RLR in snow and ice conditions, so the Phase II project scope was valid new research.

This section of the report contains an abbreviated literature review. The complete literature review is found in Appendix A. In this review of literature, we focused on the following issues:

- Methodologies and devices used to collect RLR data
- Outcomes of similar studies
- Pedestrian countdown timers and the dilemma zone
- Countermeasures considered as a result of efforts in other states
- Current published research and how it supports the scope of this project continuing forward

Alaska has no state law or programs involving the use of red light or speed cameras. Alaska is a “permissive yellow” state (Article 13 AAC 02.010, Traffic-Control Signal Legend). In the NCHRP Report 731, Guidelines for Timing Yellow and All-Red Intervals at Signalized Intersections (McGee et al., 2011), permissive yellow is defined as the following:

> Under a permissive yellow law, drivers may enter the intersection during the entire duration of the yellow change interval and legally be in the intersection while the red signal indication is displayed, so long as entrance occurred before or during the yellow signal indication.

History of permissive yellow law can be broken down to two classes, *Class 1* - vehicles can enter the intersection at any point during the yellow change interval and if entered during yellow, it is legal to be in the intersection during the red, *Class 2* - vehicles cannot enter or be in the intersection on red (Eccles et al, 2001). In this study the definition given in NCHRP Report 731 will be adopted here on as Alaska is a Class 1 permissive State.

Many research studies have been conducted to identify the factors that contribute to RLR violations at an intersection and possible countermeasures. Use of cameras that can record the area of an intersection including traffic signal heads is the most common method of detecting RLR violations. Some experiments have used a combination of cameras and sensors to monitor RLR. Microprocessor-controlled Gatso red light cameras and hidden video cameras have also been used to record violations and exposure data. ATD Northwest PATH cameras and a DVR system were used in Phase I of the Alaska RLR project to detect RLR violations. The ATD Northwest camera system with a DVR is technologically obsolete, and various new camera recording systems would have been adequate for the Phase II research, including SmartMicro Radar Detection Device, the MESSOA LPR610, the FLIR Systems FXV101-W Outdoor Wireless HD Video Camera, The Best Vision BV-IR140-HD 1000TVL Bullet Security Camera, or Reolink RLC-411S. The COUNTcam 200 is relatively inexpensive and very effective, storing up to 200 hours of footage on a 64 GB SD card before the battery needs recharging.

Many studies have analyzed RLR to determine influential factors related to the violation. Factors considered have included various intersection characteristics and traffic variables such as geometric design, control system, location, traffic direction, speed while crossing the intersection, speed of traffic in crossroad, width of crossroad, volume of traffic at intersection, number of traffic lanes in the direction of consideration, and red light interval. Generally, younger drivers are more prone to RLR violations than any other age group. The majority of violations occur within 1 second of the red light signal (after the signal turns red), during the weekend and during non-peak hours. The presence of one or more passengers and the presence of front-seat passengers have been found to be a factor for decreasing RLR violations. Careless driving and a higher number of travel lanes were found to be contributing factors in influencing RLR-related crashes. The major factors associated with RLR violations suggested by different studies are listed in Table 1.1; details are addressed in Appendix A.

Table 1.1: List of factors associated with RLR violations.

• Road width • Red light interval • Speed • AADT or ADT per phase per cycle • Violation rate • Maximum number of phases per cycle • Speed limit • Drivers' age group	• Day of the week • Non-peak hour • Presence of passenger in the vehicle • Drivers' gender • Vehicle type • Presence of front seat passenger • Number of travel lanes

Some researchers carried out various experiments, both in real and simulated environments to minimize RLR, and suggested possible countermeasures. Five types of crash events such as running red lights, stop signs or yield signs, hitting a stopped or stopping vehicle from the rear, running off the road and striking an object, swerving into another occupied lane, and turning left and colliding with an oncoming vehicle were introduced for an urban area. Applying a green signal countdown device (GSCD) resulted in significant reduction in RLR violations, although the effectiveness of this measure dissipated over time. Before and after analysis of Green countdown device showed above 60% reduction of RLR after 1.5 month of installation. However, after around 8 months of installation of that device the RLR violations reached to its before condition and thus not effective for a long term solution (K.M. Lum and Harm Halim, 2006). Pavement markings in the dilemma zone (a physical zone where a driver chooses to either proceed through the signal or come to a stop at the onset of a yellow change interval) reduced RLR violations, increasing safety. Even though camera enforcement can sometimes increase rear-end collisions, many researchers consider it an effective solution to RLR violations. Different studies show that increasing the yellow interval duration and the presence of signal back plates successfully reduce RLR violations. The possible countermeasures recommended by different researchers are summarized in Table 1.2. Some countermeasures are not applicable in the case of this project, others will be discussed in the analysis section of the report. More details are provided in Appendix A.

Table 1.2: List of countermeasures for reducing RLR violations.

• Increase signal visibility • Reduce speeds • Use red light camera enforcement • Use green signal countdown device • Provide green extension • Improve signal coordination • Improve signal operation • Improve sight distance • Improve visibility of signal • Improve visibility of signal with yellow LEDs	• Increase conspicuity of signal with back plates • Add advance warning signs without flashers • Add advance warning signs with active flashers • Remove unneeded signals • Add capacity with additional traffic lanes • Flatten sharp curves • Add pavement markings in the dilemma zone • Increase the yellow interval duration • Add signal back plates • Add blue confirmation light

CHAPTER 2 – FINDINGS

This summary consists of a comparison of the intersections studied including an analysis of RLR violations, highlighting pavement surface conditions. We used geometric design criteria in analyzing RLR violations at each intersection, especially sight distance, total number of violations per 1000 entering vehicles and MEV, violations based on movement type, severity, vehicle composition, and phasing pattern. Geometric design is important when analyzing RLR violations. Five of the six study intersections are four-legged; the sixth intersection—Northern Lights and UAA Drive—is a T intersection. We analyzed RLR violations for through-movement violations and left or right turning RLR in locations where applicable. Sight distance is crucial because without proper utilization, RLR violators may be involved in a severe crash. Sight distance is satisfactory at all intersections studied except C Street and 6th Avenue. Detailed features of the geometric elements of the intersections are found in Appendix B.

The intersection at C Street and 6th Avenue is a critical case, with 25 RLR violations per 1000 entering vehicles (250 MRV). All other intersections recorded 5 RLR violations or less per 1000 entering vehicles (50 MEV). Significant through and right turning RLR violations with a severity of less than 1 second were recorded at C Street and 6th Avenue. Other severity levels were recorded at all study intersections. As part of the analysis, we considered phasing data for green time intervals, RLR violations, and traffic volume at each intersection. Figure 2.1 represents an example of the collective data. The average RLR violation follows the trend of traffic volume, except during evening hours. More RLR violations were recorded during evening peak and off-peak periods than during morning hours. Extension of the green time interval had no significant effect on RLR violations. A higher rate of RLR violations was recorded during afternoon rush hours, with even higher rates recorded into early nighttime hours. Very few left turning RLR violations were recorded, which shows drivers' alertness toward left turning maneuvers. At the intersection of C Street and 6th Avenue, almost all RLR violations involved passenger cars; few buses and trucks were recorded. At the intersection of 15th Street and Ingra, a few semitrailers were recorded running the red light within one second of the red-light. A detailed analysis of RLR violations per 1000 entering vehicles, the amount of through or right turning RLR violations, along with RLR severity and vehicle mix for each study intersection, and a detailed comparative analysis of RLR violations at all the intersections with respect to these criteria are available in Appendix B.

We analyzed RLR violations along with concurrent pavement surface conditions to identify the effect of pavement surface conditions on RLR violations. The average number of violations for a particular pavement condition is shown in Figure 2.2. The lowest number of RLR violations was observed during dry pavement surface conditions; the highest number of RLR violations, with about 12 per 1000 entering vehicles, was recorded during wet pavement surface conditions. Icy pavement surface conditions ranked second for RLR violations, with about 4 per 1000 entering vehicles, and snowy pavement surface conditions ranked third, with about 7 RLR violations per 1000 entering vehicles. Wet and icy pavement surfaces are the most likely pavement conditions for RLR, indicating drivers' preference for running a red light to avoid braking on slippery pavement. The assumption by drivers of lower skid resistance in wet or icy conditions influences them to risk running a red light at a signal about to turn red.

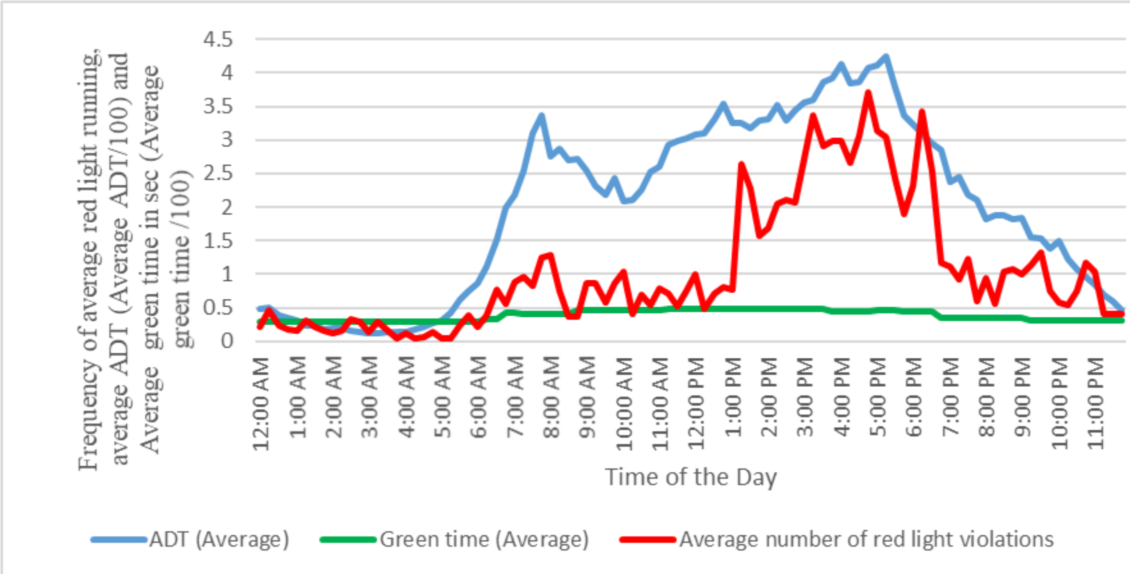

Figure 2.1: Average frequency of red light violations, average ADT, and average green time sequence throughout a day at all intersections studied.

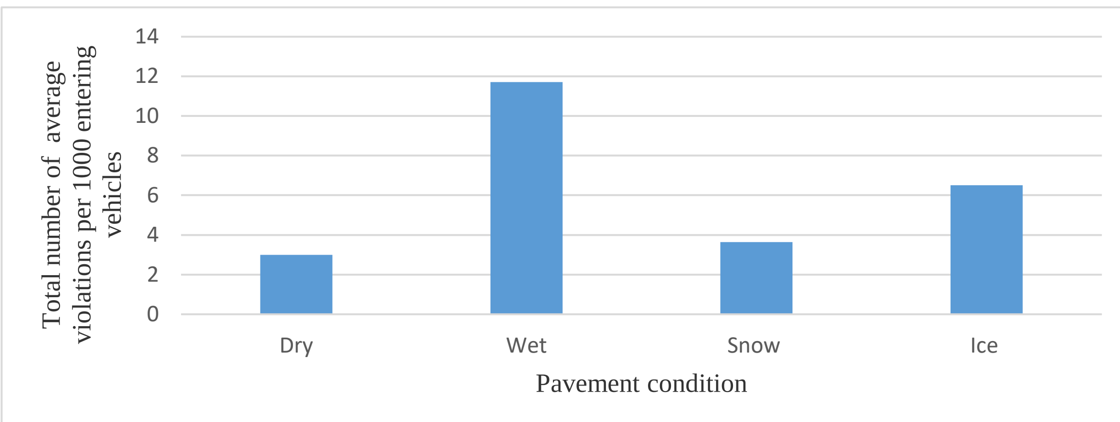

Figure 2.2: Total number of average red light violations per 1000 entering vehicles based on different pavement conditions.

Average violations based on movement type for each pavement surface condition are presented in Figure 2.3. Through movement in wet conditions had the highest rate; about 9.5 violations per 1000 entering vehicles were recorded. In icy and snowy conditions, 4 and 6 violations per 1000 entering vehicles, respectively, were recorded. About 1 violation per 1000 entering vehicles was recorded for right turning movement under dry and icy pavement surface conditions. Fewer right turning violations were recorded for snowy conditions. More details are addressed in Appendix B. Once again, drivers' tendency to avoid skidding on slippery roadways in wet or icy conditions (especially for through movement) leads to higher RLR violations.

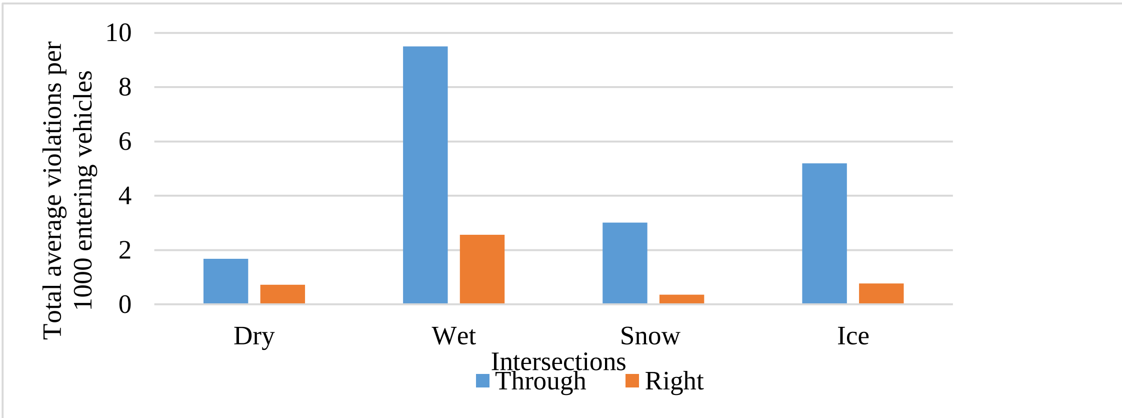

Figure 2.3: Total average number of red light violations per 1000 entering vehicles based on different pavement conditions.

An average number of violations were taken into consideration for each level of severity and pavement condition, as shown in Figure 2.4. Severity in this case indicates the depth of violation into the red light in seconds after crossing the stop bar. Wet and icy pavement surface conditions had the highest rate of violations in each severity level. The maximum rate of violations was recorded in the first two levels of severity, being less than 1 second and 1–2 seconds; few violations were recorded for the other levels of severity. Wet pavement surface conditions had the most violations in the less-than-1-second severity level. It appears that higher-than-normal approach speeds influenced the drivers to run the red light, in addition to fear of skidding or stopping beyond the stop line.

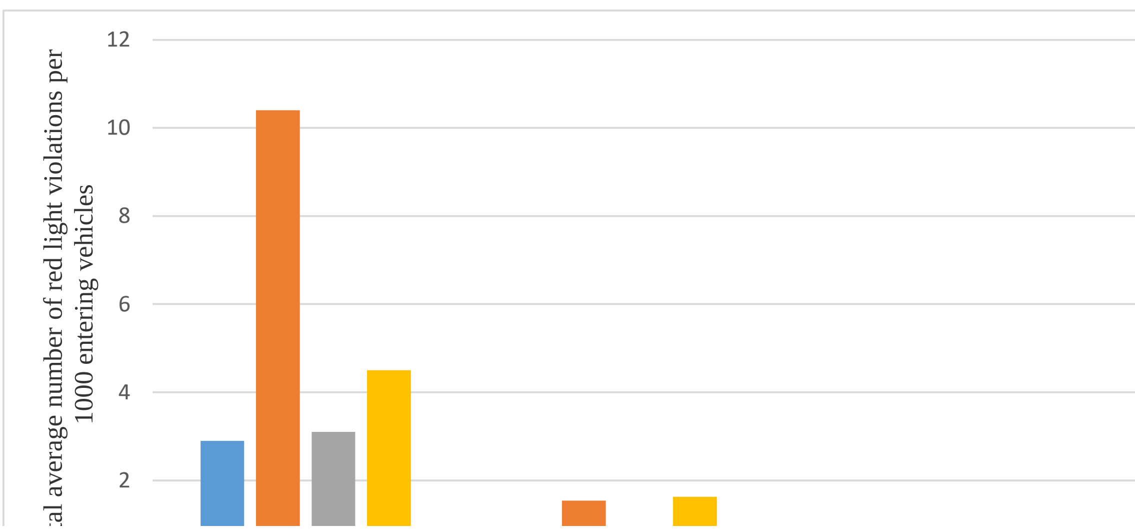

Figure 2.4: Total average number of red light violations based on severity type for different pavement conditions.

Average frequency of RLR, pavement surface conditions, traffic volume, and green time intervals for the collective data are shown in Figure 2.1. The highest number of RLR violations per 1000 entering vehicles was recorded in the afternoon and early evening period, from around 1:00 p.m. to 7:00 p.m. About 350 violations were recorded during the morning peak time, with comparable numbers in the late afternoon hours. A steady rise in traffic volume occurred at around 1:30 p.m., with a significant increase in RLR violations, even with the increase in green time interval. A decrease in violations was observed as traffic volume and green time interval decreased around 8:00 p.m., but an increase in RLR violation followed, lasting until about 11:00 p.m. In general, more RLR violations were observed in the afternoon hours compared with the morning hours. Further investigation through a drivers' survey is needed to analyze the change in drivers' behavior during afternoon hours, and effective countermeasures need to be implemented during afternoon hours. This should include snow and ice "forced"-pavement surface conditions RLR violations previously recorded under a low traffic volume in the late afternoon period as well. Note that the RLR behavior we observed differs from RLR behavior observed in other states, where this violation mostly occurs during peak hours. Locally, RLR behavior occurs during peak as well as off-peak hours. In other states and in Anchorage, the majority of RLR violations occur within 1 second of the red light interval.

Comparative analysis with other localities in the lower fort-eight are shown in table 2-1. Data from three urban areas showed the RLR violations in Anchorage Alaska are higher. In addition, crash data in Anchorage shows one fatally based on the crash data set of 2008-2014 and no fatality in 20015-2016 data while overall crashes as well as other severities are higher in general in Anchorage than the lower fort-eight with the exception of fatalities. Detailed crash analysis for Anchorage are provided as part of Appendix B. Furthermore, detailed hierarchy of RLR based on violations and crashes for the six intersections are addressed in Appendix B. This data can be used for enforcement purposes detailing the hierarchy by time of the day and location.

Table 2-1: Comparative analysis of RLR and crash rates with other localities in the United Sates.

State	City	RLR violations per 1000 entering vehicles	RLR violations per million entering vehicles	Recorded RLR crashes per 1000 entering vehicles	Recorded RLR crashes per million entering vehicles
Iowa		5.03	5026.2	X	X
Wisconsin	Milwaukee	4.0	4000	0.000427	0.43
California	Sacramento	4.2	4150	.000642	0.642
Alaska	Anchorage	5.9 **(2016-2017)**	5900 **(2016-2017)**	0.002281 **(2008-2014)**	2.2812 **(2008-2014)**
				0.0019 **(2015-16)**	1.886 **(2015-16)**

Countermeasures

Effective countermeasures, identified in our literature review, are required to limit RLR violations. Some of these countermeasures are not applicable in the case of this project others are addressed in this section with more details in appendix B. These countermeasures include red light camera enforcement, a green signal countdown device, green signal extension period, increasing visibility of signals, increasing yellow interval duration, adding advance warning signs with/without a flasher and other Intelligent Transportation System (ITS) countermeasures.

The effectiveness of using a red light camera has had mixed results in reducing RLR violations, and public perception and legal and legislative issues persist. Based on the outcomes of this study, red light camera enforcement may not be the most cost-effective solution, considering the number of RLR violations beyond the 1–2 second severity level. Other countermeasures that we describe later in the report can provide more efficient and cost-effective outcomes. Public perception in Alaska with regard to privacy issues hinder the use of red light cameras; thus, we will not address that countermeasure further. Furthermore, DOT&PF excluded this countermeasure from this research due to Alaska constitutional issues unresolved since prior red light camera enforcement efforts were tried and was not successful. It is worth to note the consideration of the use of RLR cameras for high crash sites might be an option in the future with consideration of a legal framework for it.

A green signal countdown device proved to be an effective countermeasure immediately after its implementation, but as time progressed and drivers became accustomed to the system, RLR violations increased significantly. An extension of the green time interval might not be an ideal solution in the Anchorage area or in Alaska, as a significant increase in RLR violations was recorded throughout the day after changes in the green time interval per the findings of this study (Appendix B).

Increasing the visibility of signals is another countermeasure that could be used to reduce RLR violations, but our research showed that at the intersections studied, sight distance was not a factor in limiting the number of RLR violations. In general, signals were clearly visible from the approaches except C Street and 6th Avenue.

Looking at violation severity, a significant percentage of the violations were within 2 seconds. Table 2.2 gives the proportion of RLR violations within one and two seconds interval at the studied intersections based on the violation data collected as part of this project. An extension of the yellow/red interval could be an effective means of reducing RLR violations in the Anchorage area but it might not be sustainable per some research studies (Appendix A).

The results of a 1- and 2-second increase in yellow/red interval are shown in Figures 2.5 and 2.6. An increase of 1 second in the yellow/red interval will theoretically reduce RLR violations by 70% or more at all intersections for all pavement surface conditions. In certain cases, such as at the C Street and 6^{th} Avenue intersection and the 15^{th} Avenue and Ingra Street intersection, an increase in the yellow/red interval of 1 second will theoretically reduce RLR violations by 80%. In forced conditions such as on wet pavement, an increase in yellow/red interval by 1 second will result in around a 90% theatrical reduction in RLR. Hence, overall RLR violations at all the intersections studied will decrease 70% or more but it might not be sustainable.

Table 2.2: Proportions of RLR for through movements.

Intersections	RLR Reduction for 1-second extension of yellow interval (%)	RLR Reduction for 2-second extension of yellow interval (%)
C Street and 6th Avenue	83	13
Northern Lights and UAA Drive	78	16
15th Avenue and Ingra Street	88	9
Spenard and Benson Boulevard	80	13
C Street and Benson Boulevard	71	25
Boniface and Mountain View Drive	70	28
Average	78.3	17.3

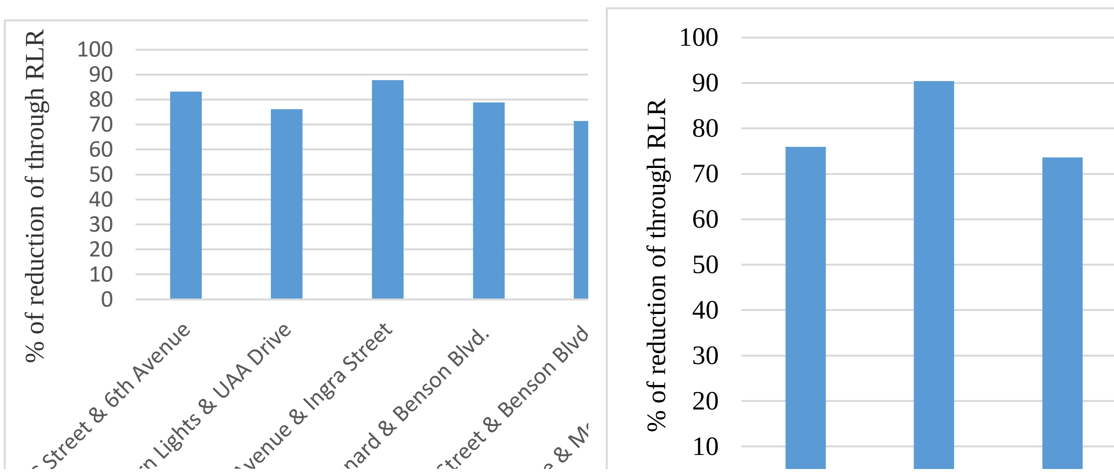

Figure 2.5: Percentage of reduction of through-movement RLR at respective intersections as well as pavement condition with an increase of 1 second in the yellow/red period.

Figure 2.6 shows that with a 2-second increase in the yellow/red interval, more than 90% theatrical reduction in RLR might be observed at all the study intersections. An appreciable number of intersections would experience more than a 95% RLR theatrical reduction in through movement. At a 95% confidence interval, RLR violations on wet, snowy, and icy pavement would be reduced as well. More than a 90% theatrical reduction in RLR violations might be expected on dry pavement. A decrease of more than 80% in overall violations might be achieved. A detailed analysis on this countermeasure are provided in Appendix B.

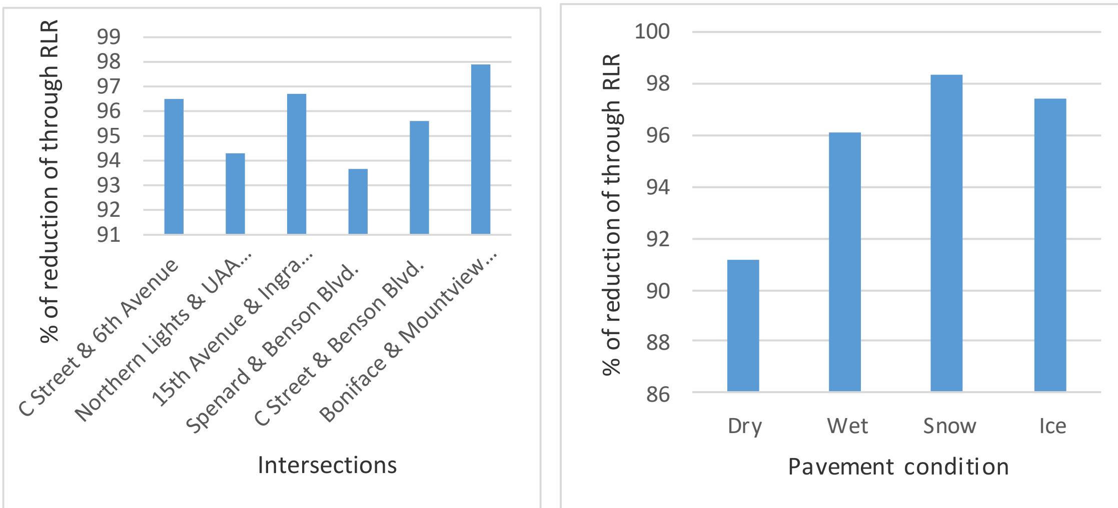

Figure 2.6: Percentage of reduction of through-movement RLR at respective intersections as well as pavement condition with an increase of 2 seconds in the yellow/red period.

Extension of yellow/red periods by 2 seconds may produce reduction in RLR violations, but as time progresses, drivers become accustomed to the extension and may start running the red light once again (Appendix A). This outcome has been observed in countermeasures implemented by other states in the United States. Increasing the yellow interval by more than 1 second has its own challenges in terms of the capacity and level of service of the intersections under consideration. If extending the yellow/red interval is to be adopted for afternoon hours when RLR is higher it might have safety implications for the morning period, as drivers' expectation of longer yellow intervals leads some to run the red light. In addition, drivers' rushing behavior in the evening peak period can only be addressed by an extension of yellow/red intervals of more than 1 second. Red light running violations beyond 2 seconds require additional countermeasures. For instance, public awareness concerning extension of the yellow interval may produce a better outcome.

Flashing warning signs are another effective countermeasure in reducing RLR at intersections (FHWA, 2009). Flashing warning signs such as flashing yellow proved effective in reducing violations/crashes, especially during vulnerable movements such as left turning movements. We address the effectiveness of techniques and systems using flashing warning signs, identified with respect to RLR, in the literature review in Appendix A. Flashing yellow signals for through movement can be an effective measure for reminding drivers about the possibility of RLR especially in wet and icy conditions. Such warning further emphasizes for drivers the change of phasing (Pant and Xie, 1995), creating awareness in drivers heading towards the approach at a higher-than-usual speed, especially in forced pavement conditions such as wet or icy pavement. Thus, drivers can avoid skidding on a wet or icy roadway surface and be able to stop.

Using the flashing yellow for the through movement might create issues for drivers who confuse the concept of flashing yellow arrow for left turn signals, already in place, and the above-mentioned flashing yellow signal for through movements. Since the suggested approach of using the flashing yellow for the through movement is only for hotspots or high

RLR violation intersections, it might be a good practice to test such countermeasures before full implementation.

Pavement markings in the dilemma zone warning drivers of signal “SIGNAL AHEAD” is an effective tool to reduce RLR but the condition of snow cover in the winter time might hinder the use of this countermeasure.

The use of advance warning signal proved to be effective in reducing RLR violations and crashes. Several systems are in use utilizing sign and signals as an advance warning for drivers to address the dilemma zone and RLR with effectiveness in reducing RLR ranging from 27-67 percent and significantly reducing angle crashes. Amongst the advantages reported on this technique it provides additional warning and reaction time, especially being effective for large, commercial vehicles and relatively low-cost improvement. Some of the disadvantages reported it can increase the dilemma zone and drivers may rely on the sign rather than checking signal changes. None of the studies showed a diminishing effect of such countermeasure overtime.

To achieve the outcome in reducing RLR violations of the 1- to 2-second or even higher severity level, the use the ITS technique of a blue confirmation light or simply a confirmation light might be the better countermeasure. This system gives an indication to law enforcement when a RLR violation is in effect (a driver is in violation of the red light). It is worth to note such a system are in place in some intersections in Anchorage but needs activation to measure its effectiveness. Other ITS countermeasures such vehicle detection technology for traffic signal programing are considered effective but adaptability and cost might hinder the use of such countermeasure.

In combination with any suggested countermeasure, public awareness programs that target age cohorts, ranging from teenage drivers to experienced drivers, and enhanced drivers training manuals (DTM), are recommended for implementation.

For further details on individual and collective analysis of the intersections studied and details on the analysis of each of the countermeasures, please see Appendix B.

CHAPTER 3 – INTERPRETATION, APPRAISAL, AND APPLICATIONS

Rates of RLR were identified at the intersections studied and for all pavement conditions in the Anchorage area. RLR violations rates are higher than other localities in the lower forty-eight and RLR crashes are aligned well with RLR violations for the studied locations. Crash rates and severity levels are higher than the lower fort-eight with insignificant fatality rates in the studied locations in Anchorage. RLR follows the general trend of traffic like the lower forty-eight except the higher RLR violation in Anchorage later at night with decreasing traffic volume. The intersection at C Street and 6th Avenue had the maximum rate of RLR violations. Through-movement RLR violations were far greater than right turning RLR violations. A severity of less than 1 second was far more frequent than other levels of RLR severity. Passenger cars had the most RLR violations. Red light running violations are most likely to occur on wet and icy roadways than on dry and snowy roadways. Red light running violations fluctuate with changes in traffic volume. The evening peak hours had the highest rate of RLR, into the late evening hours even with a significant decrease in traffic volume. Changes in green time interval proved ineffective at reducing RLR. Red light running violations of less than 1 second and 1–2 seconds predominate. Beyond these two levels of severity, RLR violations pose a greater risk of severe crashes at intersections. Though RLR violations can be reduced by using the recommended RLR countermeasures such advance warning signals and ITS RLR countermeasures. Multiple countermeasures need to be considered to avoid crashes associated with RLR. Awareness programs, enhancement of drivers training manuals (DTM), police enforcement, and others are additional countermeasures that could reduce RLR in the Anchorage area.

General Recommendations

To reduce RLR in Anchorage, advance warning signals may be the most effective approach as an immediate strategy. Implementation of awareness programs, enhancement of drivers training manuals (DTM) and police enforcement, may effectively address RLR. As a long-term strategy, the implementation of ITS technology, such as a “blue confirmation light”, which has proved an effective countermeasure in many states, will have a greater impact on reducing RLR, even for levels of severity exceeding 2 seconds. Based on the experience in other states of using these techniques, we highly recommend testing each of the techniques before implementation to ensure effectiveness, safety, and better use of funds. Further investigation through a drivers’ survey is needed to analyze the change in drivers’ behaviors in the afternoon hours especially late evening RLR violations. This survey might further identify effective countermeasures that can be implemented to reduce RLR violations.

CHAPTER 4 – CONCLUSIONS AND SUGGESTED RESEARCH

Conclusions

In Phase I of this research, we observed a number of red light running (RLR) violations under wet and dry pavement surface conditions at observed intersections. Phase II of the study affirms the phenomenon of RLR, mainly during wet and icy conditions. In monitoring RLR violations at six intersections, we considered pavement surface conditions (dry, wet, snowy, and icy), intersection geometric conditions, rate of violations, severity of RLR, and violations per movement type and vehicle type. Based on the analysis of field data, we conclude the following:

- The C Street and 6th Avenue intersection has limited sight distance for the southbound approach for traffic heading east and about 5 times more RLR violations than other intersections studied.
- The C Street and 6th Avenue intersection had the highest rate of RLR for through and right turning movement as well as the highest rate of all levels of RLR severity.
- Boniface Parkway and Mountain View Drive intersection had higher rates of RLR severity than other intersections.
- Negligible rates of left turning RLR were observed at the intersections, indicating drivers' alertness towards left turning movements at intersections.
- Although, RLR violations increased with an increase of traffic during the morning and afternoon periods, a significant increase in RLR violations was recorded during late evening hours, even with a decrease in traffic volume.
- Many RLR violations occurred in the afternoon and late evening hours at most of the intersections.
- Very few buses, trucks, and semitrailers violated the red light within one second of the red light.
- The highest rate of RLR was due to slippery pavement during wet and icy conditions.
- The rate of RLR violations during the afternoon rush hours increased significantly under all pavement surface conditions.
- Changes in the green interval had no effect on RLR for all pavement surface conditions.
- Advanced Warning Flasher (AWF) provide warning of the signal changing with a flasher. This has have been used in the lower forty-eight and Canada and covered in the MUTCD.
- ITS solutions can be more practical and efficient in reducing RLR as part of a long-term strategy.
- Countermeasures recommended in this project might be implemented at hotspots with high RLR violation and at intersections with a high RLR-related crash history.

Suggested Research

A questionnaire/survey of drivers would provide insight as to drivers' perspectives concerning RLR violations and possible countermeasures. Though the analysis of RLR was limited to the Anchorage area, RLR data from other areas of Alaska would provide more information on this issue. Implementation of new ITS technology, such as the activation of blue confirmation light already in place in some intersections in Anchorage and implementation of vehicle detection technology in signal programming may provide valuable information regarding the usefulness of these countermeasure. We highly recommend testing each countermeasure proposed in this report for effectiveness before full implementation.

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APPENDIX A – LITERATURE REVIEW

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Appendix A – Literature Review

Introduction

Red light running (RLR) is one of the leading causes of severe urban automobile collisions. The rate at which these collisions occur rises with increasing vehicle miles of travel (VMT). The goal of this project is to identify countermeasures that would reduce RLR in the Municipality of Anchorage (with its physical environment and driver behavior), analyze them for relevance and applicability, and present them to DOT&PF.

Alaska has no state law or programs involving the use of red light or speed cameras. Alaska is a "permissive yellow" state (Article 13 AAC 02.010, Traffic-Control Signal Legend). In the NCHRP Report 731, Guidelines for Timing Yellow and All-Red Intervals at Signalized Intersections (McGee et al., 2011), permissive yellow is defined as the following:

> under a permissive yellow law, drivers may enter the intersection during the entire duration of the yellow change interval and legally be in the intersection while the red signal indication is displayed, so long as entrance occurred before or during the yellow signal indication.

Table A1 defines permissive yellow laws for each state. Only eight states follow a true "restrictive" yellow, a term which means the driver "shall stop" and not enter the intersection unless the driver "cannot stop safely" (Jarlstrom, 2014). The restrictive states are Iowa, Michigan, Mississippi, Nebraska, New Jersey, Oregon, Virginia, and Wisconsin.

Table A1: Permissive yellow versus restrictive yellow, defined by states.

State	Definition
Alabama, Alaska, Arizona, California, Colorado, Connecticut, Delaware, Florida, Georgia, Hawaii, Idaho, Illinois, Indiana, Kansas, Kentucky, Louisiana, Maine, Maryland, Massachusetts, Minnesota, Missouri, Montana, Nevada , New Hampshire, New Mexico, New York, North Carolina, North Dakota, Ohio, Oklahoma, Pennsylvania, Rhode Island, South Carolina, South Dakota, Tennessee, Texas, Utah, Vermont, Washington, West Virginia, Wyoming	Permissive
Iowa, Michigan, Mississippi, Nebraska, New Jersey, Oregon, Virginia, Wisconsin	Restrictive

RLR (Phase I)

According to Abaza and Strait (2014), Phase I of the Alaska RLR project was independently conducted by the UAA Civil Engineering Department. Data collection took place from August 2011 to July 2012. Six intersections in Anchorage were chosen based on failure-to-stop citations, adequate traffic volumes, and geometry. The six intersections were recorded using ATD Northwest PATH cameras and a DVR system to capture RLR violations. The violations were observed and recorded to identify the number of violations and the severity (how many seconds after the light turned red). The intersections studied were found to have an average violation rate of 1 per 1000 vehicles entering the intersection.

The research team determined that 73% or more of RLR violations were due to wet pavement conditions.

Devices Used or Available

Throughout Phase I of this project, the ATD Northwest camera system with DVR recorded all the data analyzed. This camera system is technologically outdated for the needs and purposes of Phase II of the project.

Precision Traffic Systems (PTS) makes a SmartMicro Radar Detection Device that features sensors with advanced three-dimensional object tracking. This device, which is specialized for intersections, has been used for studies and enforcement. Its range varies from 88 feet to 295 feet. This camera meets the requirements of our ongoing research, but is likely unaffordable with the available budget.

The MESSOA LPR610 is a medium-range 2-megapixel IR bullet LPR/ANPR network camera. This camera can provide 1080p high-definition resolution for multiple-lane traffic monitoring in adverse weather conditions. The LPR610 uses a 32 GB micro SD card for memory storage. In addition, the camera has an intelligent traffic mode to optimize its parameter settings for different preprogrammed scenarios. For Phase II of the project, this camera may require more attachments to be effective.

The FLIR Systems FXV101-W Outdoor Wireless HD Video Camera is weatherproof and vandal-resistant; it is easy to install and can provide live video streaming to an iOS or Android device. Recordings are stored in a micro SD card. The camera can be battery powered and has a range of up to 70 feet. No traffic-specific programs are available with this camera. The camera may require more attachments to be effective for Phase II application.

The Best Vision BV-IR140-HD 1000TVL Bullet Security Camera is an outdoor day/night weatherproof camera. The camera is powered by 12VDC and lightweight, with a range of up to 164 feet. The video can be recorded with a DVR or a computer equipped with a video capture card. This camera may require more attachments to be effective for Phase II application.

The Reolink RLC-411S is a weatherproof day/night camera powered by 12VDC and has a range of up to 100 feet. High-definition recordings are stored on a micro SD card. This camera may require more attachments to be effective for Phase II application.

The COUNTcam 200 is a lightweight and durable compact traffic video recording device that can record up to 200 hours with a single charge. Few additional parts would be needed to complete an intersection recording. The recording is stored on a 64 GB SD card and is easily retrievable. Upon purchase, the package includes the camera, mounting bracket and padlock, mounting system, 7.4 V battery charger, and 64 GB SD card, and a year-long warranty and user’s manual. We chose this wide-angle camera, video data-collection device, for Phase II; it is able to capture an entire direction of traffic flow along with the signal head.

Numerous new camera recording systems would have been adequate for Phase II, but the most effective system for our purposes is the COUNTcam 200. Specifically, the lens on the COUNTcam 200 is wide enough to capture traffic from one direction with one camera, and it can store up to 200 hours of footage on a 64 GB SD card before the battery needs recharging.

Frequency of and Factors Associated with RLR Violations and Crashes

Al-Atawi (2013) analyzed the influence of intersection characteristics such as geometric design, control system, and location on RLR violations at 38 intersections in Tabuk, Saudi Arabia, where the rate of RLR violations recorded was ten times larger than in the U.S. and Australia. Seven variables that influence RLR, including traffic direction, speed while crossing the intersection, speed of traffic in crossroad, width of crossroad, volume of traffic at intersection, number of traffic lanes in the direction of consideration, and red light interval, were taken into account for regression analysis. It was determined that road width, red light interval, and speed were the most significant factors affecting RLR violations.

Hunter (2003) determined the severity of RLR at 20 intersections in Rhode Island. For the observed 20 intersections, the rate of violations ranged from 1.24 violations per hour to 15 violations per hour. On average, 6.3 violations per hour occurred, or a violation every 9.5 minutes. Among 8,597 violations, 53% occurred within 1 second of the red signal, 28% were recorded within 1 to 2 seconds of the red signal, and 19% of the violations occurred more than 2 seconds after the red signal. The highest rate of RLR violations occurred between 4 p.m. and 6 p.m. in every study intersection. The study found that moderate to high levels of RLR violations occurred when AADT at an intersection exceeded 36,200 vehicles. A comprehensive intersection index (CII) was also drawn to rank the intersections with respect to red light violations. This particular index showed a positive relationship with the crash rate at the studied intersections. This CII emphasized four factors as significant in RLR: AADT per phase per cycle, violation rate, maximum number of phases per cycle, and speed limit.

Dissanayake and Dias (2014) identified various factors related to RLR crashes, and analyzed the effectiveness of retro-reflective signal back plates as a RLR countermeasure at signalized intersections in Kansas. This study focused on analyzing the difference between red light crashes and other intersection crashes. The study’s outcome suggests that young and old-aged drivers had more severe RLR violations than middle-aged drivers. Safety equipment was less of a concern among RLR violating drivers, and thus crash severity was more likely to be fatal or cause major injury rather than minor injury or a property-damage-only crash. Moreover, RLR violation was observed more during the weekend and during non-peak hours, suggesting violators were not contained in the group that may drive more quickly or less safely in order to get to work or school on time. The contingency analysis reflected that less crashes were observed in wet conditions, due to RLR violations in comparison with other violations. The research revealed that the presence of one or more passengers in the vehicle lessened the chance of a crash drastically among red light violators. The second phase of this study dealt with effectiveness of countermeasures, and highlighted retro-reflective signal back plates as significantly helpful in reducing RLR violations for through and left turning traffic. For right turning traffic, this countermeasure was ineffective.

Burkey and Obeng (2004) analyzed the impact of red light cameras on severity of crashes at 303 intersections around the U.S. Statistically, red light cameras had a positive impact on increasing rear-end collisions, sideswipes, and left turning collisions, and red light cameras increased the amount of property damage and possible injury crashes 40–50%. Conversely, fatal and severe injury accidents were not positively correlated with red light cameras. Overall results do not support providing red light cameras at intersections.

Tuckel, Milczarski, and Rubin (2015) measured overall RLR violations at 50 signalized intersections in New York, taking factors such as driver gender, vehicle type, presence of front seat passenger, day of the week, and number of travel lanes. The data were collected manually by Hunter College students at observed intersections. The study revealed that of the observed 3,259 vehicles at the various intersections, 91.3% of vehicles stopped at the intersection when the signal turned red, whereas 1.7% first paused, then ran the light. In addition, 4.4% of through traffic and 2.6% of turning traffic violated the red signal. The observations suggest that male drivers (7.5%) violate the red signal more frequently than female drivers (6.8%). The presence of front seat passengers was also found to be a factor for declining RLR violations—around 94% of vehicles with a front seat passenger stopped at the red light, while the remaining 6% violated the rule. Among the vehicle types observed at the intersections, taxis were found to be the most frequent red light violators (14.5%) when compared with commercial or non-commercial vans, delivery vehicles, and trucks. In this particular study, the higher the number of travel lanes, the more recorded RLR violations. Finally, the majority of RLR violations were recorded on Sunday (11%), Monday (13%), and Wednesday (10%) with respect to total recorded violations.

"Characteristics of red light running crashes in Florida" by Elnashar (2008) studied 20,752 RLR crashes in Florida from 2002–2004.These types of crashes cause about $60 million in damage per year. Careless driving was found to be the highest contributing factor in influencing red light related crashes. The rate of RLR violation was recorded as 25 per 1000 licensed drivers, while the RLR violation crash rate was found to be 1 per 2000 licensed drivers. Younger drivers were more prone to RLR violations than other age groups. Most of the RLR violations were through traffic (90%), and the majority of RLR crashes were recorded as angle crashes (65%). Slightly higher rates of crashes were observed on Friday and Saturday as well as in the evening period. No significant impact of weather was observed, as most of the red light violation crashes occurred during clear weather conditions. Around 77% of the RLR crashes caused varying levels of injuries, which was about 9000 per year and 60 deaths per year.

Countermeasures and Their Effectiveness

Yang and Najm (2006) presented RLR violation analysis at 11 intersections in Sacramento, California, by using red light photo enforcement cameras. Their investigation revealed that the highest number of RLR violations occurred from 2:00–2:59 p.m., and the average speed of RLR violations was 31.6 mph. More than 94% of the violations occurred within 2 seconds of the red signal, and young drivers were more prone to RLR than any other age group. Logistic regression showed that young drivers tended to drive at higher speeds when crossing the intersection compared with older drivers. Moreover, the RLR violation rate of the 11 studied intersections ranged from 0.064–0.294 violations per 1000 entering vehicles.

Retting et al. (1995) obtained police-reported data on crashes from Akron, Ohio; New Orleans, Louisiana; Yonkers, New York; and Arlington County, Virginia. The results were weighted to give each area equal representation. In total, 4,526 crashes were examined. Five types of crashes accounted for 76% of all crash events in the urban area. These five types included running red lights, stop signs, or yield signs (22%); hitting a stopped or stopping vehicle from the rear (18%); running off the road and striking an object (14%); swerving into another occupied lane (13%); and turning left and colliding with an oncoming vehicle (9%). Of the incidents of cars running traffic controls, 41% occurred at intersections controlled by stop signs, while 31% occurred at intersections controlled by traffic signals. The researchers recommended increased signal and sign visibility, increased sight distances, reduced speeds, stronger enforcement, and/or red light enforcement cameras.

According to Boakye (2014), a blue confirmation light in RLR at signalized intersections in Kansas not only made the task of catching a red light offender easier for police, but also diminished RLR overall. RLR violation data before and after installation of the confirmation light at six left-turn approaches were collected from two treatment sites (site-contained confirmation light) and 11 non-treated intersections (six spillover sites where intersections are nearby the treatment sites and five control sites where intersections are far from the treated intersection). This study showed a 42.7% decrease in left-turn RLR violations at the 2 treatment sites and a 31.7% decrease in the spillover sites. No change was observed in the control sites in terms of red light violation.

Red light running treatment should focus on red light-related crashes, which automatically leads to a reduction in RLR violations at intersections, according to a report by the Texas Transportation Institute (Beeber and Safer, 2010). At the first approach, the author found numerical factors such as approach flow rate, cycle length, yellow interval duration, running speed, clearance path length, platoon ratio, use of signal head back plates, and use of advance detection significantly affect the red light violation rate. This detailed study revealed that a reduction of 1 second of yellow time increased violations about 110%. Overall, decrease in flow, increase in yellow duration, decrease in speed, increase in clearance path length, decrease in platoon density, and addition of signal head back plates were found effective in reducing RLR violations. However, at the countermeasure implementation section, a contradiction was observed between implementation of photo enforcement and extending the yellow light duration when comparing the associated cost of the two. Finally, camera enforcement was found to be an effective solution after considering all other viable solutions regarding RLR violation. Figure A1 gives a detailed flow chart of reaching this conclusion for red light violation countermeasures.

The effectiveness of RLR cameras at two intersections—Mission Street and 25th Street—in Oregon were mentioned in a report published by the Oregon Department of Transportation (Ross and Sperley, 2011). A before-and-after study regarding camera installation showed that crashes decreased about 77.4% after 21 months of camera installation, whereas 50 months after installation an even lower rate of crashes was recorded at the studied intersections. While RLR cameras significantly reduced angle crashes and increased less severe crashes, the cost of crashes increased from $16,296 to $27,738. Finally, violations were decreased by 43% in the westbound direction and 23% in the northbound direction. It was determined that the majority of violations were due to left turning vehicles.

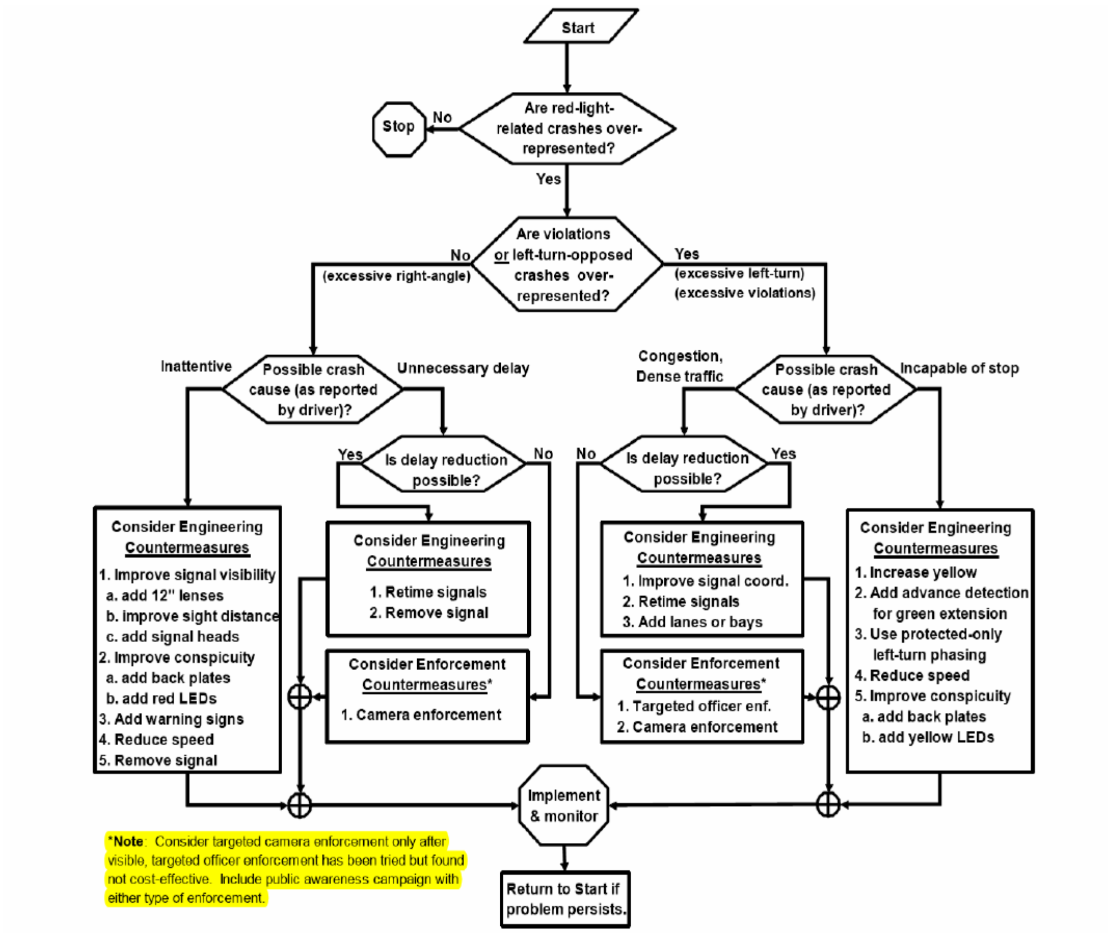

Figure A1: Flow chart of red light running countermeasures.

Lum and Halim (2006) described a before-and-after study that evaluated the difference in driver response along an approach of a signalized intersection equipped with a green signal countdown device (GSCD). The main purpose of a GSCD is to provide drivers with a countdown timer that assists them in making informed stopping/crossing decisions during the yellow interval change. This study took place in Singapore, Thailand, at the intersection of two one-way arterials in an urban setting. Data collection using a data logger took place for four continuous days before the GSCD was installed and a series of four various days after the GSCD was installed. The findings indicated that RLR violations were reduced by about 65% within 1.5 months following installation of the GSCD. The effectiveness dissipated over time, and violation numbers rose to almost the pre-GSCD level. The diminishing effect of the GSCD in reducing RLR violations during the longer term generally occurred under high traffic flows. Vehicles choosing to stop during the onset of yellow were increased significantly, by about 6.2 times within 1.5 months after GSCD installation. The impact of the GSCD installation appeared to dissipate over time, as the RLR numbers returned almost to the non-GSCD level after roughly 8 months. More research should be done before considering this alternative. Though the extension of green time is an effective way to reduce RLR violations, extending yellow time phasing proved to reduce RLR significantly.

Bonneson, et al (2002) published a report titled Engineering Countermeasures to Reduce RLR. This report discusses countermeasures other than enforcement cameras used to reduce frequency and crashes caused by RLR. Table A2 shows the different countermeasures addressed in this report.

Table A2: Countermeasures used to reduce frequency and crashes caused by RLR.

Countermeasure Category	Specific Countermeasure	Reported RLR Effectiveness[1]	
		Frequency	**Related Crashes**
Signal Operation (modify signal phasing, cycle length, or change interval)	Increase the yellow interval duration	-50 to -70%	--
	Provide green-extension (advance detection)	-45 to -65%	--
	Improve signal coordination	Varies[2]	--
	Improve signal operation (increase cycle length 20 s)	-15 to -25%[3]	--
Motorist Information (provide advance information or improved notification)	Improve sight distance	--	--
	Improve visibility of signal (12" lens, add heads)	--	-33 to -47%
	Improve visibility of signal with yellow LEDs	-13%	--
	Increase conspicuity of signal with back plates	-25%	-32%
	Add advance warning signs without flashers	--	-44%
	Add advance warning signs with active flashers	-29 to -67%	--
Physical Improvement (implement safety or operational improvements)	Remove unneeded signals	--	-24%
	Add capacity with additional traffic lanes	--	--
	Flatten sharp curves	--	--

Note:
1 Negative values indicate a reduction. "--" indicates data not available.
2 Red light running frequency is likely to increase with improved coordination; however, this increase may be offset by the larger cycle length typically required for good progression.
3 Reductions associated with an increase in cycle length may not be realized if motorist delay increases significantly.

Bonneson et al (2004) reported a before-and-after study of the effect of increasing the yellow interval duration of a light cycle in relation to the frequency of RLR violations. The study took place at 10 intersections in 5 cities in Texas. Data used in the yellow interval study included 3,370 signal cycles at 8 of the intersection approaches. Data analysis indicated a 50% reduction in RLR violations (see Figure A2). Although red light violations were reduced, the effects on red light-related crashes were more modest, as drivers adapted to the increase in the yellow phase duration.

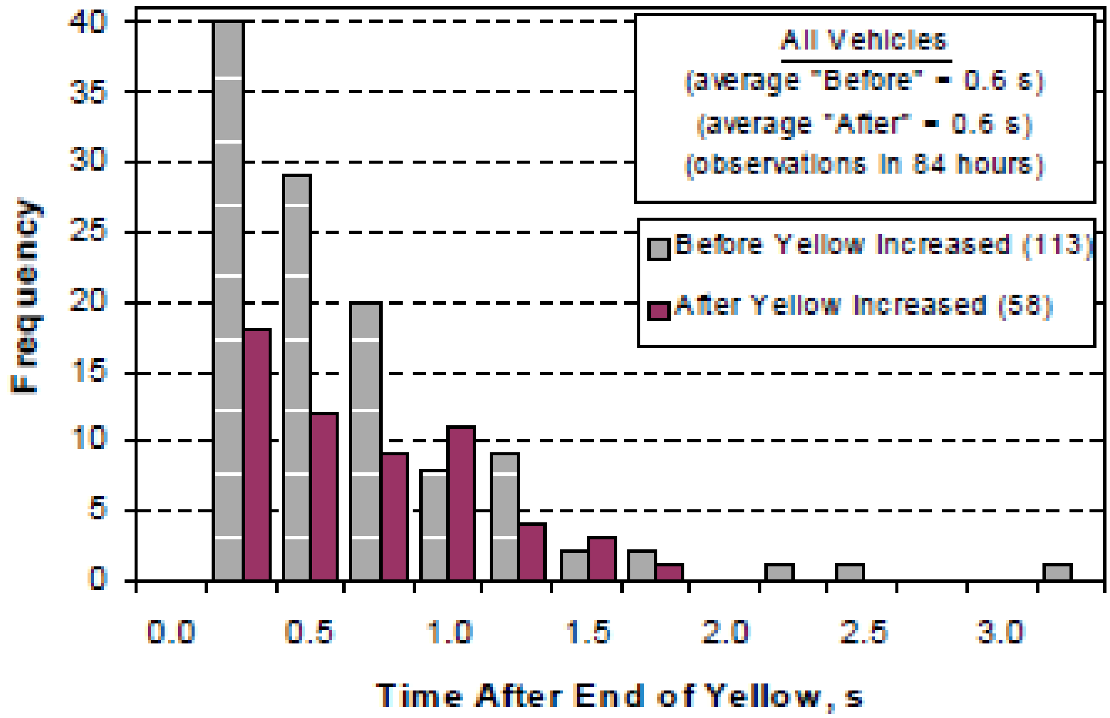

Figure A2: Effect of an increase in yellow interval duration on the frequency of RLR.

According to Walden (2008), photographic traffic signal enforcement systems were a productive countermeasure for reducing crash frequency at 56 intersections in Texas. The study showed an overall annual crash decrease of 30%, with a 42% decline in annual right-angle crashes at studied intersections after installation of cameras. On the other hand, a 5% increase in rear-end collisions was observed after a one-year period of observation, where these particular crashes were unchanged or decreased afterwards at more than half of the intersections taken into account.

According to the Federal Highway Administration (2009), an average of 916 annual fatalities was recorded due to RLR violation during 2000–2007. However, in 2008, 883 fatalities were recorded, lower than the previous average. Despite the decrease, fatalities were still significantly high, thus the need for countermeasures regarding RLR violations was proposed. Countermeasures were divided into four categories: improved signal visibility, increasing the likelihood of stopping, removing reasons for intentional violations, and eliminating the need to stop. The framework is provided in Table A3.

The Illinois Department of Transportation (Schattler et al., 2016) implemented the flashing yellow arrow (FYA) at more than 100 intersections for protected/permissive left turning vehicles. The effectiveness of this particular implementation was determined by the study of before-and-after crash analysis for 3 years. Three years of before-and-after crash data of 86 intersections with 164 approaches were compared using the Empirical Bayes Method. Crash modification factors for statistically significant crash reductions at the FYA approaches based on the Empirical Bayes Method are provided. The findings of this research, conducted on 164 FYA approaches in the Peoria area of Illinois, indicated that FYAs for

Protected/Permissive Left-Turn (PPLT) control improved safety for left turning vehicles. The results of the economic effectiveness of the FYAs yielded a beneficial cost ratio of 19.8 to 1.0. The results of this research may be used to make informed decisions on future installations of the FYA countermeasure to improve safety at signalized intersections.

Table A3: Summary of engineering countermeasures for red light violation.

Category	Improve signal visibility/ Conspicuity	Increase the likelihood of stopping	Remove reasons for intentional violations	Eliminate the need to stop
Countermeasure	Signal for each approach through lane	Install signal ahead signs	Adjust yellow change interval	Coordinate signal operation
	Install back plates	Install transverse rumble strips	Provide or adjust all red clearance intervals	Remove unwarranted signals
	Modify the placement of signal heads	Install activated advance warning flashers	Adjust signal cycle length	Construct a roundabout
	Increase size of signal displays	Improve pavement surface conditions	Provide dilemma zone protection	---
	Install programmable signals/ visors or louvers	---	---	---
	Install LED signal lenses	---	---	---

According to the Indiana 2010 Strategic Highway Safety Plan (Brehmer et al., 2003), "Crashes at the intersection of two or more roadways in Indiana produce one in four of all severe outcome crashes and about one in five fatal crashes." Implementation of the flashing yellow arrow in Indiana represented an opportunity to reduce such crashes and save lives. It also improved operational flexibility by permitting lagging left turns. Such lagging left turns would otherwise create a yellow trap, and thus opened up many additional opportunities to improve mobility through intersection coordination along corridors. Implementation of the flashing yellow arrow may be done as a part of signal visibility improvement projects.

In experimenting with installation of flashing yellow in Marana, Arizona, the FHWA (2009) found that crashes and RLR decreased. Traffic conflict studies (Klugman et al., 1992) of active advance warning signs conducted in Minnesota found the lowest rates of RLR violations at locations with active advance warning signs. Similarly, an Ohio study (Pant and Xie, 1995) found fewer RLR conflicts on high-speed approaches to signalized intersections with active advance warning signs. These studies also revealed that drivers accelerated at the onset of yellow, but drivers decelerated at the beginning of the dilemma zone when the beacons were flashing and the signal indication was green.

Green Flashing and Green Countdown in Phasing

Jia-jun et al. (2015) examined the effects of flashing green on drivers' stop/go decisions at a signalized intersection in China. The study aimed at drivers' reaction to flashing green at signalized intersections. After processing data by means of photogrammetry, the paired-samples *t*-test was used to compare operating speeds of vehicles before and after the starting of flashing green in the intersections. Amber-running violation was analyzed, and a logistic model was developed for stop-and-go decisions. The developed decision models showed that the probability of a go decision is higher when the distance from the stop line is shorter or operating speed is higher, which indicates flashing green is an effective way to enhance intersection safety. The traffic signs near critical distance and reasonable speed limitation were found to be beneficial to the safety of intersections in this research.

The safety impact of common signal device (CSD), green signal countdown device (GSCD), and green signal flashing device (GSFD) was evaluated at six signalized intersections in Changsha, China (Huang et al., 2014). The study compared drivers' decision-making process under these three different signal strategies during the period of ending green phase to starting of red phase in the respective intersections. The empirical analysis revealed that decision making (to stop or go) before amber commencement was earlier with a GSCD than with other signal devices. In addition, decision making was quite swift under GSFD than under CSD, indicating improved safety of the intersection under modified signal phasing than under conventional ones. Moreover, the logistic regression results highlighted that drivers were less likely to be trapped in the dilemma zone under GSFD than with other signal devices. Though both GSCD and GSFD recorded lower rates of RLR violations than CSD, GSCD was found to be the best strategy for improving safety as well as reducing RLR violations at signalized intersections in Changsha.

The impact of a GSCD was also assessed in the signalized intersections of India, and vehicular approach speed was taken into consideration while crossing intersections (Devalla et al., 2015). Two approaches, one having a GSCD and other having a conventional green signal, at several intersections were taken into account to assess the safety and efficiency of the GSCD. The presence of a GSCD marked with reducing RLR violations; in fact, it decreased the mean RLR violations through intersections, but increased the speeding of cars especially during the amber phase. Though a reduction of RLR may increase the safety aspect of intersections, the inclination to speed through intersections during the amber period may contribute to crashes as well.

Awad (2014) carried out research on drivers' behavior at signalized intersections operating with flashing green signal in Jordan. The impact of a flashing green signal on driving behavior was assessed using signalized intersections operated with flashing green and without flashing green. Average approach speed and the proportion of vehicles were found to be higher, though the proportion of vehicle jumps before green were found to be lower at the intersections with flashing green than at the intersections without flashing green. Shen et al (2015) indicated that flashing green is an effective way to enhance intersection safety, but it should work together with a strict enforcement. In addition, traffic signs near critical distance and reasonable speed limitation are also beneficial to the safety of intersections.

An investigation involving the response of three drivers to a green signal and a red signal countdown device was conducted at Taiwan (Chiou and Chang, 2010). The driver's response towards the GSCD was assessed in terms of late-stopping ratio, dilemma zone, and decision to cross the intersection, while the performance of the red signal countdown device (RSCD) was measured on the basis of early start ratio, start-up delay, and discharge headway. Although the GSCD was effective at reducing the late stopping ratio, the dilemma zone was increased by about 28 m and the decision to cross the intersection was found more inconsistent, which may increase rear-end collisions. On the other hand, the RSCD was found efficient at reducing start-up delay and saturated headway, but start-up delay returned to its original position as the months progressed following installation. Based on the analysis, RSCD was recommended over GSCD due to its efficiency and effectivity in increasing traffic safety at intersections.

Pedestrian Countdown

A study was carried out on the effects of pedestrian countdown timers (PCT) on the safety and efficiency of operations at signalized intersections in Lincoln, Nebraska (Sharma and Schmitz, 2011). A before-and-after study was performed to analyze the effects on both pedestrian and driver, which included the performance measure of pedestrian compliance, average pedestrian walking speed, probability of stopping, and speed gain of vehicles at the stop bar during the yellow phase. Various detectors were used to collect data, and data were analyzed using statistical models. It was observed from the study that the pedestrian walking speed was increased, thus pedestrian violations decreased. It was also observed that the RLR and dilemma zone boundaries were reduced due to the presence of PCT.

Schattler et al. (2007) performed research on the effect of pedestrian countdown timers on pedestrian compliance, yellow light runners (YLR), and RLR using 13 intersections in Peoria, Illinois. A comparative analysis method was carried out for 10 of the intersections, and a before-and-after study was carried out for three of the intersections. The research outcome showed that pedestrian countdown timers do not significantly increase or reduce the number of RLR and YLR.

Chen et al. (2015) conducted a study on red light violations of motorcycles in response to a pedestrian green signal countdown device (PGSCD) in Taiwan. Motorcyclists' red light violation behaviors were investigated in this research using video/speed cameras. Though no negative effects of PGSCD on motorists in terms of speed and RLR had been found from earlier studies, the study found that the percentage of red light violations by motorcyclists increased at the intersection with a PGSCD, and the travelling speed of motorcycles was higher. Male/young riders, moped/large motorcycle users, higher approaching speeds of motorcycles, riders with tropical helmets, and lower traffic volume were identified as crucial factors associated with RLR violations of motorcycle users in Taiwan.

According to Alaska RLR surveys in 2011, pedestrian countdown timers are specifically designed as an aid to pedestrians crossing the intersections. In case of some intersections, the timers coincide with the end of the green light cycle and drivers approaching those intersections can see how long before the light will change to yellow, which affects the rate of RLR, though many of the intersections showed no such correlation.

Bundy, B. (2008) studied the driver behavior modification based on information from pedestrian countdown timers in Kansas. Speed data of four intersections of two with countdown timers and two without were collected, and drivers' decisions were recorded in response to pedestrian countdown timers. The analysis revealed that the speed of the driver was reduced to reach the intersection before the beginning of the red phase in the presence of a pedestrian countdown timer, and some drivers stopped before the starting of the yellow phase, which indicated improved driver behavior.

Kitali and Sando (2017) focused on the safety effects in Florida of pedestrian countdown signals (PCS) in response to drivers' behavior using crash modification factors and crash modification functions. The safety impacts of PCS on drivers were quantified by means of full Bayes before-and-after with a comparison group method. The study suggested that drivers' safety improved significantly for total, PDO, and rear-end collisions, and that treatment effectiveness varied considerably with post-treatment time and traffic volume.

Advance Warning Signs and Signals

Several systems are in use utilizing signs/signals as an advance warning for drivers to address the dilemma zone and RLR. Chang, G., et al, 2014, published a report titled "Design and Implementation of a Detection, Control, and Warning System (DCWS) for Dilemma Zone Applications.". The results indicate that the proposed system offers the best protection on safety measures. Sensitivity analyses have also been conducted to assess the impact on the number of red-light running vehicles if different locations are selected for the advanced warning sign and under the different traffic volumes. Sunkari, S., addressed the "Performance of advance warning for end of green system (AWEGS) for high-speed signalized intersections". Results of AWEGS implementation illustrated an improvement in traffic operations. AWEGS consistently enhanced the dilemma zone protection at intersections and reduced red light running by about 40%.

Hallmark, S., et al (2012) published a report "Toolbox of countermeasures to reduce red light running" addressing the results of the advance warning signs. Agent and Pigman (1994) as cited by Bonneson et al. (2002), conducted a study comparing the frequency of red light running at 16 intersections without advance warning signs with two intersections with signs and active beacons. The researchers observed 100 signal cycles and found 67 percent fewer red light runners at signals without advance warning than those without active beacons. Farraher et al. (1999) studied the effect of advance warning beacons at one intersection by using a motion-imaging-recording-system technology in Minnesota. The study found the warning sign with active beacons reduced the RLR frequency by 29 percent. Agent et al. (1996) suggested a 25 percent CRF when using intersection advance warning beacons based on surveys of states and literature. Messer et al. (2004) found that the reduction in RLR within the first 5 seconds of red to be about 40 to 45 percent when using a system that provided advance warning at the end of the green phase based on a study of two sites in Texas.

Drivers Training Manual (DTM)

Mohammed H. (ITE, 2018) addressed the "Variable Driver Responses to Yellow Indications". Based on the consideration of yellow light laws and the driver training manual guidance from across the country, the author concluded that many driver training manuals provide yellow light guidance that may be confusing to drivers when considered in conjunction with the associated state law. A large percentage of states follow Class 3 guidance (vehicles should stop during the yellow indication, but they may proceed with caution through the intersection if it is not possible to do safely (restrictive type)) in DTMs while the vast majority of states laws (74 percent) were categorized as Class 1 (permissive) in NCHRP Report 731. In addition, he stated that the inconsistency between state yellow laws and DTM guidance is another example of inconsistencies that may contribute to variability of driver comprehension and decision making in response to circular yellow indications.

APPENDIX B – DATA ANALYSIS AND RESULTS

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Appendix B – Data Analysis and Results

Introduction

To understand and address red light running (RLR) within the Anchorage urban area, we observed six intersections and recorded red light violations. We have highlighted the general characteristics of the six intersections studied and the characteristics associated with RLR violations. Due to Alaska's greatly varying weather, it is pertinent to examine different weather conditions to understand and predict RLR year-round. We analyzed four pavement conditions: wet, dry, snowy, and icy. The four pavement conditions were taken into account to highlight the differences in rates of total violations, violations per movement type, severity of violations, types of violating vehicle, and number of violations per phasing time across various periods and green time intervals.

The rate of RLR violations with respect to 1000 and million entering vehicles for each pavement condition at each intersection studied was based on video data collection. We depicted the rate of violations based on movement type of vehicle in each of intersection with respect to each pavement condition. In the analysis, we present the severity of RLR violations on a typical weekday at each intersection for different pavement conditions, and highlight graphically the composition of vehicle types over a one-day period for each of the selected pavement condition types.

Phasing is an important characteristic used in addressing RLR violations with respect to change of green, yellow, or red signal timing. The only variable that could be considered in the phasing data at the intersections was the green time interval, as red and yellow timing intervals are fixed throughout the day. Fifteen-minute intervals were considered in the analysis. The research team tried to capture as much data as possible for each pavement condition.

Intersections Studied

Geometric design, especially sight distance, is an essential characteristic of intersections when studying and analyzing driver behavior during RLR violations. The general geometric characteristics of each intersection studied are presented in Table B1.

Most of the intersections studied are four leg, except for at Northern Lights Boulevard and UAA Drive, a three-legged T intersection. Spenard Street and Benson Boulevard is a tilted four-leg intersection. Excluding Northern Lights Boulevard and UAA Drive, and Boniface and Mountain View Drive, all intersections are one-way at the approach taken into account. Three or more lanes were observed for each intersection, with at least one lane provided for necessary right or left turning. The intersections were chosen by DOT&PF because of the various geometric features and special consideration relevant to RLR violations. At C Street and 6th Avenue, sight distance is limited at the northeast corner of the intersection due to a building with limited easement. Besides this intersection, all had satisfactory sight distance. In some cases, sight distance was obstructed by buildings, structure, or trees while approaching towards the intersection, but satisfactory sight distance was achieved when in proximity of the intersection.

Table B1: Overview of the general geometrical characteristics the studied intersections

Intersection	Type	Approach	Number of Way (on approach being examined)	Number of Lanes in Studied Direction	Movement Type			Sight Distance
					Through	Right	Left	
C Street & 6th Avenue	Four leg	EB*	One way	3	X	X		Obstructed by building
Northern Light Blvd. & UAA Dr.	Three leg (T)	NB**	Two way	3 (2 normal 1 RT lane)	X	X		Satisfactory
15th Ave. & Ingra Street	Four leg	NB**	One way	5 (4 normal 1 RT)	X	X	X	Satisfactory while pretty close
Spenard Rd. & Benson Blvd.	Four leg with 80° tilted	EB*	One way	4	X	X	X	Satisfactory while pretty close
C Street & Benson Blvd.	Four leg	EB*	One way	4	X	X		Buildings blocking while approaching
Boniface Parkway & Mountain View Drive	Four leg	NB**	Two way	3 (2 normal 1 LT)	X		X	Satisfactory

*EB= East Bound, **NB= North Bound

C Street and 6th Avenue

The intersection of C Street and 6th Avenue is located in downtown Anchorage. This multilane two-way signalized intersection experiences high traffic volumes. An image of this intersection is provided in Figure B1. Sight distance of the approach, especially for southbound traffic, is obstructed by a building on the corner. Because the intersection is located in a densely populated area of the city, sight distance is hard to achieve. As a result, limited sight distance contributes to RLR crashes at the intersection.

Figure B2 shows that the highest rate of RLR violations occurs during wet pavement surface conditions. This higher rate of RLR may be due to Alaskan drivers not perceiving wet pavement as a driving hazard. Drivers do not adjust their speed or braking distance to slow down and stop effectively, and find themselves in a situation of running the red light. Drivers perceive snowy and icy conditions as hazardous and adjust their driving behavior, generally slowing down and allowing themselves longer braking distance so that they can stop before the intersection and maintain a lower violation rate.

Figure B1: C Street and 6th Avenue intersection (Source: Google Earth).

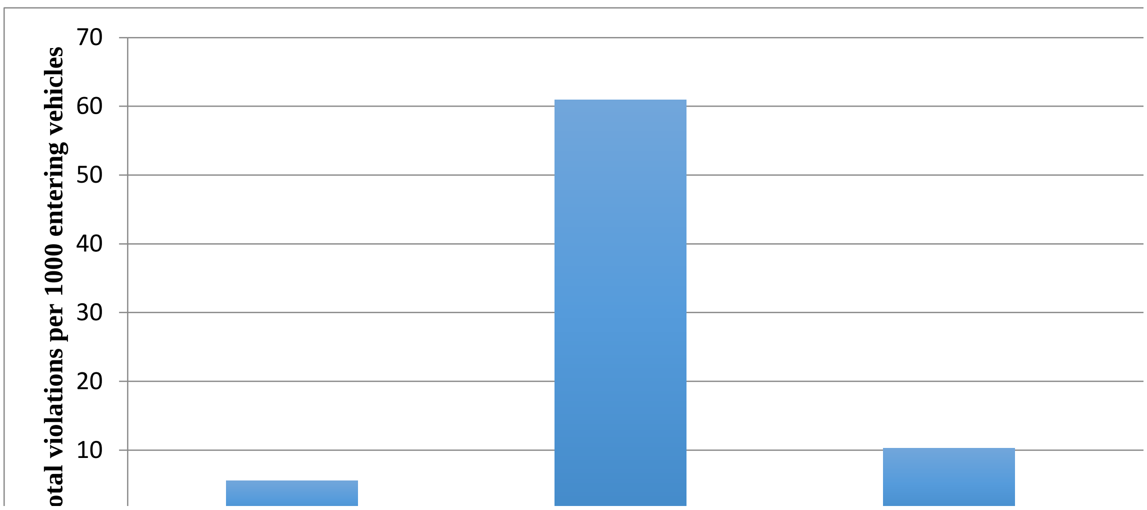

Figure B2: Frequency of red light violations per 1000 entering vehicles at C and 6th Avenue intersection.

There are two forms of movement associated with RLR at the intersection of C Street and 6th Avenue: vehicles that move straight through the intersection (through movement) and vehicles that turn right. For closer examination of RLR violations, see Figure B3, which is a comparison of RLR violation frequency per 1000 entering vehicles for all four pavement surface conditions. Through-movement RLR violation was higher than right turning violation for each of the pavement conditions. As expected, wet conditions had a higher rate of violations than any other type of pavement condition. The lowest rate of through-movement RLR violation was observed for dry pavement conditions; for snowy and icy conditions, 10 and 15 RLR violations, respectively, were recorded. About the same rate of RLR violations were observed for right turn movements in dry, snowy, and icy pavement conditions.

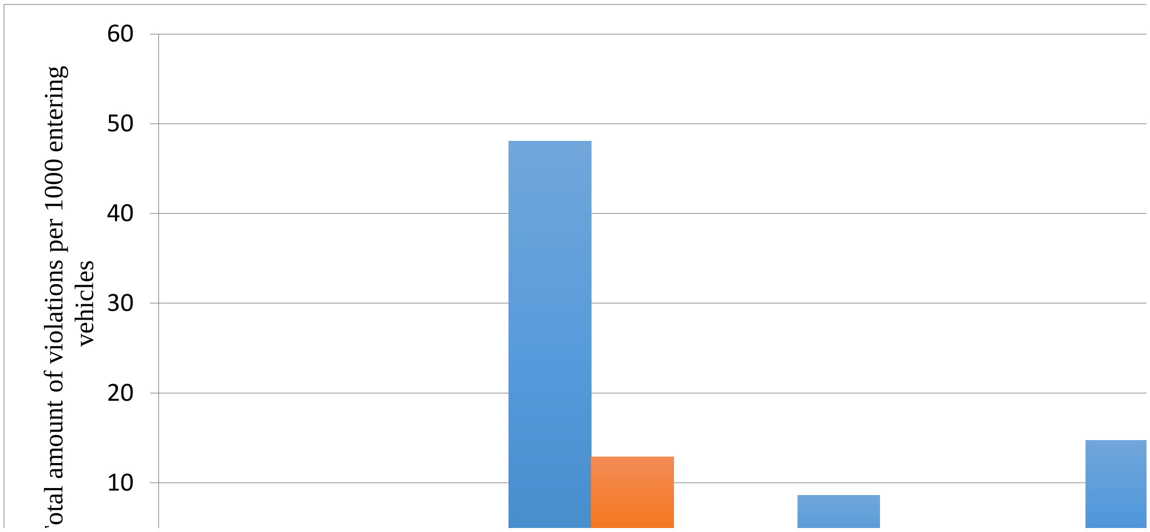

Figure B3: Frequency of red light running violations based on movement type for each pavement condition at C and 6th Avenue intersection.

Figure B4 shows that the lower level of severity, less than 1 second, was significantly higher for all pavement conditions. Among the four pavement conditions, a higher rate of violations for a severity level of less than 1 second occurred on snowy pavement. A severity level of 1 to 2 seconds was observed (around 65%) under icy conditions, while about 12% of RLR violations were recorded during the other pavement conditions. A severity level of 2 to 3 seconds was observed at higher rates in wet and icy conditions. The highest level of severity (greater than 3 seconds) was observed in limited rates for each pavement condition type. Icy conditions had a notably higher percentage of under 1–2 second severity level violations compared with the other pavement conditions, possibly because drivers were aware of the adverse pavement conditions. Rather than applying the brakes in those forced conditions, the drivers felt they would have a better chance of avoiding skidding by running the red light.

Passenger cars were the most frequent red light runners at the C Street and 6th Avenue intersection, as shown in Figure B5. A small number of buses and semitrailers were found violating the red light signal. This situation is a concern, considering the consequences of a large vehicle crash.

<u>Phasing</u>

Comparatively, morning rush hours (6:45 a.m. to 9:00 a.m.) had fewer RLR violations than evening peak hours (5:00 p.m. to 7:30 p.m.), as shown in Figure B6 through B9. To represent RLR violations of a typical day of the week, video footage of 6 to 17 hours for dry, wet, and icy conditions was collected and analyzed. Figures B6 through B9 reflect the analysis of RLR violations with respect to ADT, green time, and the four pavement surface conditions. Red light running violations fluctuated throughout the day, with evening peak period having the highest rate corresponding to higher ADT and green time interval. For dry conditions after 8:30 a.m., when green time is reduced to 25 seconds, RLR violations were observed even though ADT was declining.

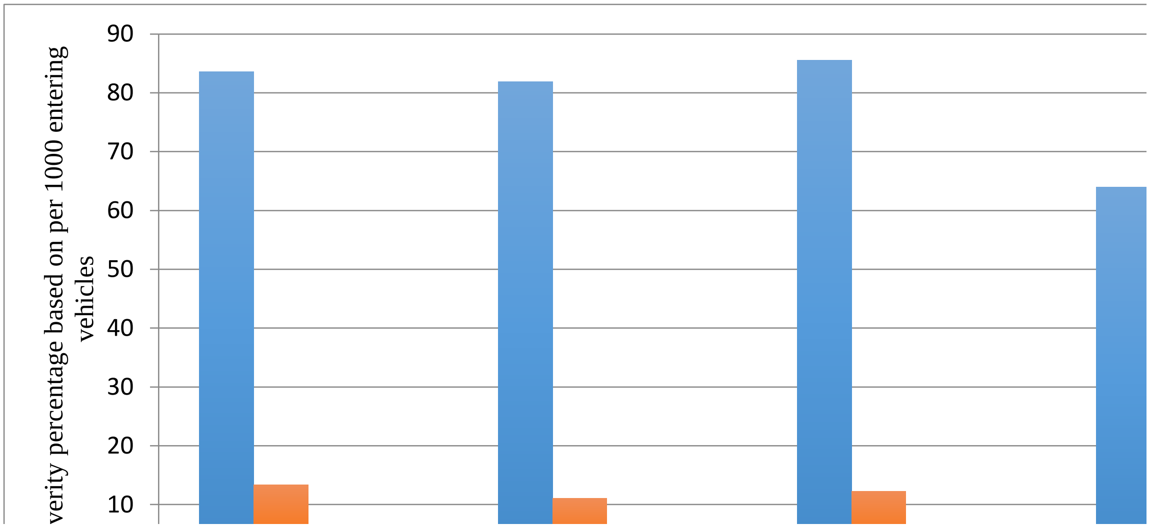

Figure B4: Severity percentage of red light running violation based on four pavement conditions at C and 6th Avenue intersection.

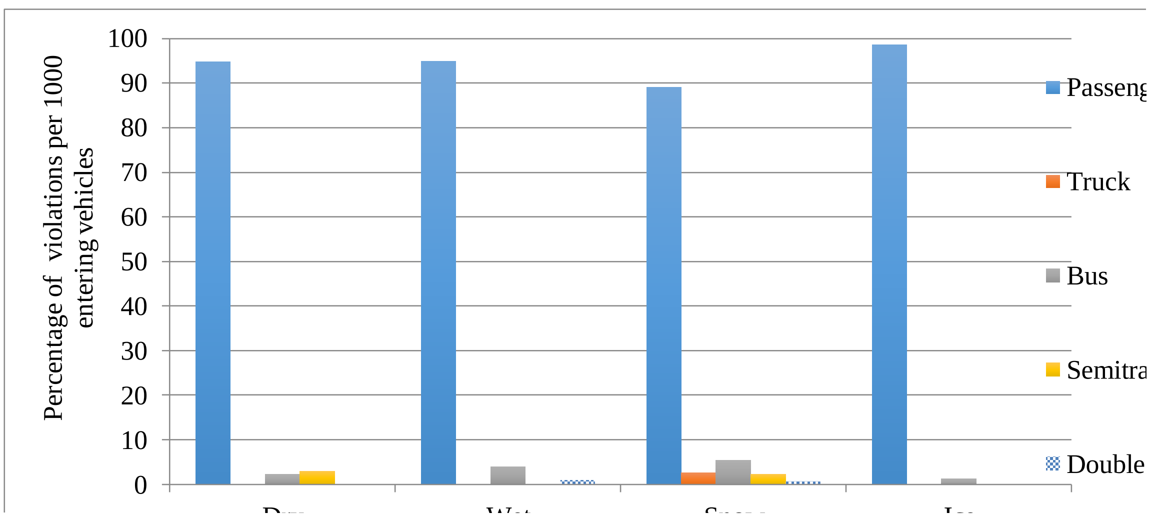

Figure B5: Percentage of red light running violations based on vehicle composition for each of the pavement conditions at C and 6th Avenue intersection.

Afterwards, a steady increase of traffic was recorded, with fluctuations in the rate of RLR violations even with an increase in the green time interval (29 seconds). A further increase of green time interval (33 seconds) during the evening peak period reflects the same phenomenon of increase in RLR violations for all pavement surface conditions. In the late afternoon period (after 7:45 p.m.), a significant rate of violations for dry, snowy, and icy pavement conditions was recorded, even with a significant decrease in ADT. Six hours of wet-conditions data showed significantly higher rates of violations even with the extension of the green light interval. After 10:30 a.m. in snowy conditions, higher rates of RLR violations were observed and continued throughout the day. In addition, under snowy conditions, significant rates of RLR violations were observed after ADT reached its peak in the afternoon period. Small rates of early morning RLR violations were observed for icy conditions in comparison with the evening peak period. As stated before, significantly higher rates of RLR were recorded during nighttime under icy conditions, even after 10:30 p.m. when traffic movements were low, an indication that RLR is more associated with pavement condition than just with traffic conditions.

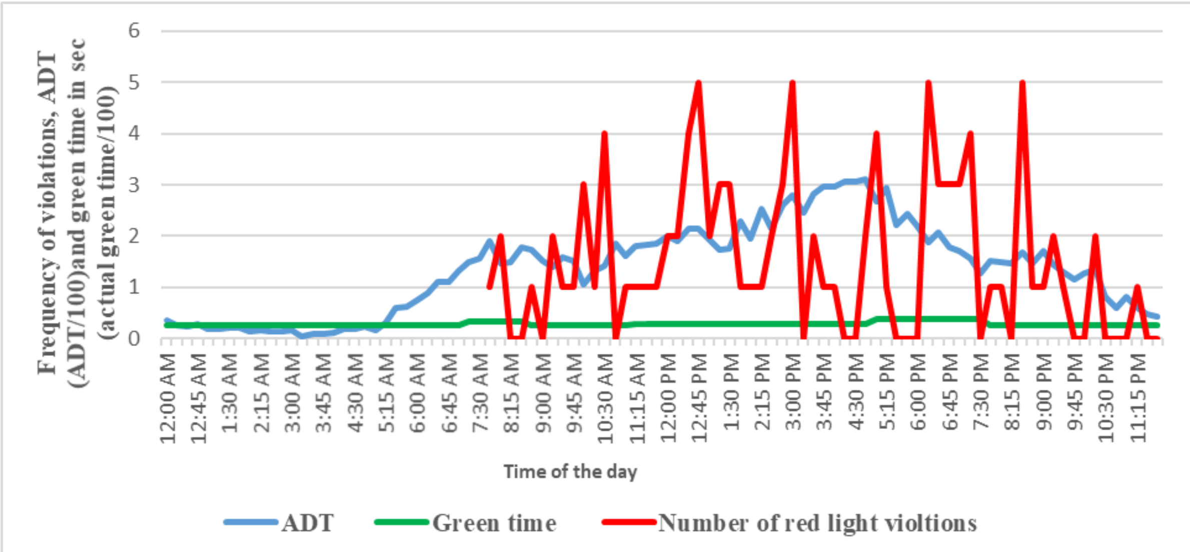

Figure B6: Frequency of red light violations, ADT, and green time sequence throughout a day for dry pavement conditions at C and 6th Avenue intersection.

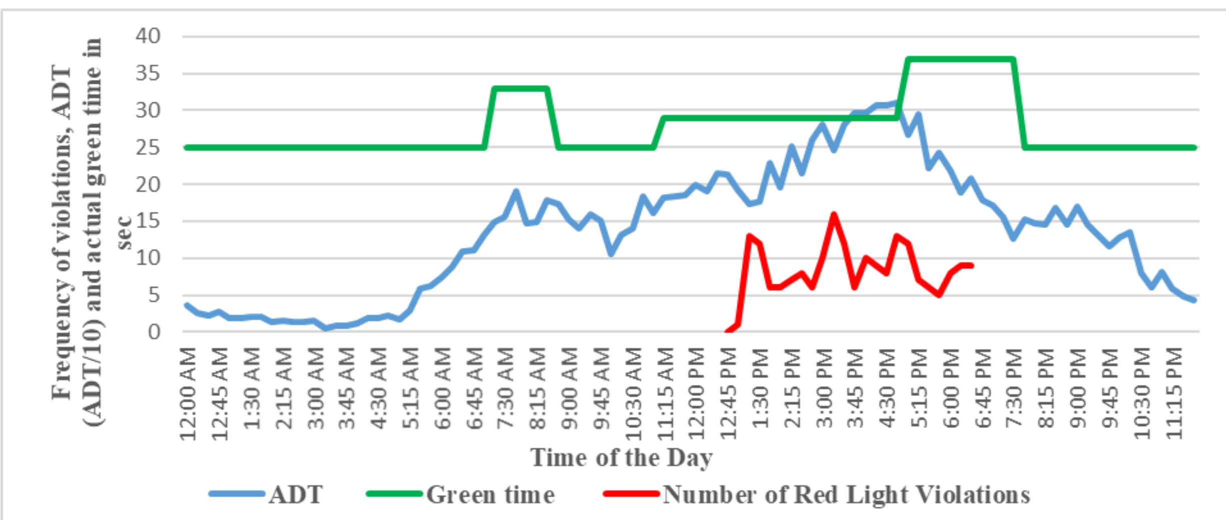

Figure B7: Frequency of red light violations, ADT, and green time sequence throughout a day for wet pavement conditions at C and 6th Avenue intersection.

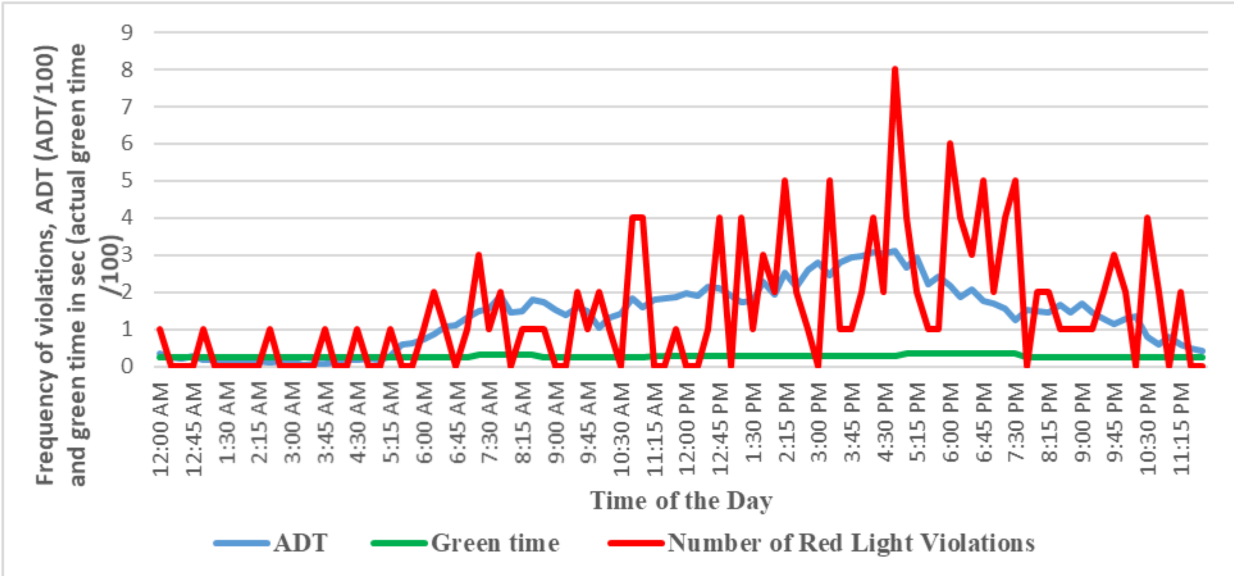

Figure B8: Frequency of red light violations, ADT, and green time sequence throughout a day for snowy pavement conditions at C and 6th Avenue intersection.

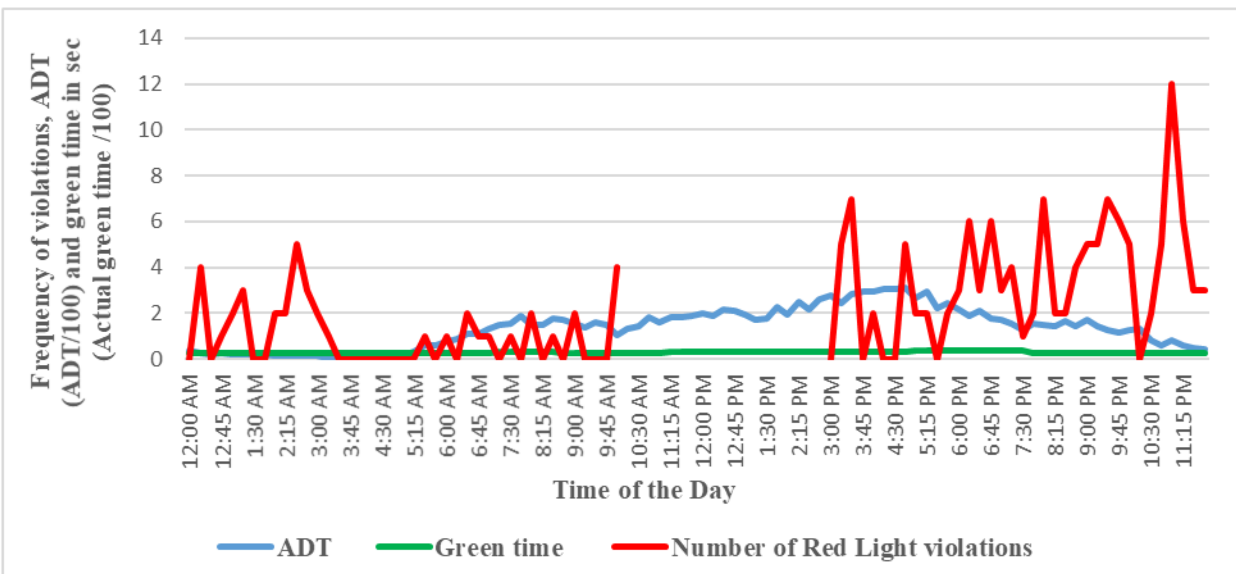

Figure B9: Frequency of red light violations, ADT, and green time sequence throughout a day for icy pavement conditions at C and 6th Avenue intersection.

Northern Lights Boulevard and UAA Drive

Northern Lights Boulevard and UAA Drive is a three-legged signalized multilane intersection with sufficient sight distance on all approaches, as shown in the aerial view in Figure B10.

Figure B11 shows the rate of RLR for different pavement conditions. The highest rate of violations at this intersection were recorded when pavement conditions were snowy. Around 1.5 violations per 1000 entering vehicles in the approach were recorded when conditions were icy. During both dry and wet pavement conditions, fewer than 1 RLR violation per 1000 entering vehicles was recorded in the approach.

Figure B10: View of Northern Lights Blvd. and UAA (Source: Goggle Earth).

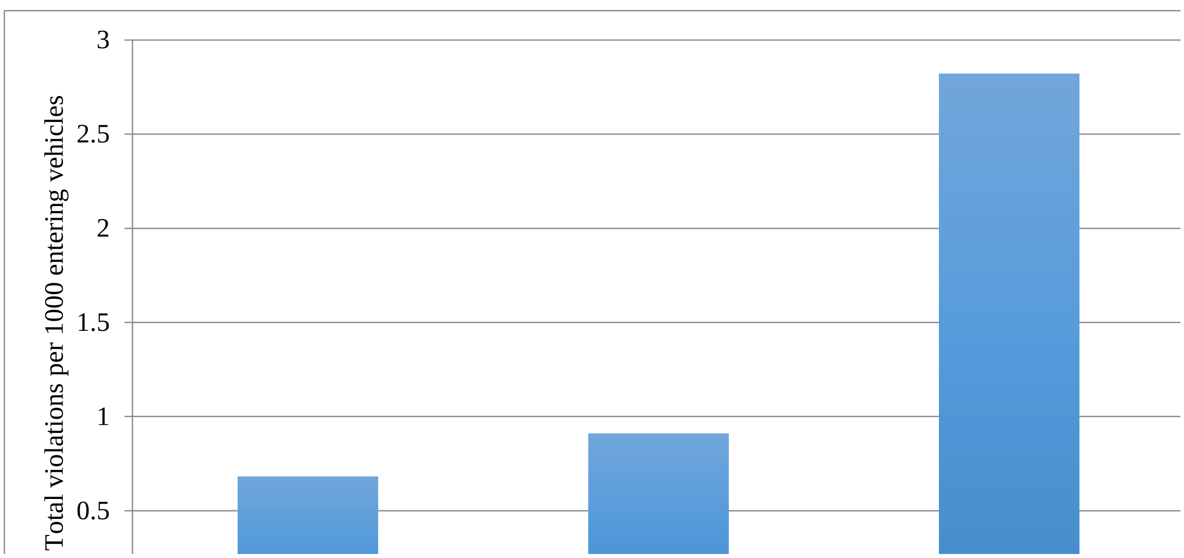

Figure B11: Frequency of red light violations per 1000 entering vehicles for different pavement conditions at Northern Lights Boulevard and UAA Drive

The violations at the intersection of Northern Lights Boulevard and UAA Drive were predominantly in the through movement, as shown in Figure B12. All the conditions showed higher rates of through RLR violations as compared with right turning movement. In icy conditions, right turn violations made up around 20% of overall RLR, whereas fewer (around 10%) of violations were recorded for wet and snowy conditions.

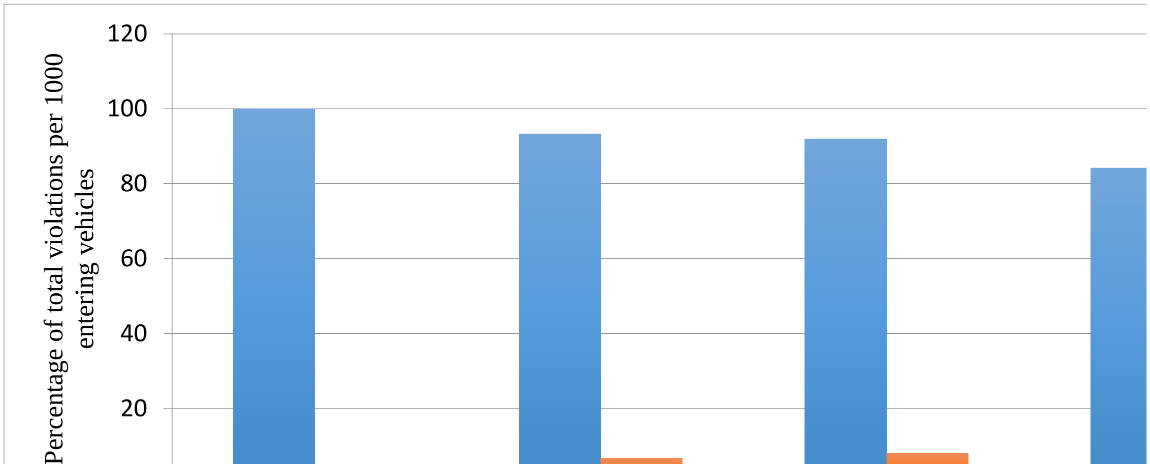

Figure B12: Frequency of red light running violations based on particular movement type for each pavement condition at Northern Lights Boulevard and UAA Drive.

One of the most important attributes of RLR violations is the severity of the event. Figure B13 shows violation severity at Northern Lights Boulevard and UAA Drive for all pavement conditions. Violations less than 1 second after the signal changed to red were predominant for all pavement conditions. A considerable number of RLR violations (around 20%) at the severity level of 1–2 seconds occurred in wet, snowy, and icy conditions. Around 10% of 2–3 second RLR violations were reported for icy conditions, suggesting drivers' intention of not stopping at the intersections because of slippage and lower skid resistance. A 1-second severity level is slightly higher in dry and snowy conditions than in wet and icy conditions; greater than 3-second violations were observed at higher rates in wet pavement conditions than in others.

Almost all the violations at the intersection of Northern Lights Boulevard and UAA Drive were associated with passenger cars rather than other vehicle types.

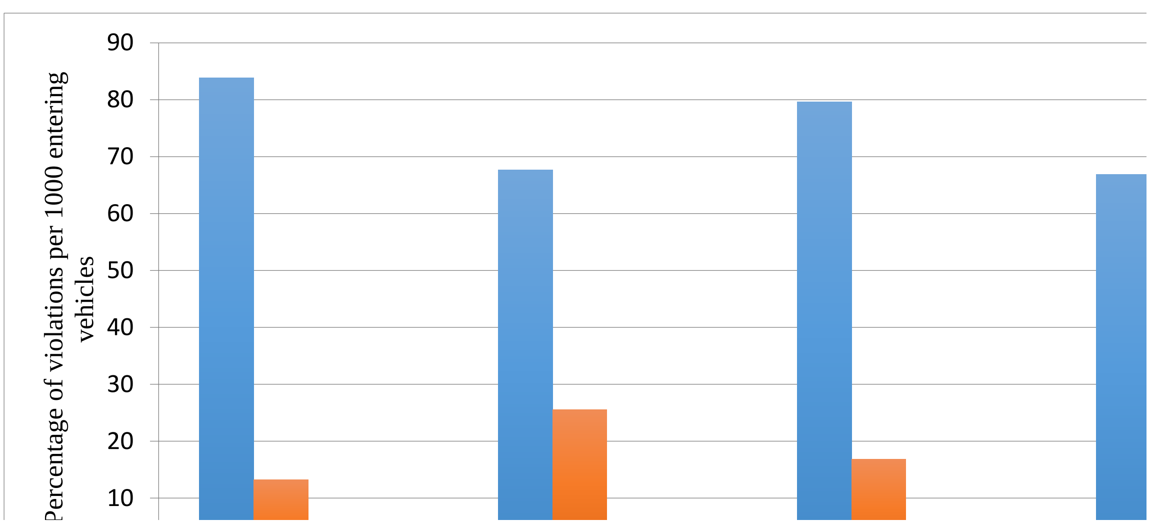

Figure B13: Frequency of red light running violations based on severity for each pavement condition at Northern Lights Boulevard and UAA Drive.

Phasing

At the intersection of Northern Lights Boulevard and UAA Drive, significantly higher rates of violation were recorded in the evening hours than in the morning hours, as shown in Figures B14 through B17. The largest peak of RLR violations was observed from 9:00 p.m. to 6:00 a.m., with a relatively shorter green interval for snowy pavement surface conditions. A low rate of RLR violations was found for dry and snowy conditions during the morning peak hours (6:00 a.m. to 8:30 a.m.) with considerable increase in traffic volume, starting at 6:00 a.m. Wet and icy conditions showed higher rates of RLR for the respective period. Green time was reduced to 29.5 seconds with considerable increase in traffic volume from 11:00 a.m. to 2:00 p.m. Most of the evening RLR violations recorded at this intersection were during dry pavement conditions. The increase in the green time interval in the evening peak period (3:45 p.m. to 6:45 p.m.), along with the increase of traffic volume, reduced RLR violations slightly in wet and icy pavement conditions. Changes in the green time interval was associated with a significant increase in RLR violations, particularly in the evening peak period. Yellow and red times were fixed for the intersection throughout the day at 3 and 3.5 seconds, respectively. Snowy and icy pavement conditions also showed a significant increase in RLR violations, even with an increase in green time. This may be a result of drivers trying to avoid skidding.

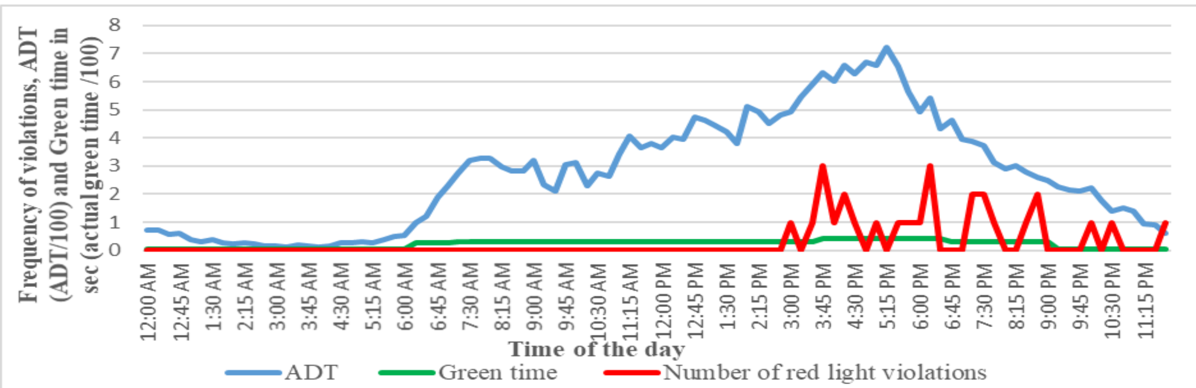

Figure B14: Frequency of red light violations, ADT, and green time sequence throughout a day for dry pavement conditions at Northern Lights Boulevard and UAA Drive.

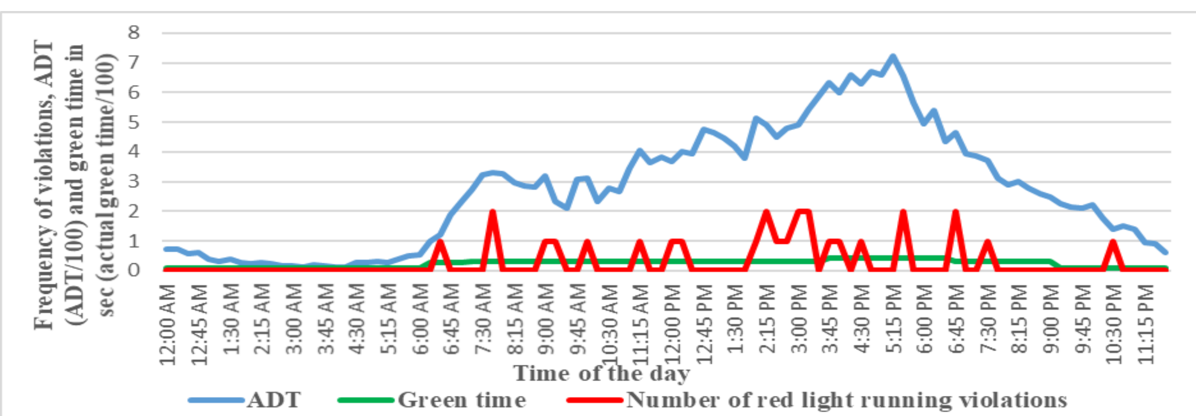

Figure B15: Frequency of red light violations, ADT, and green time sequence throughout a day for wet pavement conditions at Northern Lights Boulevard and UAA Drive.

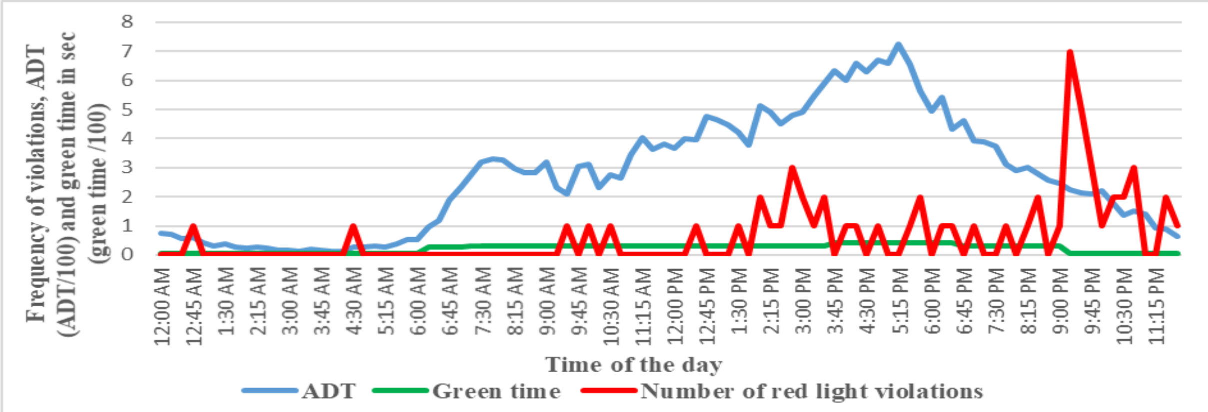

Figure B16: Frequency of red light violations, ADT, and green time sequence throughout a day for snow pavement conditions at Northern Lights Boulevard and UAA Drive.

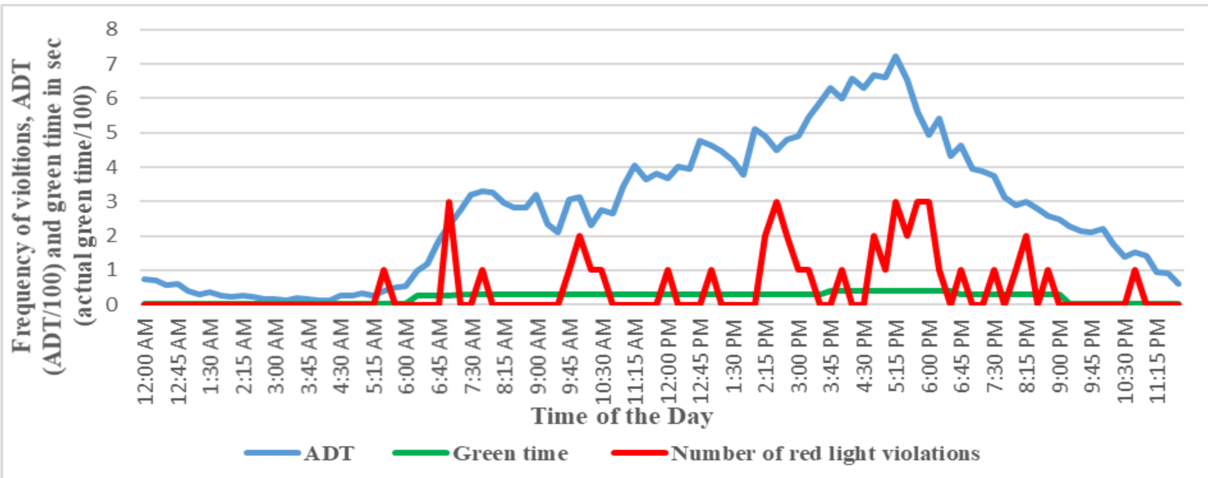

Figure B17: Frequency of red light violations, ADT, and green time sequence throughout a day for icy pavement conditions at Northern Lights Boulevard and UAA Drive.

15th Avenue and Ingra Street

The intersection of 15th Avenue and Ingra Street is a two-way and one-way high-traffic-volume intersection with relatively good sight distance. An aerial image of the intersection is given in Figure B18.

The highest RLR violations at this intersection (Figure B19) were recorded during icy pavement conditions. During wet and dry pavement conditions, a high rate of RLR violations (around 4 per 1000 entering vehicles) was recorded. The rate of RLR violations was significantly lower (around 1 per 1000 entering vehicles) for snowy compared with other pavement conditions. Drivers' fear of skidding on wet or icy pavement at this intersection was apparent, as these conditions resulted in the highest rates of RLR.

For all pavement conditions, through movement had the highest rate of violation, as shown in Figure B20. The rate for right turning RLR violations was the highest in dry pavement conditions, while the rate of through-movement RLR violations was highest in snowy pavement conditions. The tendency of drivers to avoid skidding and slipping caused higher rates of RLR violations on wet, snowy, and icy rather than dry pavement conditions. Moreover, reduced visibility during snowfall may have influenced the lower rate of right turning RLR violations on snowy pavement compared with icy and wet pavement.

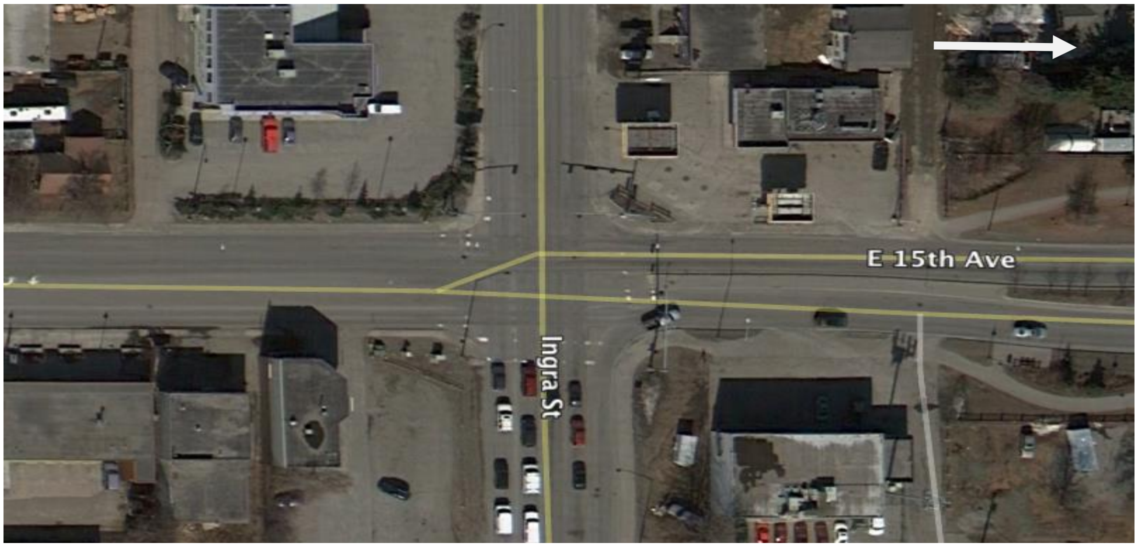

Figure B18: Aerial view of intersection 15th Avenue and Ingra Street (Source: Goggle Earth).

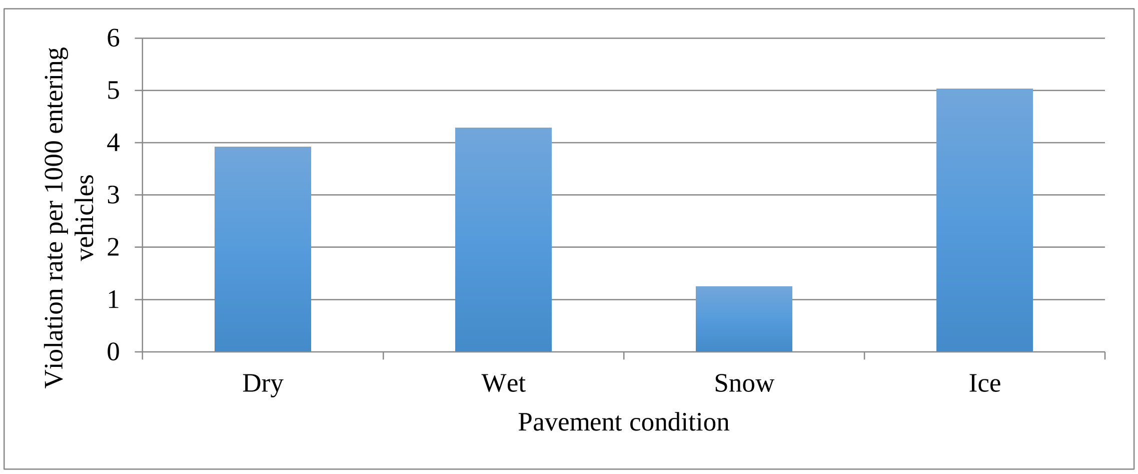

Figure B19: Frequency of red light violations per 1000 entering vehicles for different pavement conditions at 15th Avenue and Ingra Street.

The further into the red light that a vehicle enters the intersection, the higher the chance of a fatal or severe injury crash. Crashes with a severity of less than 1 second had the highest violation rate in all pavement conditions (Figure B21). As expected, on icy and wet pavement, a higher rate of more than 2-second severity level was recorded than on snowy or dry pavement. Once again, this suggests that drivers attempt to avoid skidding by violating a signal, especially on wet and icy pavement. More severe categories of RLR were recorded for dry, wet, and icy conditions as well. Due to limited visibility and eventually lower speed, almost no violations at the higher severity level were recorded in snowy conditions.

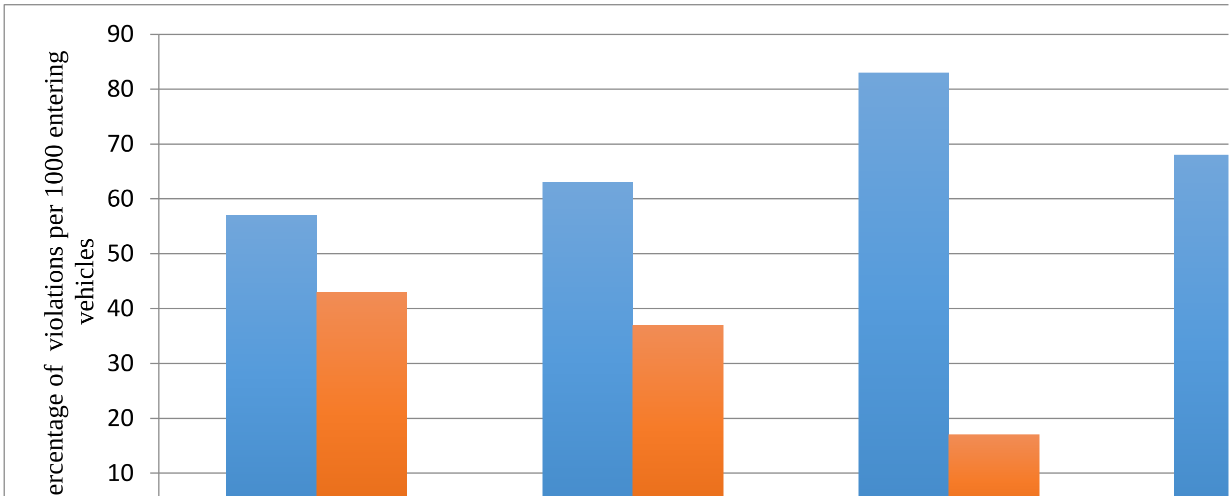

Figure B20: Frequency of red light violations based on movement type for different pavement conditions 15th Avenue and Ingra Street.

Almost all violations were by passenger cars, as shown in Figure B22. A small percentage of semitrailers were recorded running the red light in wet and snowy pavement conditions, as were a few trucks in snowy and icy pavement conditions. The larger the vehicles involved in RLR violations, the higher the risk of severe crashes. Thus, this is cause for concern.

<u>Phasing</u>

Considerable RLR violations were recorded in each of the pavement conditions (Figure B23-B25) during the morning and evening peak-traffic period (6:45 a.m. to 9:45 a.m. and 3:45 p.m. to 6:45 p.m., respectively) at the intersection of 15th Avenue and Ingra Street.

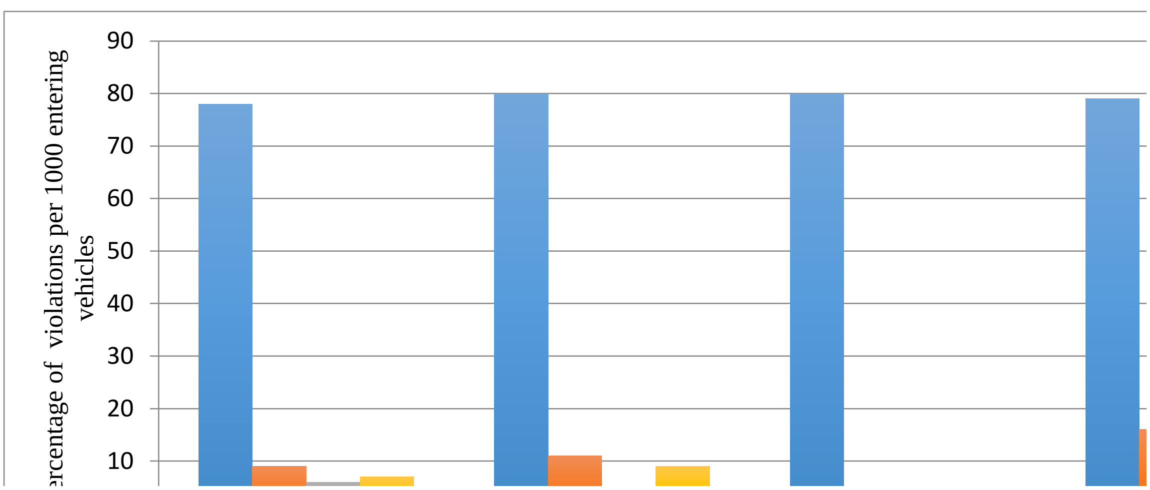

Figure B21: Percentage of red light violations based on severity type for different pavement conditions 15th Avenue and Ingra Street.

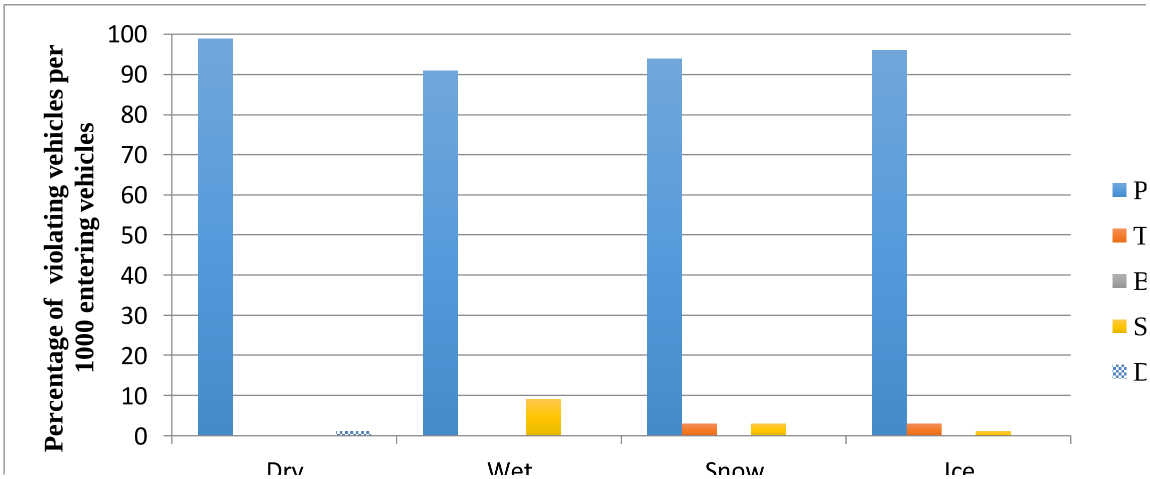

Figure B22: Percentage of red light violations based on vehicle mix for different pavement conditions 15th Avenue and Ingra Street.

Due to low visibility under snow conditions, weekday data for this condition were not available for this particular intersection. The ADT started increasing at 5:00 a.m. and reached its peak at 7:30 a.m. during the morning peak-traffic period. Fluctuations in traffic volume were observed throughout the day, and reached peak value in the evening period. Morning and evening green time peak periods were 72.3 seconds and 84.3 seconds, respectively. The yellow and red times of 4.3 and 1.4 seconds, respectively, were fixed throughout the day. We observed that an extended period of a steady increase of traffic in the morning peak period and a steady decrease in traffic in the afternoon off-peak period under dry pavement conditions had a considerable number of RLR violations. Green time had no effect on RLR violations for all pavement conditions. Though green time and ADT were decreased in the late afternoon period for all the pavement conditions, a significant increase in RLR violations was observed for dry and icy pavement conditions. Maximum off-peak period RLR violations were recorded in the evening off-peak period and after midnight in icy pavement conditions. Red light running violations on icy pavement may be due to rushing drivers in the late afternoon period. Significant rates of RLR violation in the morning peak period, even with the extended green time, occurred when pavement conditions were wet. Red light violations dropped significantly with the increase in ADT in the morning off-peak period and extended green time of 64.3 seconds.

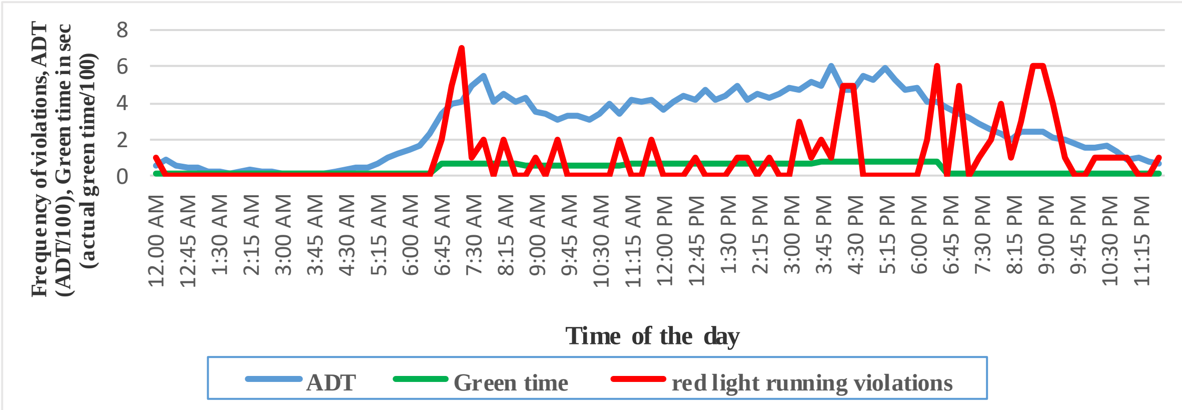

Figure B23: Frequency of red light violations, ADT, and green time sequence throughout a day for dry pavement conditions 15th Avenue and Ingra Street.

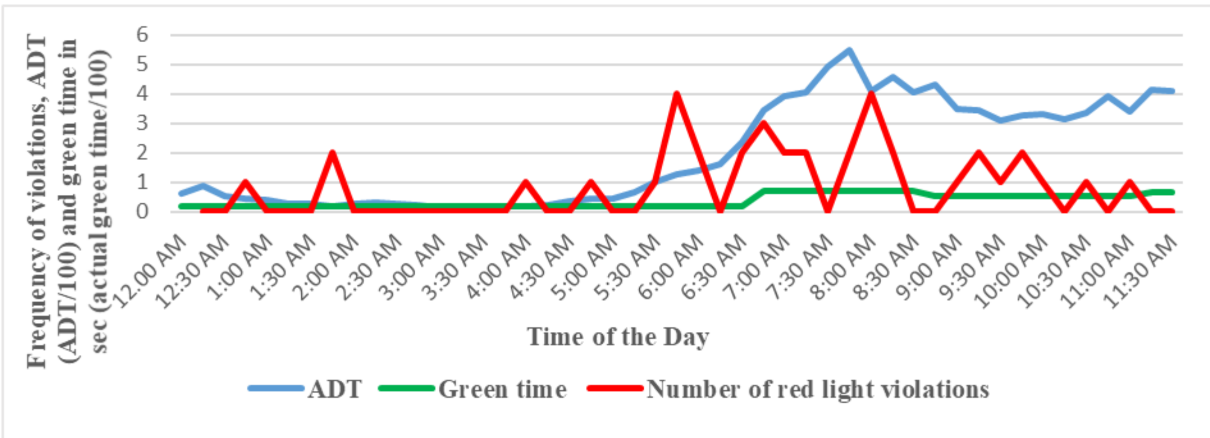

Figure B24: Frequency of red light violations, ADT, and green time sequence throughout a day for wet pavement conditions 15th Avenue and Ingra Street.

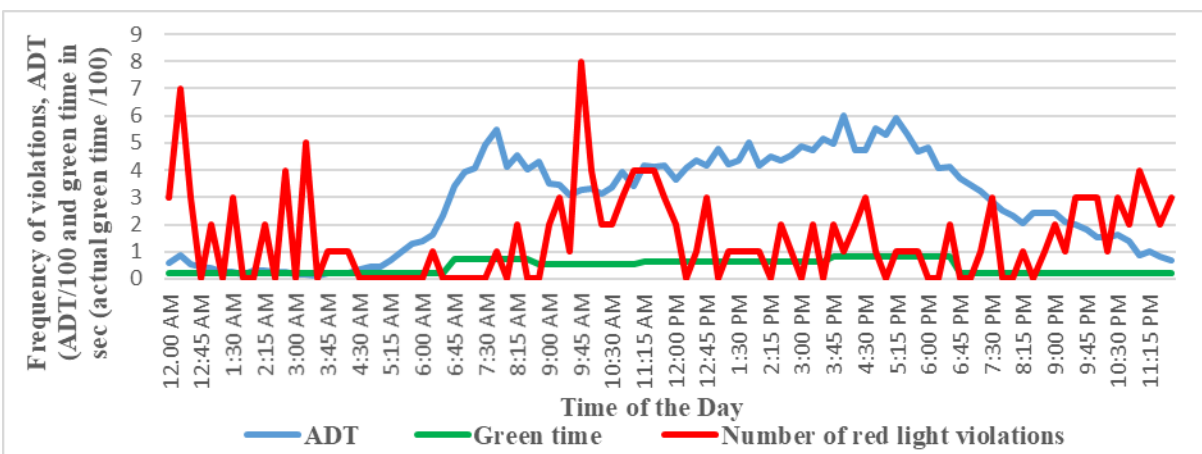

Figure B25: Frequency of red light violations, ADT, and green time sequence throughout a day for icy pavement conditions 15th Avenue and Ingra Street.

Spenard Road and Benson Boulevard

The intersection of Spenard Road and Benson Boulevard is an 80° angle intersection of two-way and one-way roads with sufficient sight distance, as shown in Figure B26. At this intersection, while violation rates during dry and snowy conditions are similar (about 3 per 1000 entering vehicles), there are more than twice as many violations during icy conditions, as shown in Figure B27. This trend is due to various reasons. On dry pavement, drivers are better able to predict when they will be able to stop, so their violation rates are lower. On snowy pavement, the violation rates are lower, since drivers expect to drive at a lower speed to avoid running a red light. In icy conditions, however, predicting how a car will react is more difficult for drivers, so they may find it harder to stop on time, causing them to run the light more often.

Figure B26: Aerial view of Spenard Rd, and Benson Blvd, (Source: Google Earth).

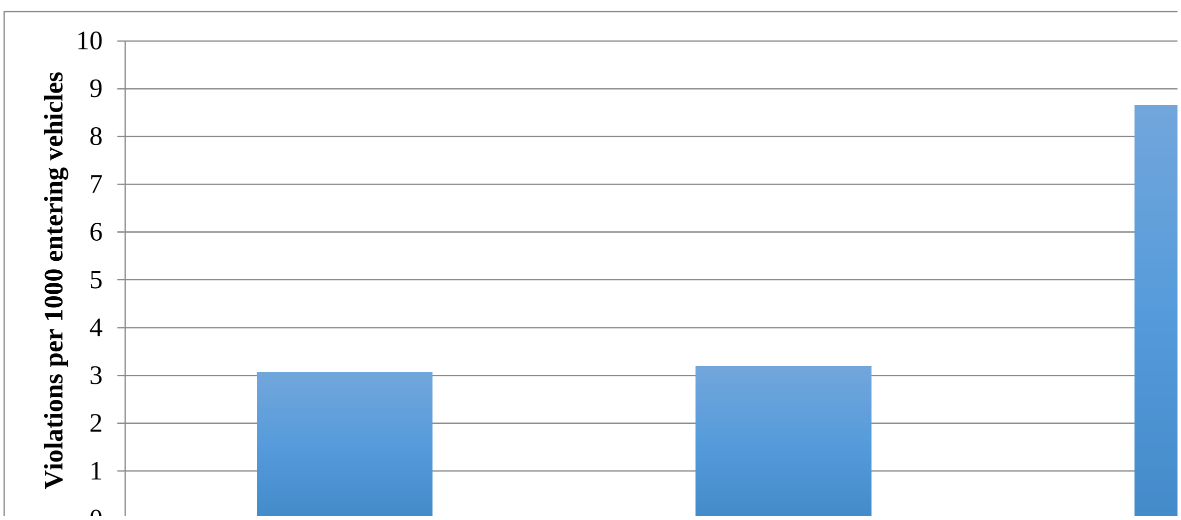

Figure B27: Frequency of red light violations per 1000 entering vehicle for different pavement conditions at Spenard Road and Benson Boulevard.

Through movement was more frequent in RLR violations than right turning for all pavement conditions, as shown in Figure B28. Through movement had the maximum rate of RLR violations for icy pavement conditions, followed by dry and snowy conditions with around 26% each. No left turning violations were observed, which indicates drivers' alertness towards left turning at the intersections.

The severity levels of RLR violation at the intersection of Spenard Road and Benson Boulevard are shown in Figure B29. An equal percentage of 1- to 2-second RLR severity was recorded for dry and icy conditions. The maximum rate of high-severity RLR violations was recorded for snowy pavement conditions. About 30% of 1- to 2-second RLR violations occurred on snowy pavement compared with about 12% on dry and icy pavement.

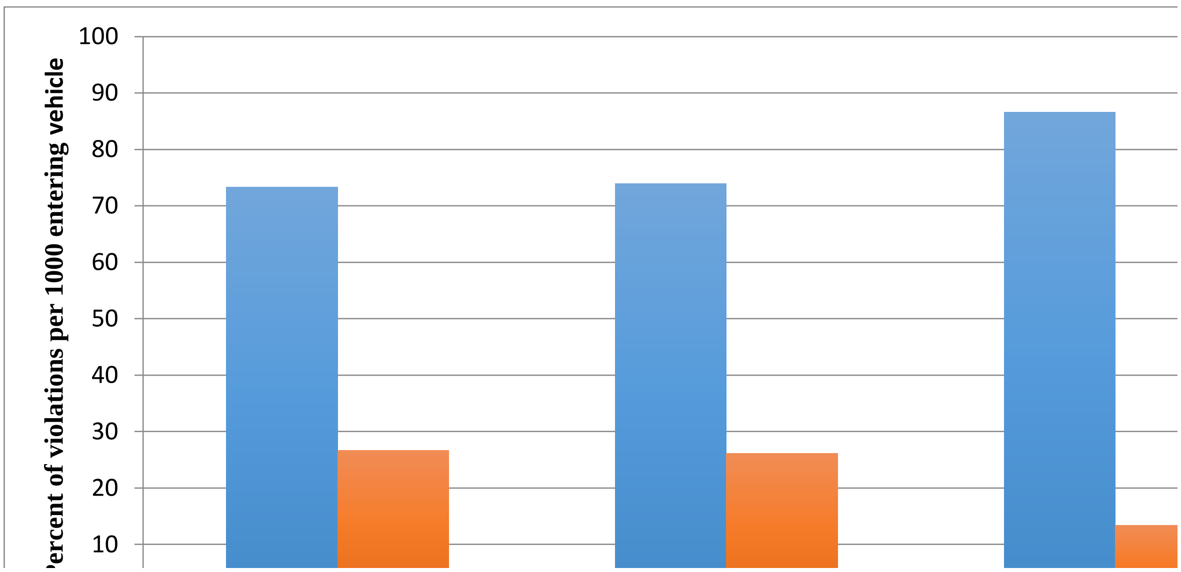

Figure B28: Frequency of red light violations based on movement type for different pavement conditions at Spenard Road and Benson Boulevard.

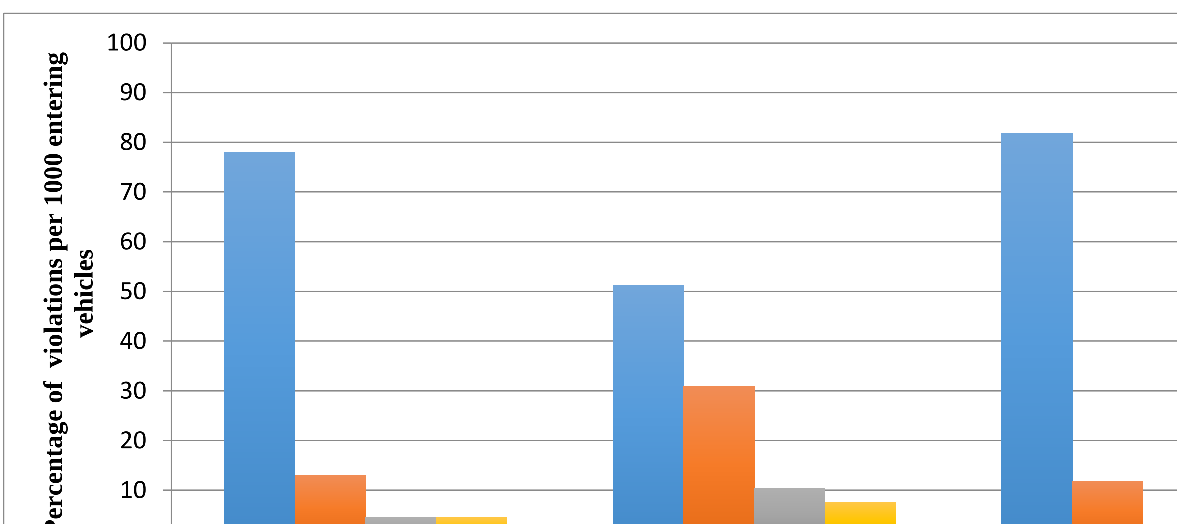

Figure B29: Frequency of red light violations based on severity type for different pavement condition at Spenard Road and Benson Boulevard.

Passenger cars were found to be the most frequent violators of the red light at the intersection of Spenard Road and Benson Boulevard in all pavement conditions (Figure B30). Few trucks and semitrailers violated the red light, particularly on icy pavement, justifying the cause of this being the desire to avoid skidding while approaching an intersection.

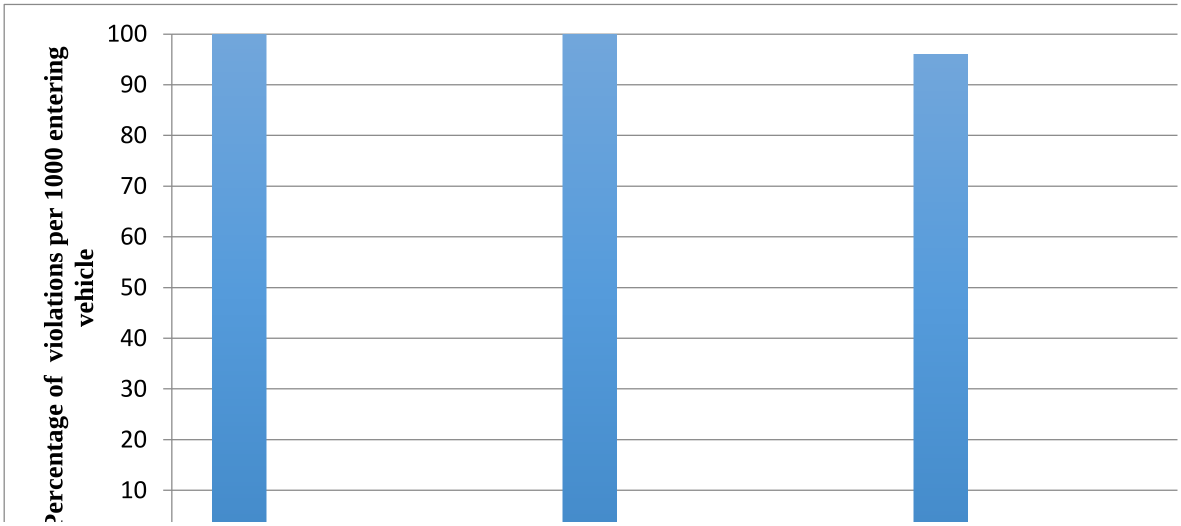

Figure B30: Frequency of red light violations based on vehicle composition for different pavement conditions at Spenard Road and Benson Boulevard.

Phasing

Red light running violations with respect to change of ADT and green time for each of the pavement conditions are shown in Figure B31 to B33. Yellow and red times were fixed for a typical weekday at 4 to 1.7 seconds, respectively. Red light running violations significantly increased with the decrease of ADT in the late afternoon period for dry pavement conditions. In the late evening period, drivers were more likely to run the red light because of less traffic. The decline of green time in the morning peak and evening peak period of traffic caused a relatively larger rate of violations for all pavement conditions. Green time was reduced to 33.3 seconds (from 48.5 seconds) after 3:30 p.m., though ADT fluctuated until 5:30 p.m., with significantly higher rates of RLR violations, particularly in dry and icy conditions.

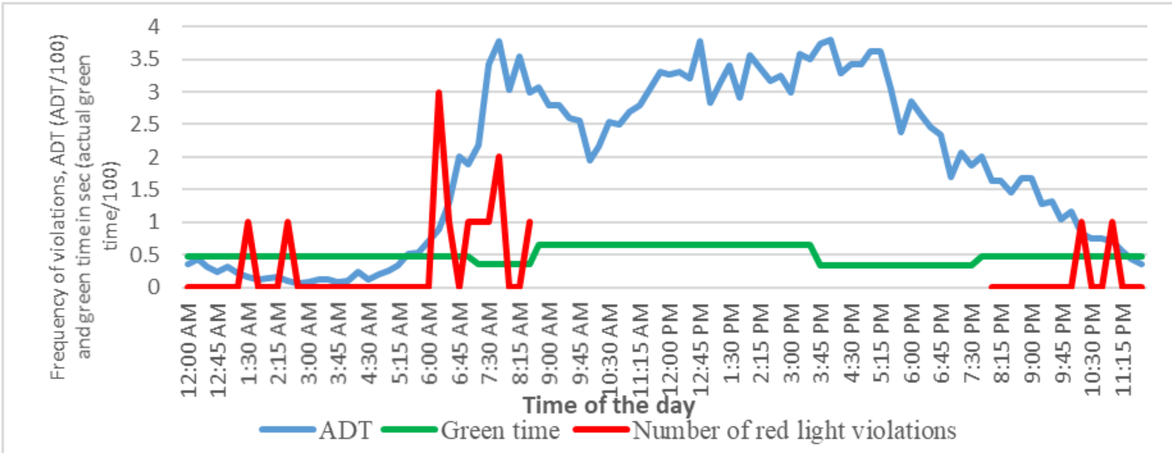

Figure B31: Frequency of red light violations, ADT, and green time sequence throughout a day for wet pavement conditions at Spenard Road and Benson Boulevard.

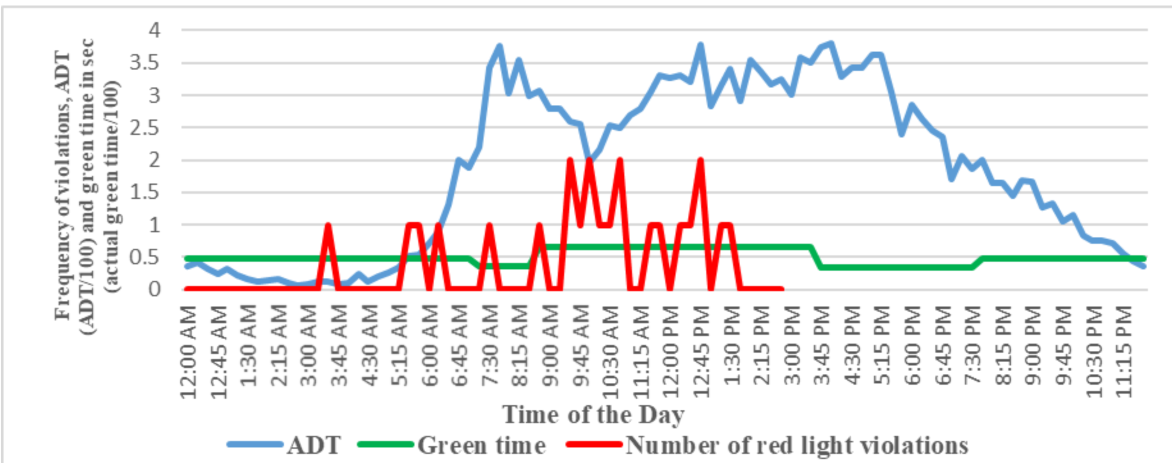

Figure B32: Frequency of red light violations, ADT, and green time sequence throughout a day for snow pavement conditions at Spenard Road and Benson Boulevard.

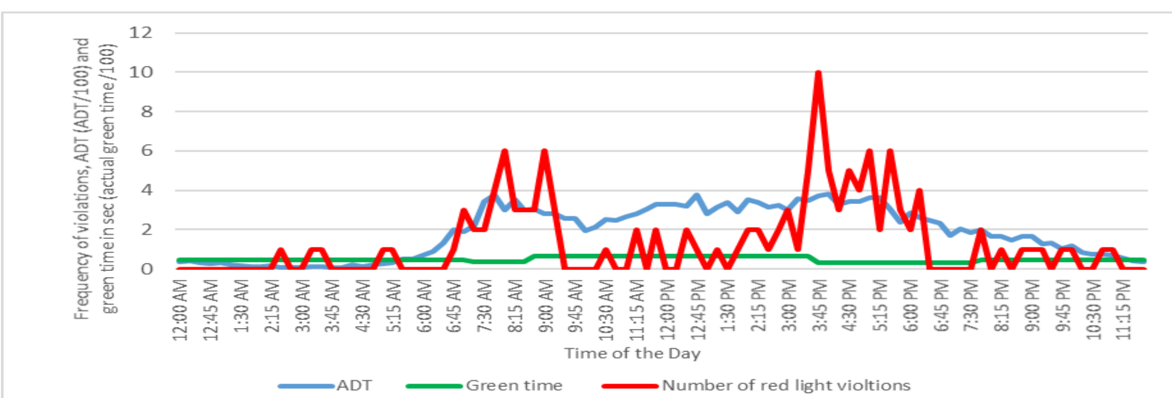

Figure B33: Frequency of red light violations, ADT, and green time sequence throughout a day for icy pavement conditions at Spenard Road and Benson Boulevard.

C Street and Benson Boulevard

C Street and Benson Boulevard is an intersection of two one-way roads with relatively high traffic volume and limited sight distance at its northeast corner (see Figure B34).

Figure B34: Aerial view of C Street and Benson Blvd intersection (Source: Goggle Earth).

Significantly higher RLR violations occurred in wet pavement conditions than in other pavement conditions (see Figure B35). Some RLR violations occurred in icy pavement conditions, while around 1 violation per 1000 entering vehicles occurred when pavement was dry or snowy. Dry and wet conditions followed the trend seen at other intersections, with most drivers continuing through the intersection (Figure B36). No RLR violations were observed under snowy and icy conditions. Around 20% of RLR right turning violations was observed for dry and wet pavement conditions. As expected, violation severities were greater in snowy and icy conditions than in dry and wet conditions (see Figure B37). The highest rate of severity was less than 1 second for all pavement conditions. Significant rates of 1- to 2-second severity (around 40%) were observed for snowy and icy conditions. Nearly the same number of 2- to 3-second severities were recorded in snowy and icy pavement conditions, while few to none occurred in wet and dry pavement conditions. Greater than 3-second severities were observed only for wet and icy conditions.

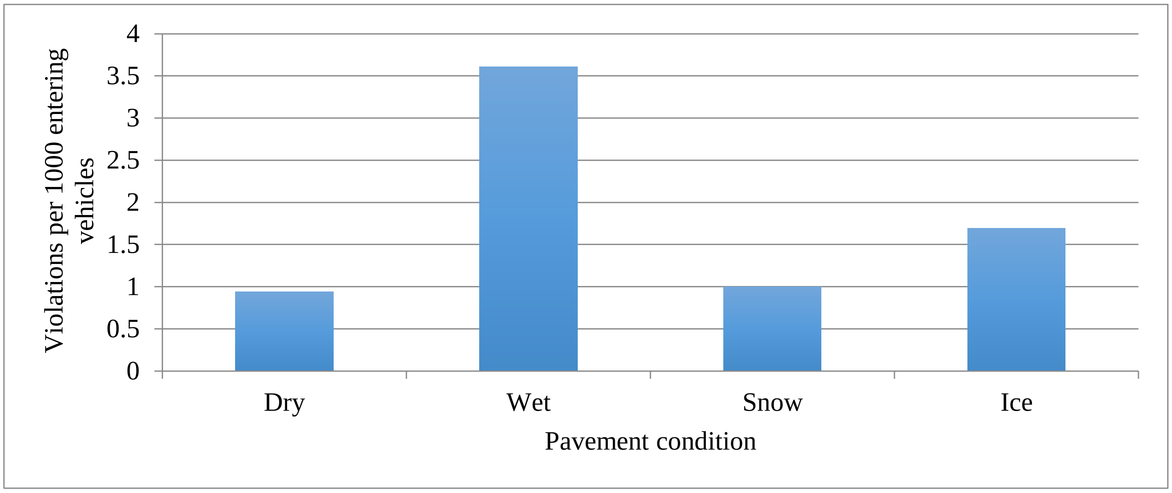

Figure B35: Frequency of red light violations per 1000 entering vehicle for different pavement conditions at C Street and Benson Boulevard.

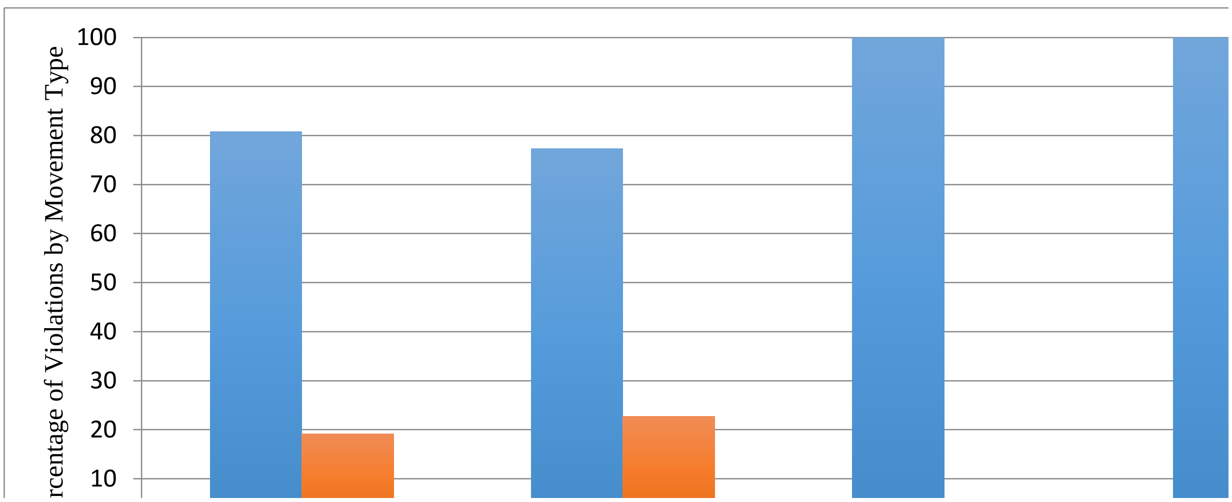

Figure B36: Frequency of red light violations based on movement type vehicle for different pavement conditions at C Street and Benson Boulevard.

One hundred percent of all RLR violations that occurred at this intersection were by drivers in passenger cars for all four pavement conditions.

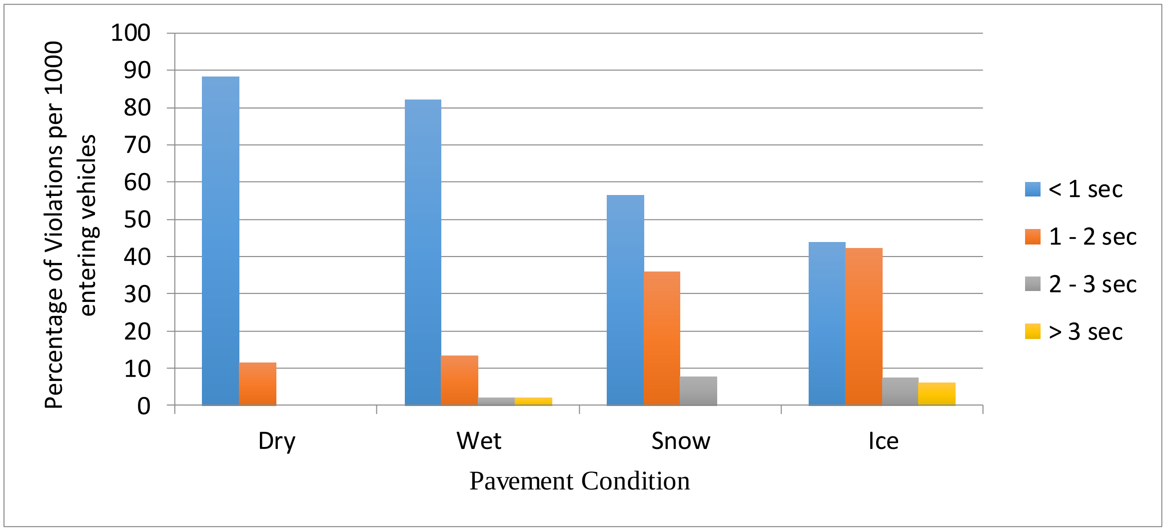

Figure B37: Frequency of red light violations based on severity type for different pavement conditions at C Street and Benson Boulevard.

Phasing

At the intersection of C Street and Benson Boulevard, the yellow and red times were fixed at 4 seconds and 1.5 seconds each. A reduction of green time to 31.5 seconds (from 43 seconds) was observed while traffic was still increasing after 3:45 p.m., followed by an increase to 58.5 seconds after 8:30 p.m. No significant changes were associated with the change of green time. Referring to Figures B38–B41, for dry pavement conditions, an increase in RLR violations was observed with the increase in ADT between 10:30 a.m. and 12:00 p.m. On wet pavement, RLR violations increased during the evening peak period (3:45 p.m. to 6:45 p.m.), while ADT showed a steady state. Considerable violations were recorded during the period of 10:30 a.m. to 3:30 p.m., even with extended green time on snowy pavement. In the late evening period (from around 7:00 p.m. until midnight), RLR violations increased, especially in snowy and icy pavement conditions, which was observed at other intersections as well.

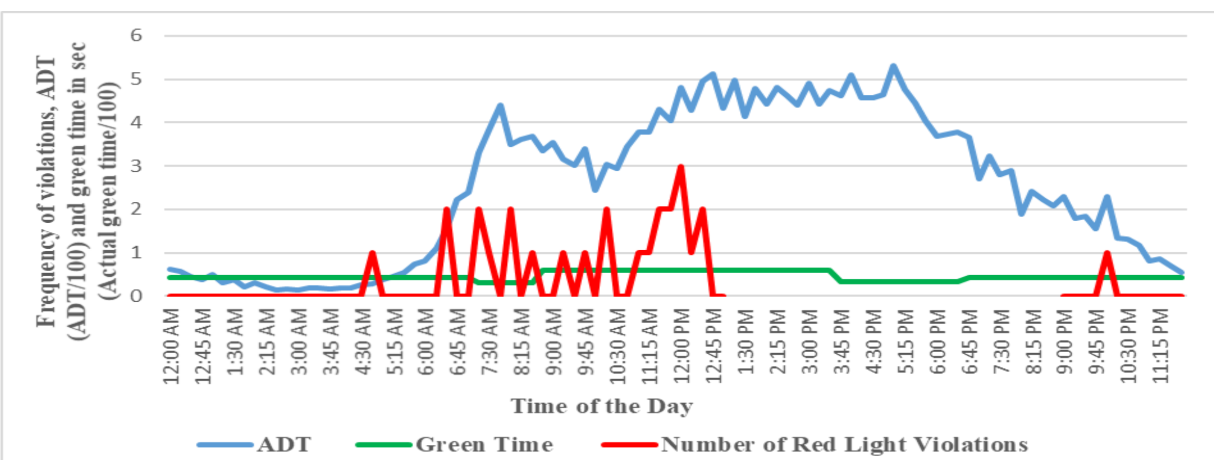

Figure B38: Frequency of red light violations, ADT, and green time sequence throughout a day for dry pavement conditions at C Street and Benson Boulevard.

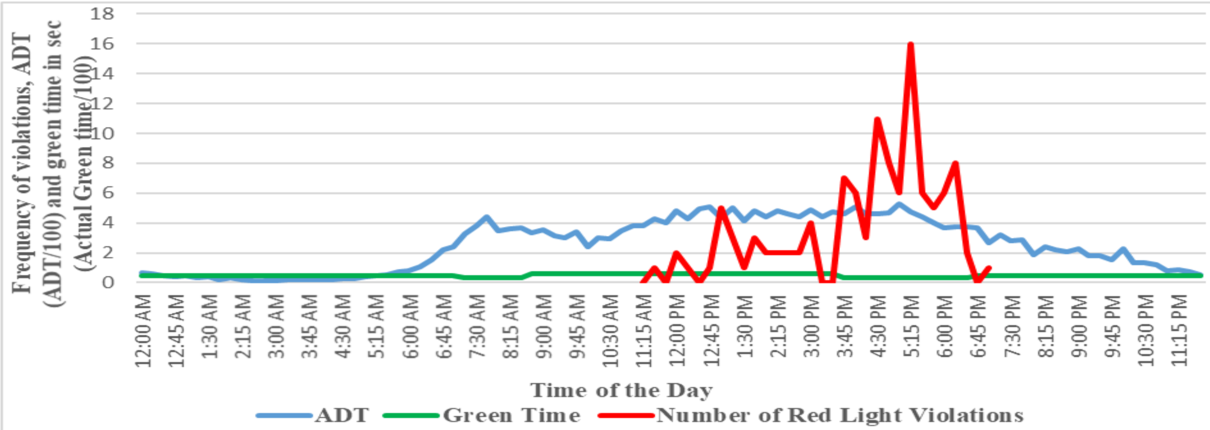

Figure B39: Frequency of red light violations, ADT, and green time sequence throughout a day for wet pavement conditions at C Street and Benson Boulevard.

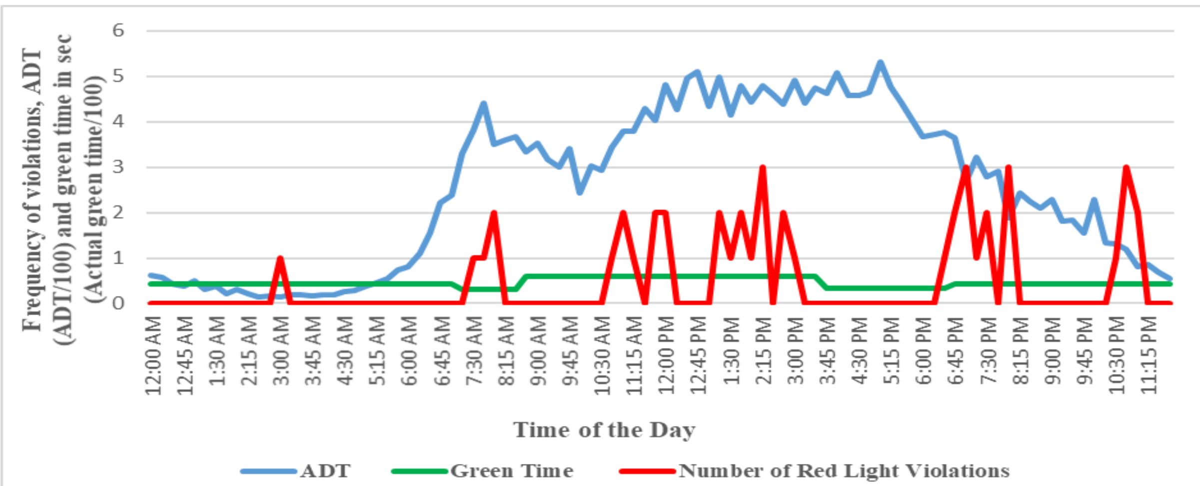

Figure B40: Frequency of red light violations, ADT, and green time sequence throughout a day for snow pavement conditions at C Street and Benson Boulevard.

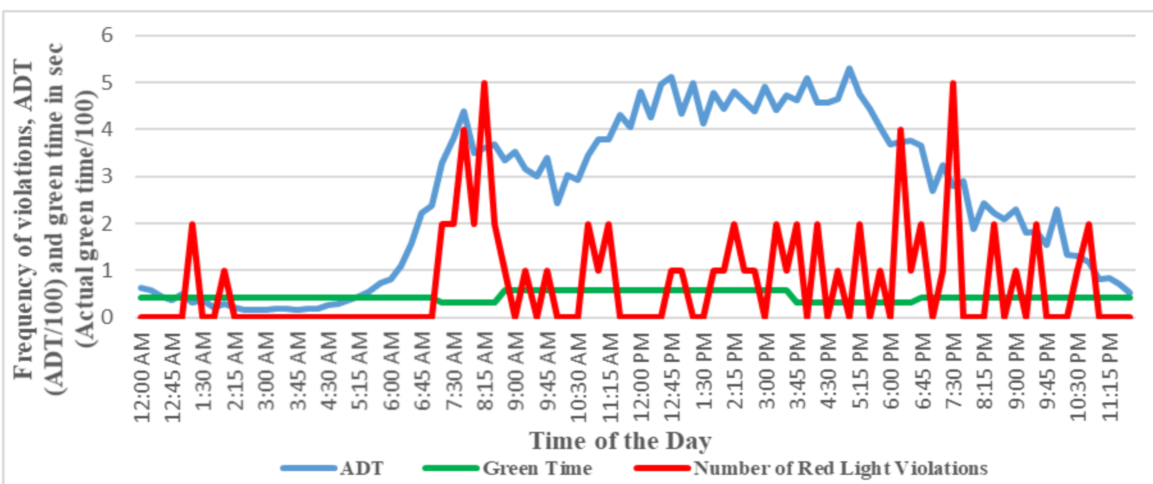

Figure B41: Frequency of red light violations, ADT, and green time sequence throughout a day for icy pavement conditions at C Street and Benson Boulevard.

Boniface Parkway and Mountain View Drive

The intersection of Boniface Parkway and Mountain View Drive is located on a highway off-ramp with a multilane road. A median exists where taking a left from the off-ramp to the divided high-traffic-volume road (see Figure B42, bottom center of image, which shows the case when turning left onto Boniface Road). Straight from the off-ramp is a two-way undivided road, and to the right is the entry to a military base. The relatively unique geometry of this intersection may play a large role in RLR violations that occur here. Sight distance is sufficient all around the intersection.

Figure B42: Aerial view of Boniface Parkway and Mountain View Drive intersection (Source: Goggle Earth).

Though a relatively limited number of violations was observed at this intersection compared with the other intersections studied, RLR violations were recorded at the highest rate, around 6 per 1000 entering vehicles, under icy pavement conditions (Figure B43). The lowest rate of violations occurred during wet conditions, while around 3 and 4 violations per 100 entering vehicles occurred during dry and snowy conditions, respectively. Only through-movement violations were recorded during each of the pavement conditions at this intersection.

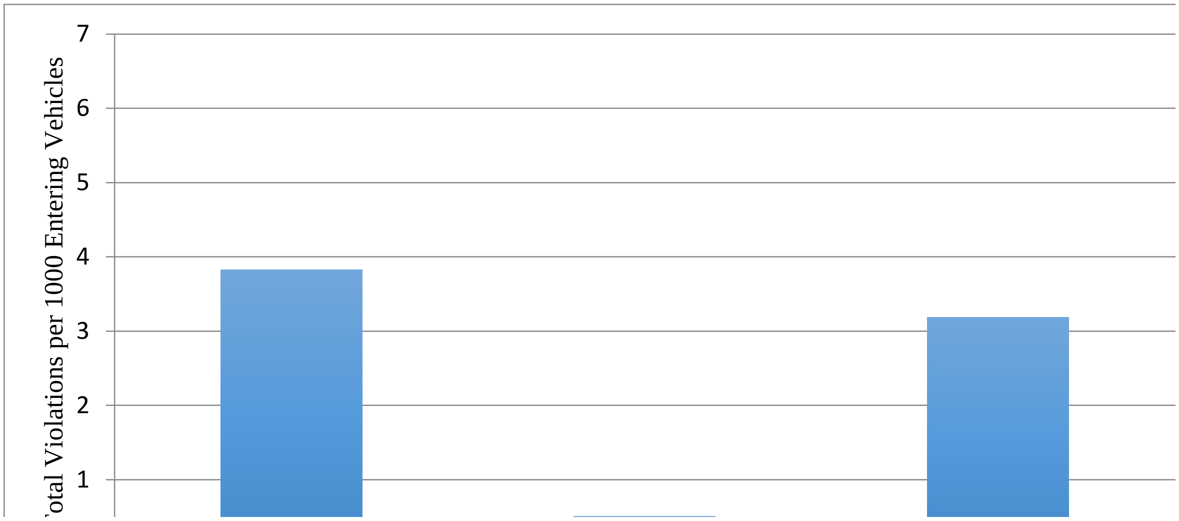

Figure B43: Frequency of red light violations per 1000 entering vehicle for different pavement conditions at Boniface Parkway and Mountain View Drive.

As shown in Figure B44, violation severities took on a different trend at this intersection. Around 55% and 60% of RLR violations of less than 1 second were recorded for dry and icy pavement conditions, respectively, and around 50% for wet and snowy pavement conditions. A considerable number of violations of 1 to 2 seconds were observed at this particular intersection, making it unlike other intersections. Only at this intersection were wet pavement conditions equal for the first two severity levels. Moreover, 1- to 2-second violations were at the maximum and even greater than less 1-second violations in snowy pavement conditions. Some higher levels of severity were also observed for snowy conditions.

As with the intersection of C Street and Benson Boulevard, only passenger cars were found to violate the red light in all pavement conditions

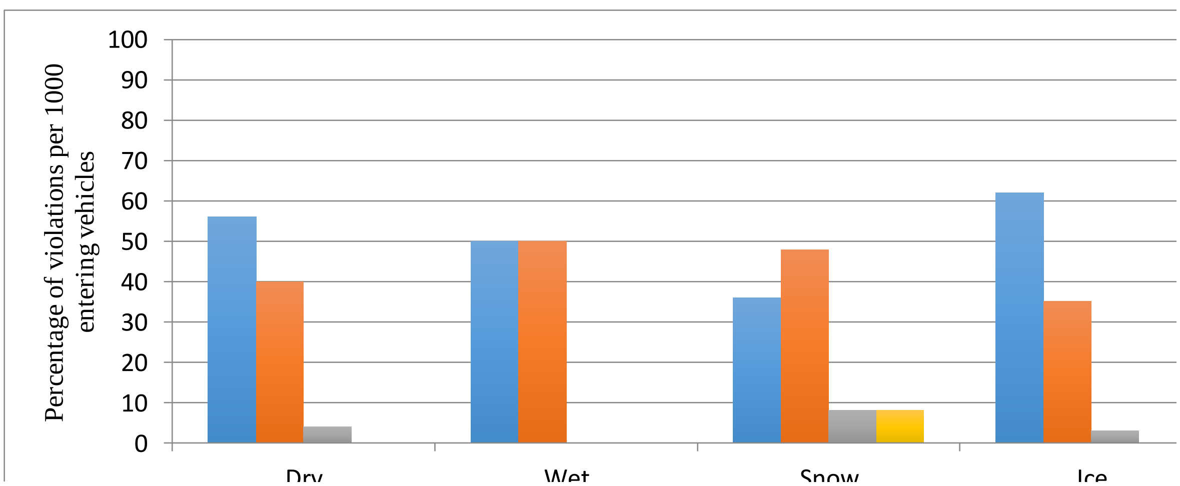

Figure B44: Percentage of red light violations based on severity type for different pavement conditions at Boniface Parkway and Mountain View Drive.

Phasing

Fixed yellow and red times of 4.4 and 1.5 seconds, respectively, were recorded at the intersection of Boniface Parkway and Mountain View Drive. A significant rate of RLR during morning peak hours from 6:45 a.m. to 8:30 a.m., with the highest amount of traffic flow, was detected for all the pavement conditions (Figure B45 to B47). As with the other intersections, green time had no effect on RLR violations. Violation rates fluctuated in the late afternoon, after green time decreased to 43.1 seconds (from 52.1 seconds). This was the case for all pavement conditions. Note that the recordings for wet conditions were minimal to make any meaningful analysis.

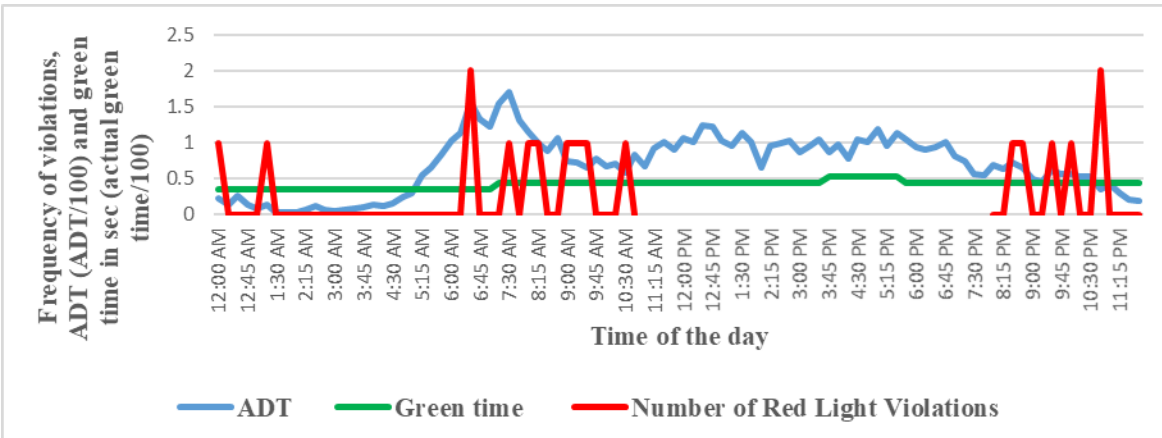

Figure B45: Frequency of red light violations, ADT, and green time sequence throughout a day for dry pavement conditions at Boniface Parkway and Mountain View Drive.

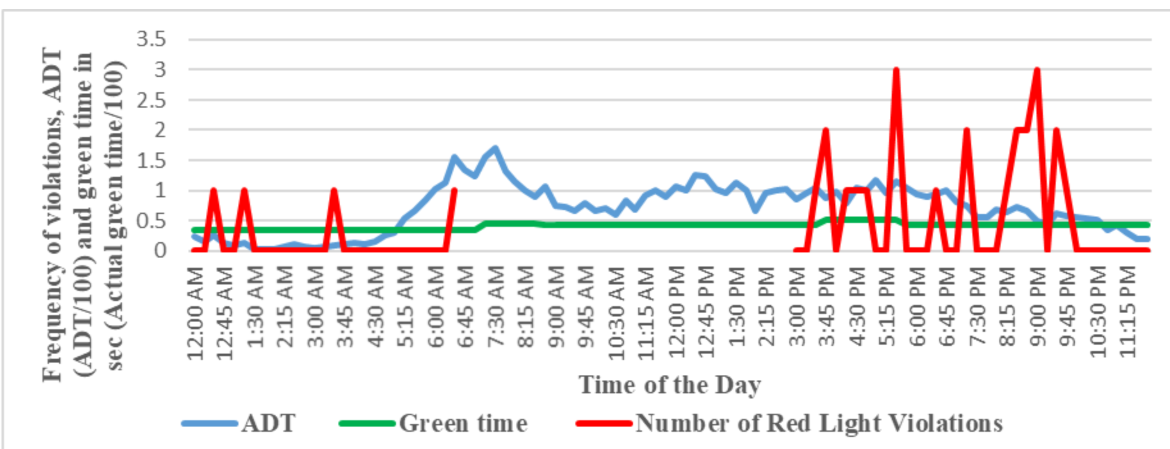

Figure B46: Frequency of red light violations, ADT, and green time sequence throughout a day for snow pavement conditions at Boniface Parkway and Mountain View Drive.

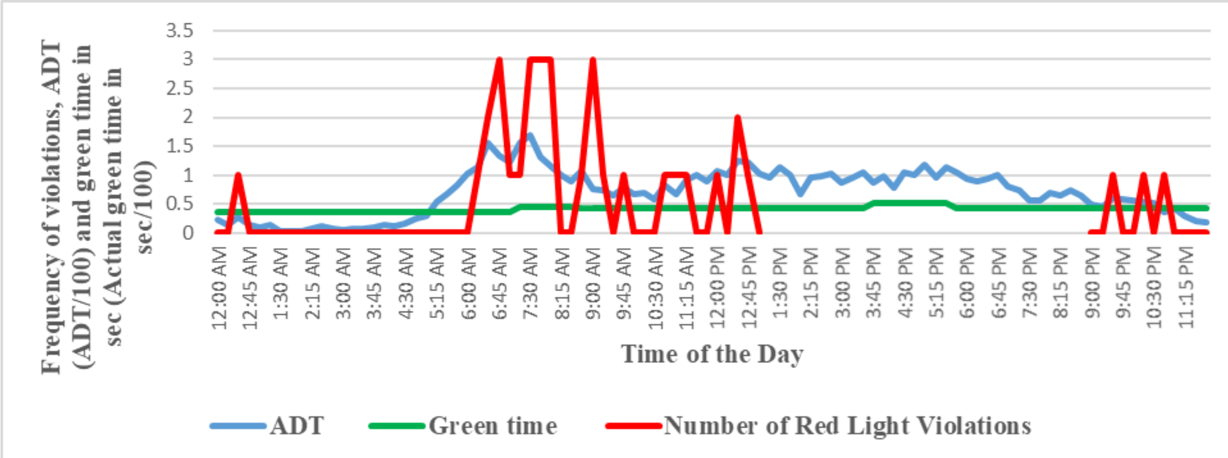

Figure B47: Frequency of red light violations, ADT, and green time sequence throughout a day for icy pavement conditions at Boniface Parkway and Mountain View Drive.

Summary

This summary consists of two parts: a comparative RLR analysis of the intersections studied, and a highlight of pavement conditions based on analysis of RLR violations. The criteria used for analyzing RLR violations at each intersection were geometric design (especially sight distance), total number of violations per 1000 entering vehicles, violations based on movement type, severity and vehicle composition, and phasing pattern.

1. Comparative analysis of red light violations at intersections

We considered the average number of violations for each of the four pavement conditions for the six intersections. For phasing, we counted the average number of RLR violations under all pavement conditions for a single intersection. We have highlighted the phasing characteristics by considering average violations for each intersection with respect to average green time and average ADT.

The intersection of C Street and 6th Avenue had the maximum rate of RLR violations, close to 25 per 1000 entering vehicles. This rate is far greater than other intersections (Figure B48). This intersection lacks satisfactory sight distance; RLR violations in the selected approach signify awareness for safety of travelers. The intersections at 15th Avenue and Ingra Street and at Boniface Parkway and Mountain View Drive had around 3 violations, while the intersections at Northern Lights Boulevard and UAA Drive and at C Street and Benson Boulevard had around 2 violations per 1000 entering vehicles. Spenard Road and Benson Boulevard had 5 RLR violations per 1000 crossing vehicles.

The intersection of C Street and 6th Avenue was found to be the most vulnerable zone for RLR in all movement types (through and right turning) at all intersections (see Figure B49). Through-movement RLR was found higher than right turning violations at all intersections. Around 4 through-movement violations were recorded for both the Spenard Road and Benson Boulevard intersection and the Boniface Parkway and Mountain View Drive intersection. The Boniface Parkway and Mountain View Drive intersection does not permit right turning, thus no right turning violations were observed. The intersection at C Street and

6th Avenue recorded the maximum rate of right turning violations, about 5; lower rates were recorded at the other intersections. Though the left turning movement occurred at some intersections, the absence of left turning violations suggests increased driver alertness while turning left in an approach to an intersection.

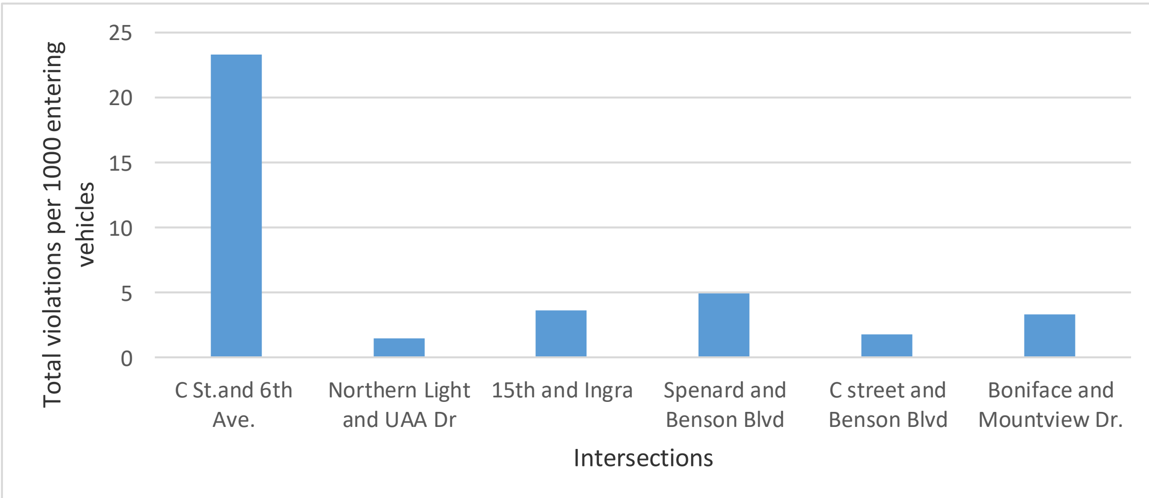

Figure B48: Frequency of red light violations per 1000 entering vehicles in different intersections.

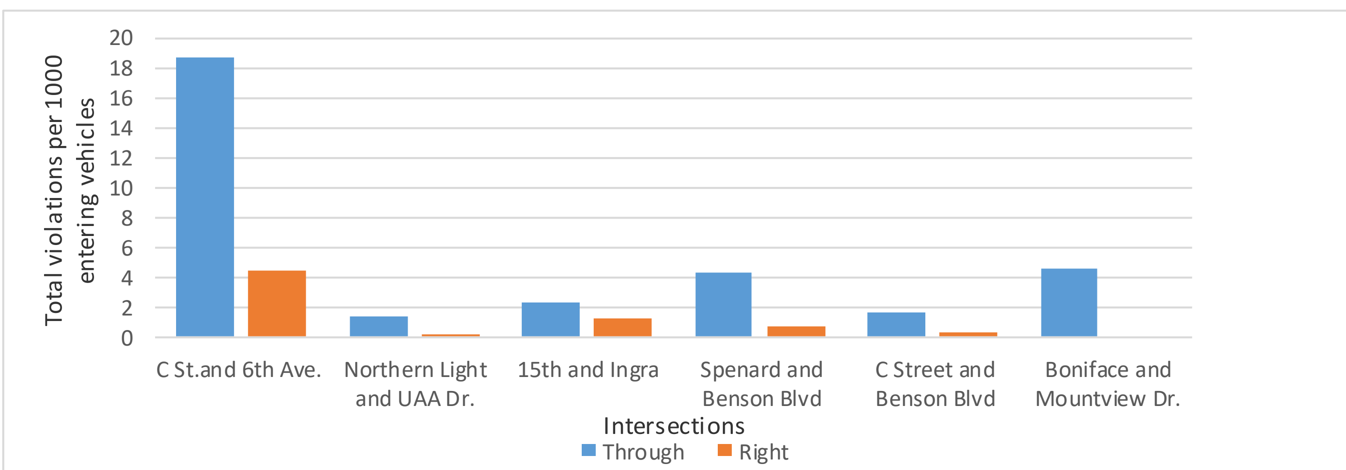

Figure B49: Frequency of red light violations based on movement type for different intersections.

Less than 1-second RLR severity level was predominant at all intersections, as shown in Figure B50. A significant rate of about 19 RLR violations per 1000 vehicles of less than 1-second severity was observed at C Street and 6th Avenue, which was higher than any other severity level and location. Higher RLR severity levels of 1 to 2 seconds were more frequent at the Boniface Parkway and Mountain View Drive intersection. Very few higher severity levels of 2–3 seconds and greater than 3 seconds were recorded at the intersections of C Street and 6th Avenue, 15th Avenue and Ingra Street, and Spenard Road and Benson Boulevard. Moreover, 1–2 second violations were observed at the intersections considered.

We observed that, of all vehicles, passenger cars violated the red light most frequently at all the intersections. We observed buses and trucks violating the red light, also, but the number was negligible compared with passenger vehicles.

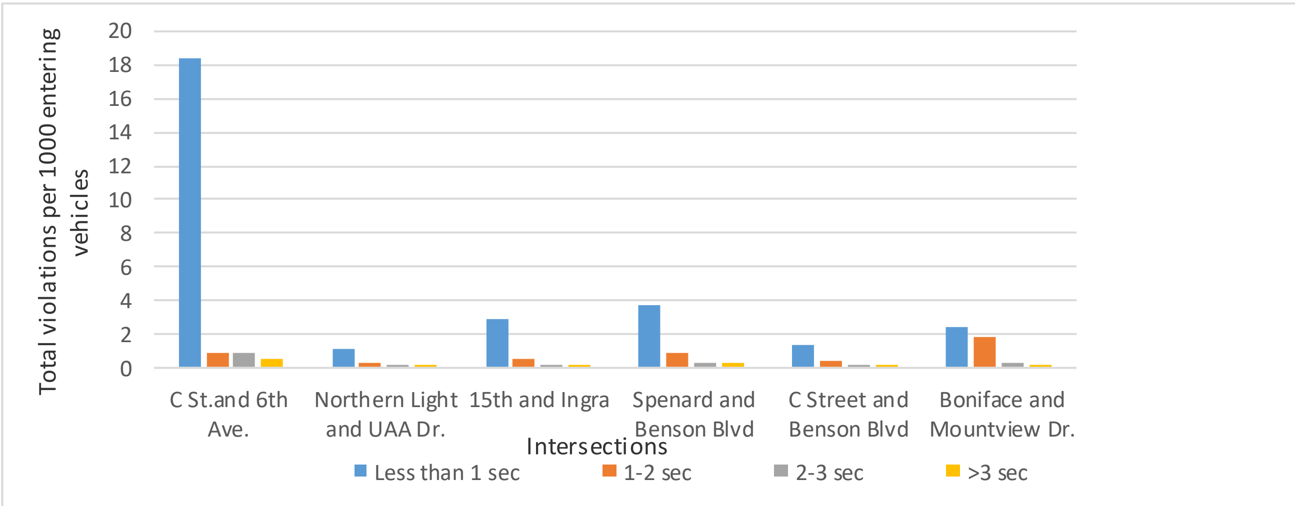

Figure B50: Frequency of red light violations based on severity type for different intersections.

<u>Phasing</u>

We considered the average number of violations for all the pavement conditions at each intersection. The highest rate of RLR violations was recorded at C Street and 6th Avenue. More RLR violations were recorded in the evening peak and off-peak hours in comparison with morning peak (see Figure B51). Crossing the 200 vph (volume per hour) threshold for this approach at this intersection, especially during the evening period, caused a high rate of violations in spite of the extended green time of the signal phase for a couple of hours. In addition, a considerable rate of RLR violations was observed not only in the afternoon or late afternoon period but also after midnight and after a significant drop in traffic volume in the afternoon period after 4:30 p.m. This phenomenon clearly indicates the rushing behavior of travelers particularly in the late afternoon period going home.

The lowest rate of RLR violations was recorded at the Northern Lights Boulevard and UAA Drive intersection (see Figure B52). Though, more traffic exits at the Northern Lights intersection than at C Street and 6^{th} Avenue, fewer violations were recorded. More RLR violations were recorded in the afternoon and late afternoon periods compared with morning hours in spite of the increase in the green time phase and the declining traffic volume into the evening hours.

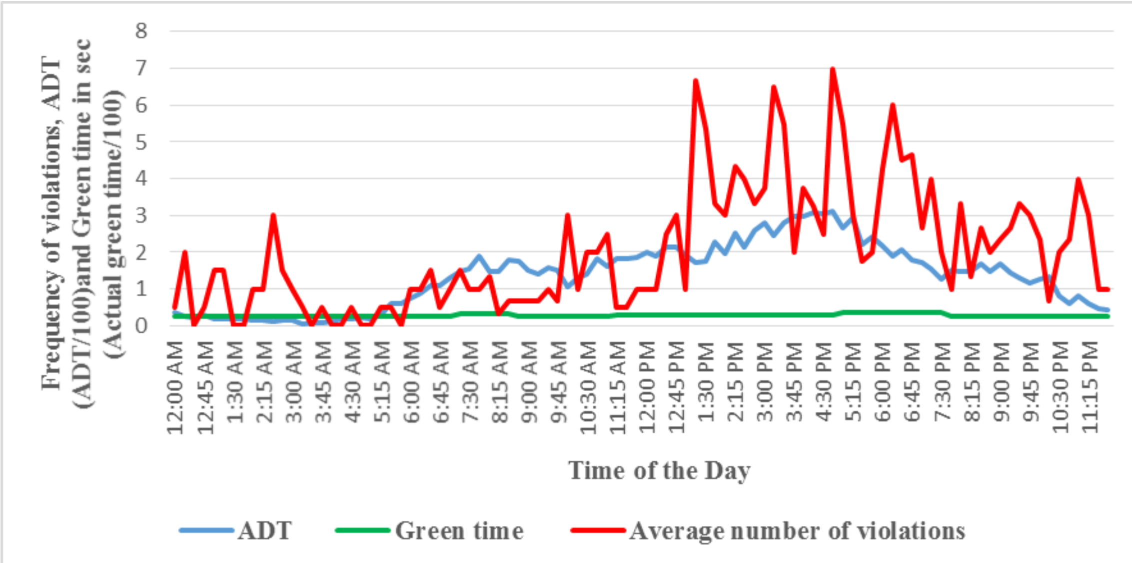

Figure B51: Frequency of red light violations, ADT, and green time sequence throughout a day for C Street and 6th Avenue.

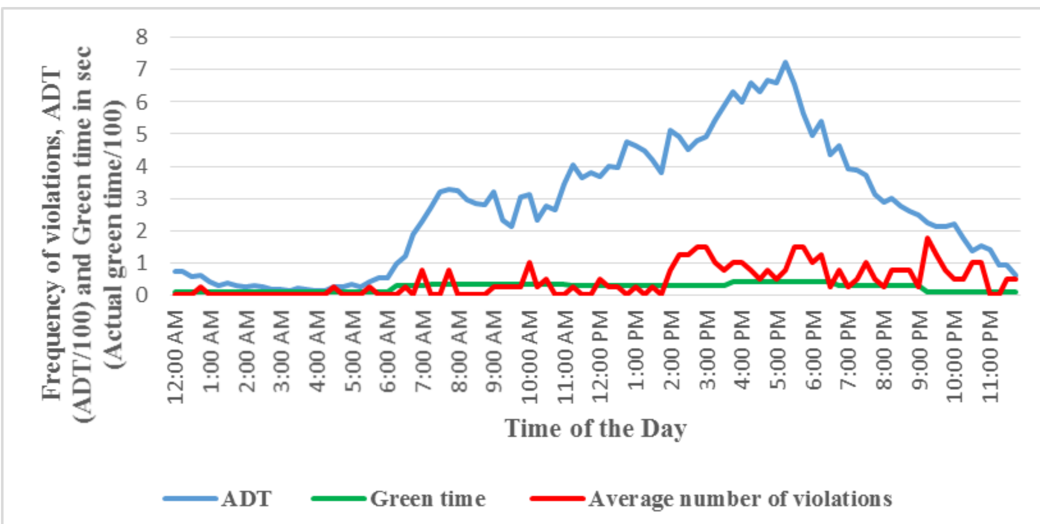

Figure B52: Frequency of red light violations, ADT, and green time sequence throughout a day for Northern Lights and UAA Drive.

A higher rate of RLR violations in the afternoon period was also recorded at the 15th Avenue and Ingra Street intersection (see Figure B53). A higher rate of violations in the morning and evening peak period was recorded, while traffic volume reached at or beyond 200 vph at that approach. The rate of violations decreased significantly in late afternoon and after midnight at this intersection, with decline in traffic volume. Still, evening rushing was observed for this intersection, more so than in the morning period.

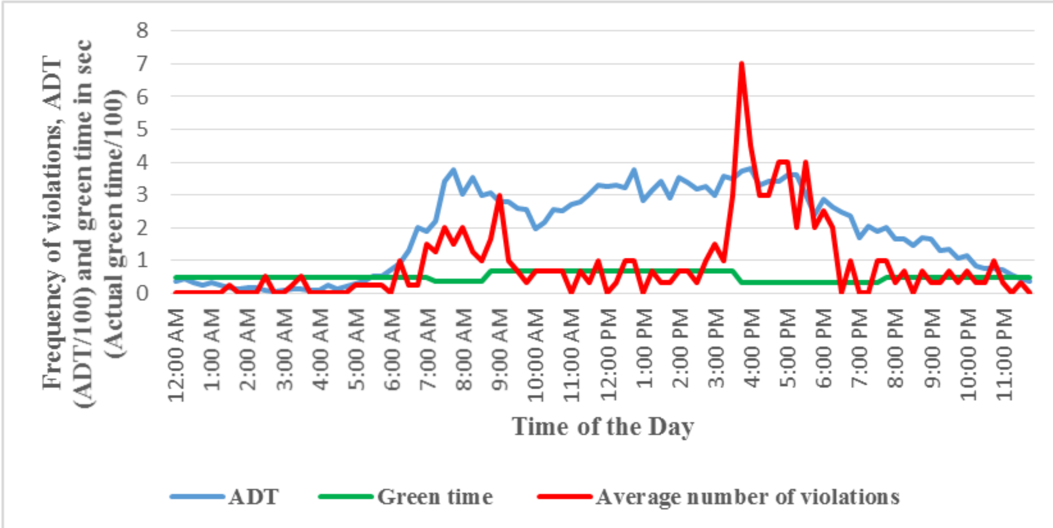

Figure B53: Frequency of red light violations, ADT, and green time sequence throughout a day for 15th Avenue and Ingra Street.

Considerable rates of RLR violations were recorded at C Street and 6th Avenue, along with Spenard Road and Benson Blvd. Violation rates with respect to traffic volume and green time interval are shown in Figure B54. Red light running violations were recorded throughout the day, even after midnight, when traffic volume and green time change. Extended green periods did not reduce RLR violation, which proves that green time interval has no significant effect on RLR violations. Red light running violation was correlated with traffic volume, but was not the sole factor.

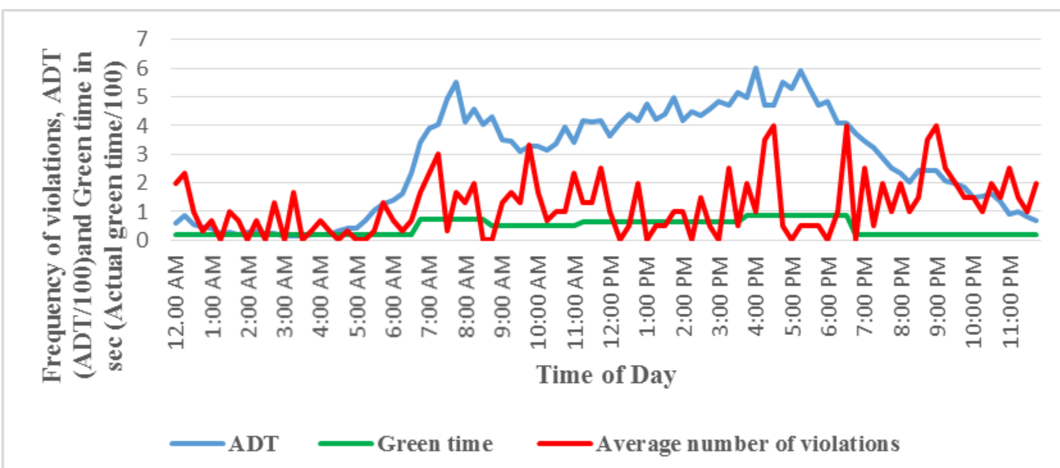

Figure B54: Frequency of red light violations, ADT, and green time sequence throughout a day for Spenard Road and Benson Blvd.

Like at other intersections, a higher rate of RLR violations was recorded at C Street and Benson Boulevard in the afternoon peak period than in the morning peak period (see Figure B55). The characteristics of fluctuating RLR violations with respect to green time and ADT were found similar to the 15th and Ingra intersection. Traffic volume in the range of 300–500 vph after 4:00 p.m. was associated with changes in green timing interval causing a high rate of RLR violations. A violations fluctuation of 2 to 3 RLR violations per 1000 entering vehicles was observed with higher green time interval as well.

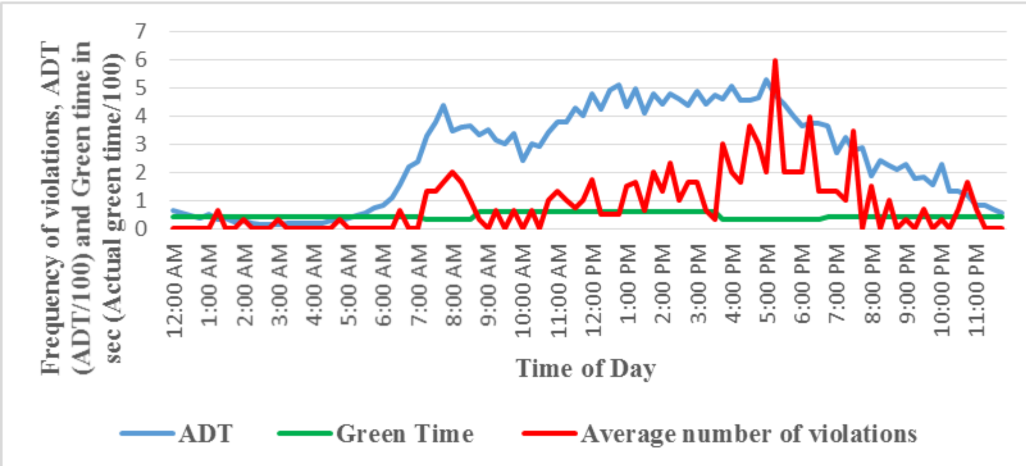

Figure B55: Frequency of red light violations, ADT, and green time sequence throughout a day for C Street and Benson Blvd.

A similar rate of total RLR violations and similar characteristics were observed for the Spenard Road and Benson Blvd. and the Boniface and Mountain View Drive intersections. Traffic volume at these intersections is less than at the other intersections. Violations were recorded throughout the day even with a higher green time interval (Figure B56). A considerable rate of RLR violations was observed in the morning and evening peak period of traffic. However, traffic volume in the morning peak period is higher than traffic volume during the evening peak period. Although traffic volume decreases during the late afternoon period, RLR violations occurred at an appreciable rate.

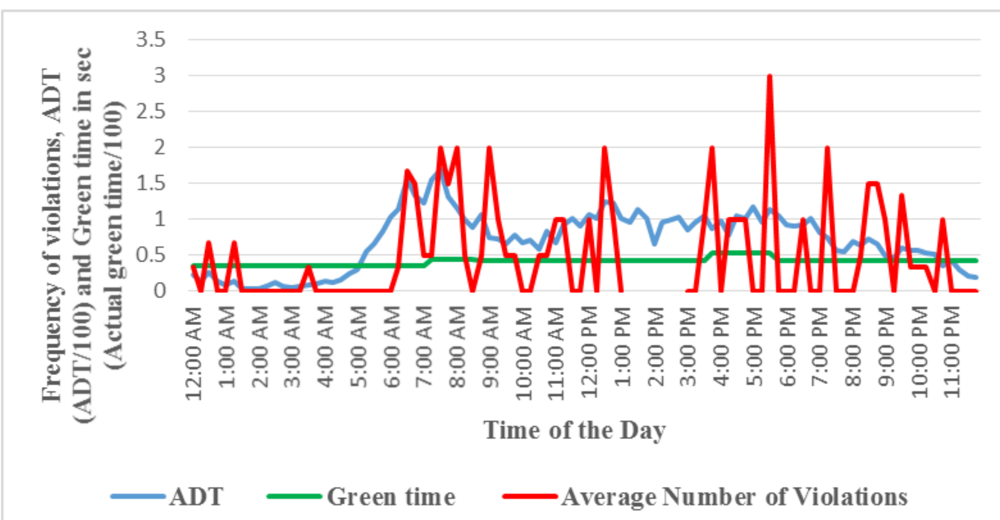

Figure B56: Frequency of red light violations, ADT, and green time sequence throughout a day for Boniface and Mountain View Drive.

2. Comparative analysis of red light violations based on pavement surface conditions

The criteria described earlier for measuring RLR violations were taken into consideration for each intersection based on diverse pavement conditions. As mentioned, we found that C Street and 6th Avenue was the most vulnerable intersection, registering the most frequent rate of RLR violations (Figure B57). A significant rate of RLR violations, about 60 per 1000 entering vehicles, was recorded during wet pavement conditions at C Street and 6th Avenue; in icy and snowy pavement conditions, 15 and 10 RLR violations, respectively, per 1000 entering vehicles were recorded. Violations in icy conditions were at maximum rates for three of the intersections: 15th Avenue and Ingra Street, Spenard Road and Benson Boulevard, and Boniface Parkway and Mountain View Drive. Higher rates of RLR violations were recorded at C Street and Benson Boulevard during wet conditions. At Northern Lights and UAA, maximum rates of RLR violations were recorded under snowy conditions. A smaller rate of RLR violations under dry conditions was recorded for each of the intersections.

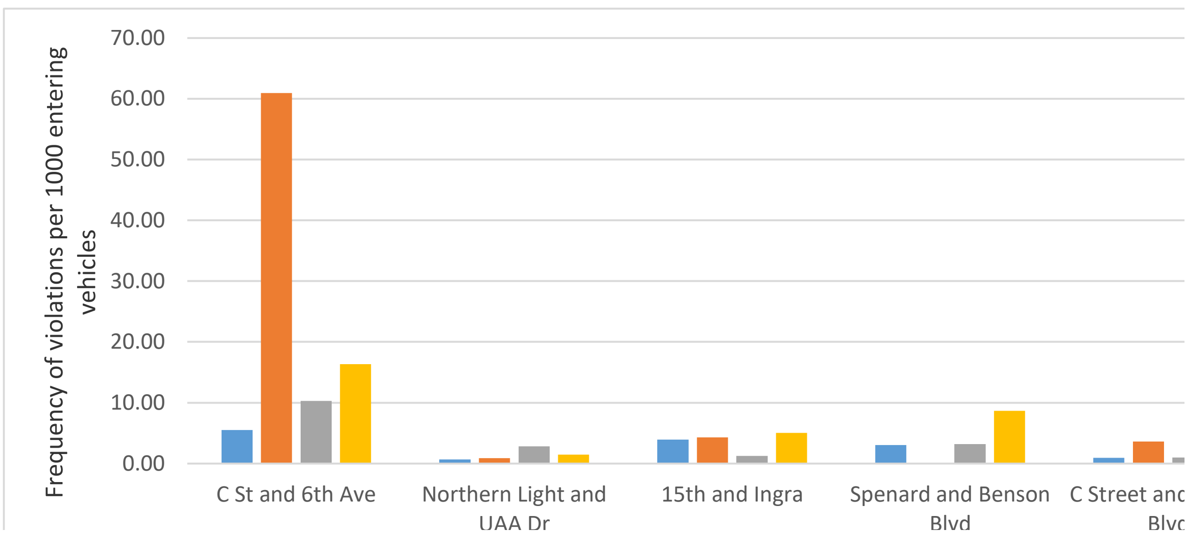

Figure B57: Total number of red light violations per 1000 entering vehicles based on different pavement conditions for studied intersections.

As expected, the rate of through-movement RLR violations was far greater at C Street and 6th Avenue in all pavement surface conditions, than at the other intersections (Figure B58). The highest rate of wet condition through violations was recorded at C Street and 6th Avenue and C Street and Benson Boulevard, while icy condition through violations dominated at 15th Avenue and Ingra Street and Spenard Road and Benson Boulevard. Snowy and icy through-movement RLR violations were considerable, around 10 to 15 recorded, at C Street and 6th Avenue. Snowy condition through violations dominated at Northern Lights and UAA Drive. A small rate of through violations in dry pavement conditions was observed at all intersections. Higher rates of through violations in all pavement conditions were recorded at C Street and 6th Avenue, without considering the limited sight distance, which may be responsible. In summary, through-movement violations increase significantly in wet and icy conditions compared with dry and snowy pavement conditions. These violations could be due to drivers' tendency to avoid skidding, particularly on wet and icy pavement.

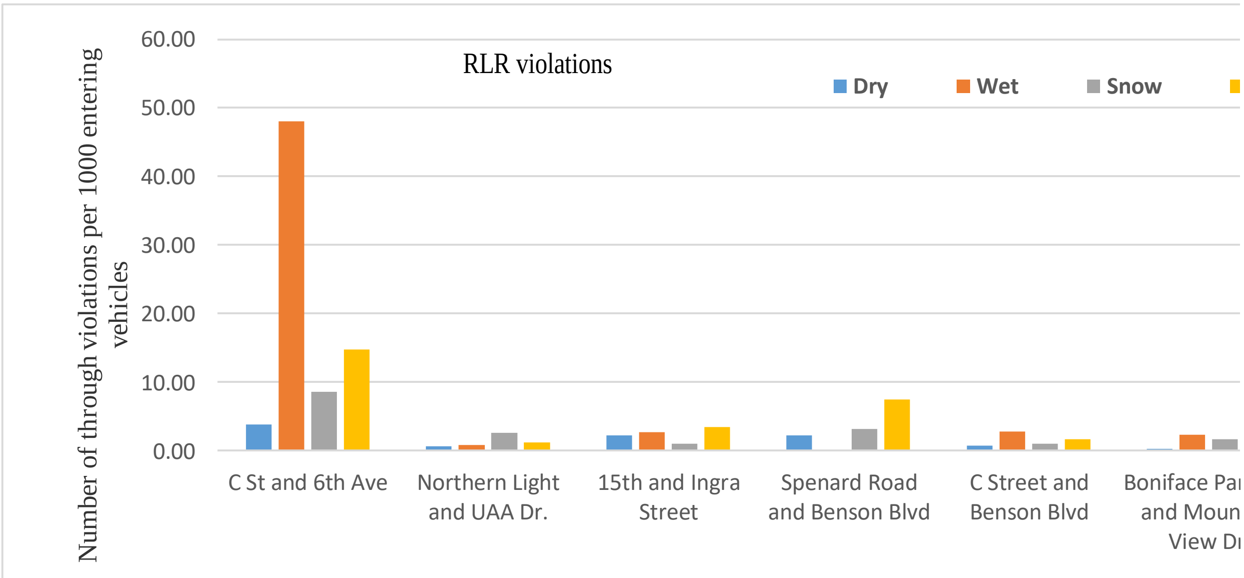

Figure B58: Total number of through red light violations per 1000 entering vehicles based on different pavement conditions.

Boniface and Mountain View Drive did not have the right turning criteria for the movement to consider in the analysis, thus it was not included in Figure B59. No left turning RLR violations were observed for any of the intersections studied, signifying drivers' alertness while turning left at an intersection. The highest rate of right turning RLR violations, around 13 and 2, was observed on wet and snow pavement, respectively, at C Street and 6th Avenue. The lowest rate of right turning violations was observed at the Northern Light and UAA Drive intersection. For right turning, wet conditions at C Street and Benson Boulevard recorded the highest rate of RLR violations. A considerable rate of RLR violations in icy conditions was observed at C Street and 6th Avenue, at 15th and Ingra Street, and at Spenard and Benson Blvd. About 2 right turning RLR violations in dry pavement conditions were identified at 15th Avenue and Ingra Street and at C Street and 6th Avenue, which otherwise recorded a lower rate compared with the other intersections. Excluding the Northern Lights Boulevard and UAA Drive intersection, wet and icy pavement conditions dominated in recordings of right turning RLR violations for all intersections studied.

Figure B60 shows RLR violation severity levels of less than 1 second. Wet condition RLR violations of about 50 and 3 were observed for C Street and 6th Avenue and for C Street and Benson Blvd., respectively. Dry condition violation rates, more so than with other pavement surface conditions, were highest at Boniface Parkway and Mountain View Drive. The considerable rate of violation of less than 1 second was recorded for icy pavement conditions especially at the intersections of C Street and 6th Avenue, 15th Avenue and Ingra Street, and Spenard Road and Benson Boulevard. Overall, wet condition RLR violations dominated at the C Street and 6th Avenue intersection. Icy condition RLR violations were dominant at 15th Avenue and Ingra Street and Spenard and Benson Blvd. intersections. In addition, snowy conditions were found specifically influential in RLR violations at Northern Lights and UAA Drive. Overall, RLR violations of less than 1 second are recorded more in wet and icy pavement conditions.

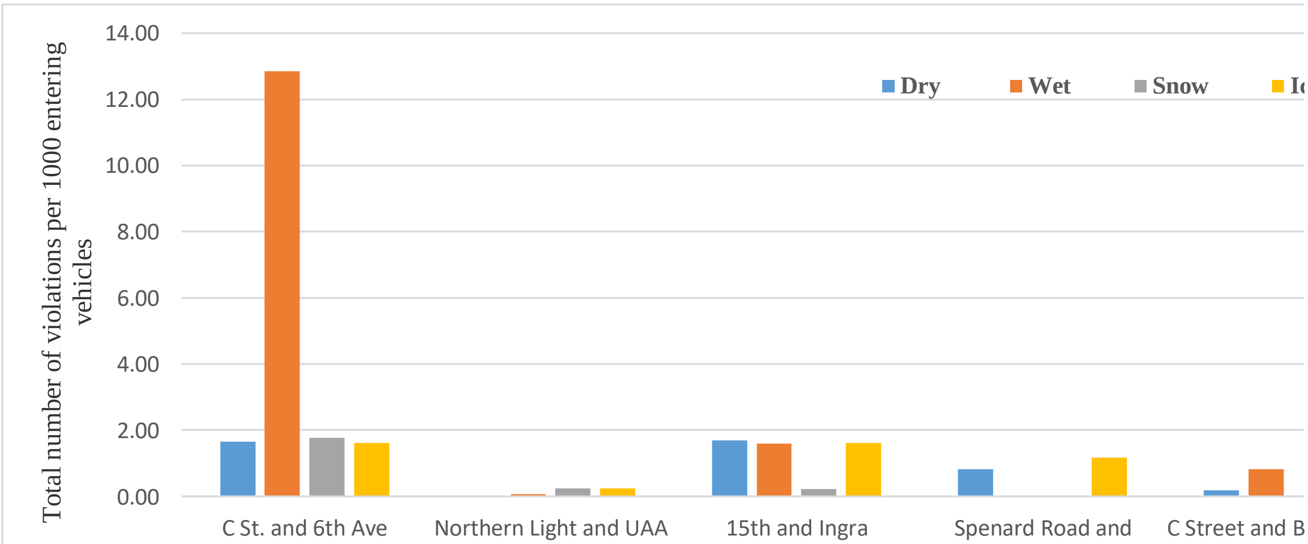

Figure B59: Total number of right turning red light violations per 1000 entering vehicles based on different pavement conditions.

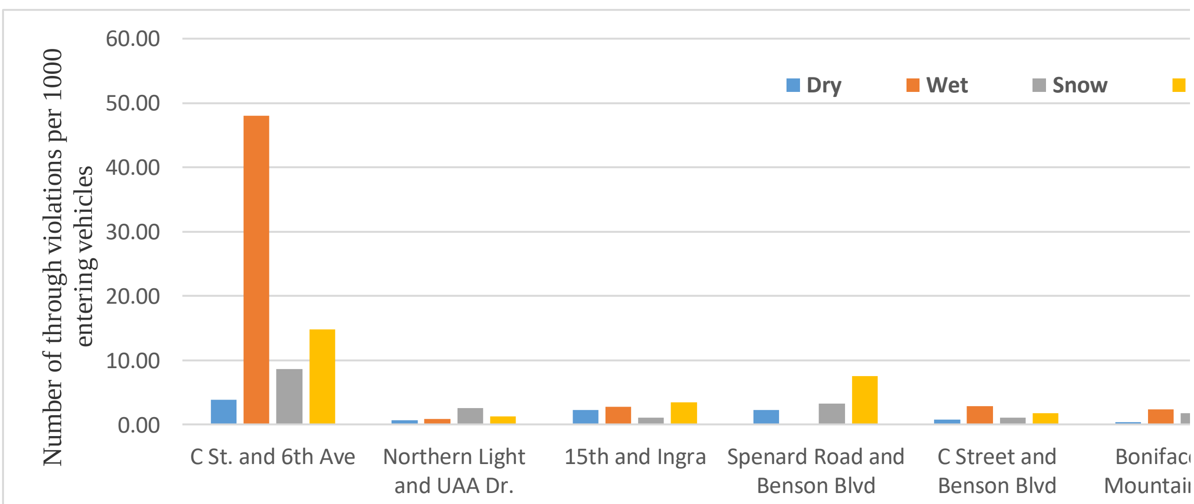

Figure B60: Total number of less than 1-second severity-based red light violations for different pavement conditions.

A RLR severity level of 1–2 seconds occurred in conditions of wet pavement at the C Street and 6th Avenue intersection. About 7 RLR violations were recorded per 1000 entering vehicles (Figure B61). Snowy pavement condition RLR violations at this particular intersection were comparable to wet condition RLR violations: about 5. We found that wet and icy conditions were crucial pavement surface conditions in the 1–2-second RLR severity level at 15th Avenue and Ingra Street as well as at C Street and Benson Boulevard. This type of RLR severity was common in wet and icy pavement conditions, as shown in Figure B61. Considerable snow condition violations were recorded at Northern Lights and UAA Drive, Spenard Road and Benson Boulevard, and Boniface and Mountain View Drive. Moreover, in icy conditions, higher rates of RLR violations were recorded at Boniface and Mountain View Drive. Limited RLR violations of this severity in dry pavement conditions were seen at a couple of the intersections studied.

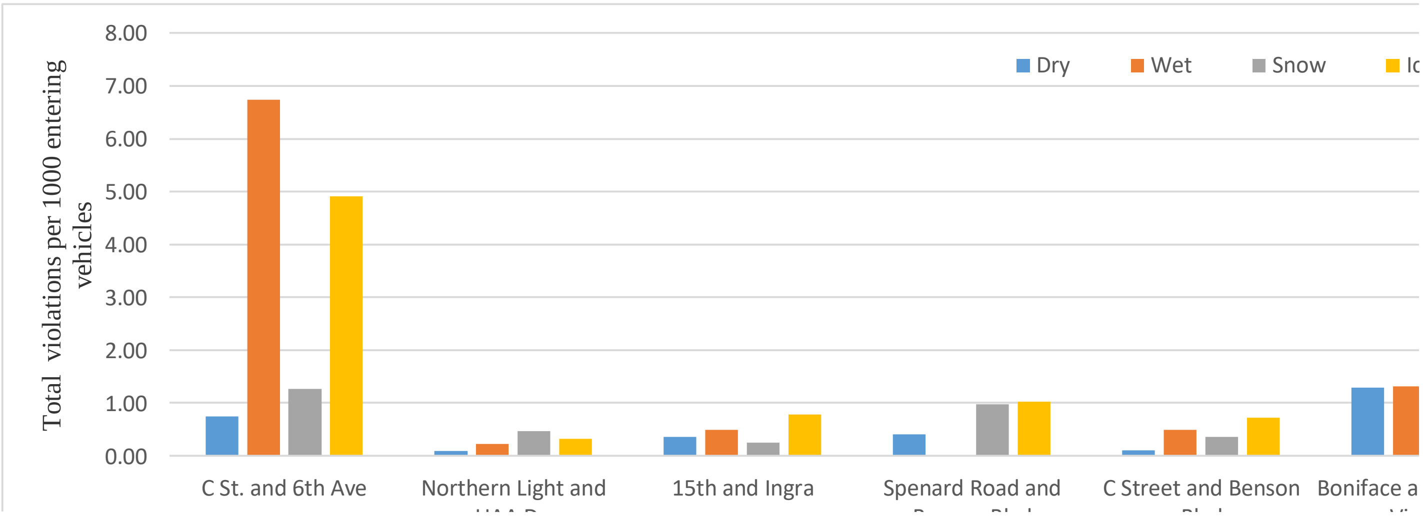

Figure B61: Total number of 1–2-second severity-based red light violations for different pavement conditions.

While a 1- to 2-second severity level is considered serious and might lead to a crash, 2- to 3-second RLR violations are more severe in this regard (Figure B62). The maximum rate of RLR violations at this severity level (3-second) was recorded at C Street and 6th Avenue. Some influential characteristics of snowy pavement were also identified, registering 2- to 3-second violations, particularly at Spenard Road and Benson Boulevard and at Boniface Parkway and Mountain View Drive. Moreover, a predominant rate of dry condition RLR violations at this severity level was observed at 15th Avenue and Ingra Street. Significant rates of 2- to 3-second RLR violations were recorded during wet, icy, and snowy pavement conditions.

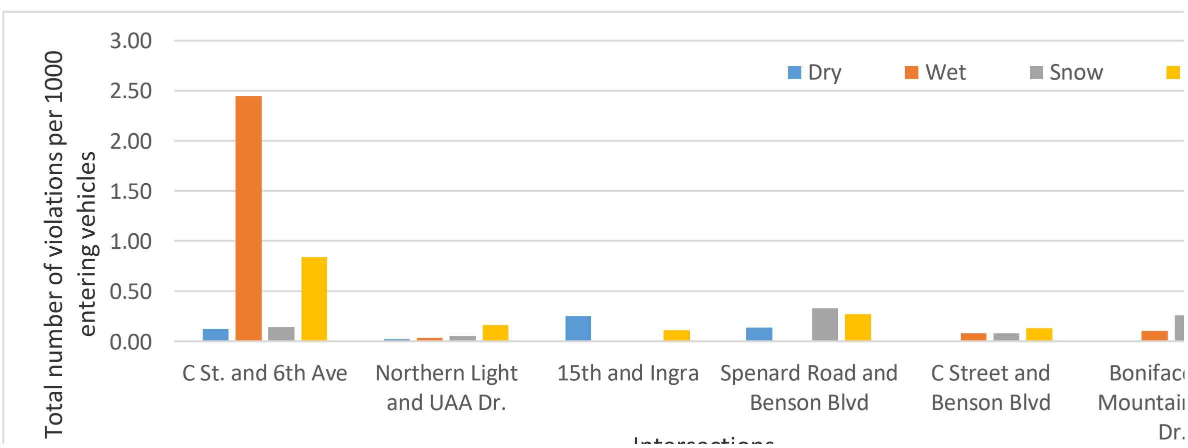

Figure B62: Total number of 2–3-second severity-based red light violations for different pavement conditions.

Only a few RLR violations of greater than 3 seconds were recorded (Figure B63). The intersection of C Street and 6th Avenue had the highest number at this severity level under wet pavement conditions, followed by 15th Avenue and Ingra Street. Wet and icy pavement seemed more influential in RLR violations of greater than 3 seconds at the intersections of C Street and Benson Boulevard and Boniface Parkway and Mountain View Drive. Several violations at this level in snowy and icy conditions were recorded at Spenard Road and Benson Boulevard. This level of severity was recorded less at Northern Lights and UAA Drive.

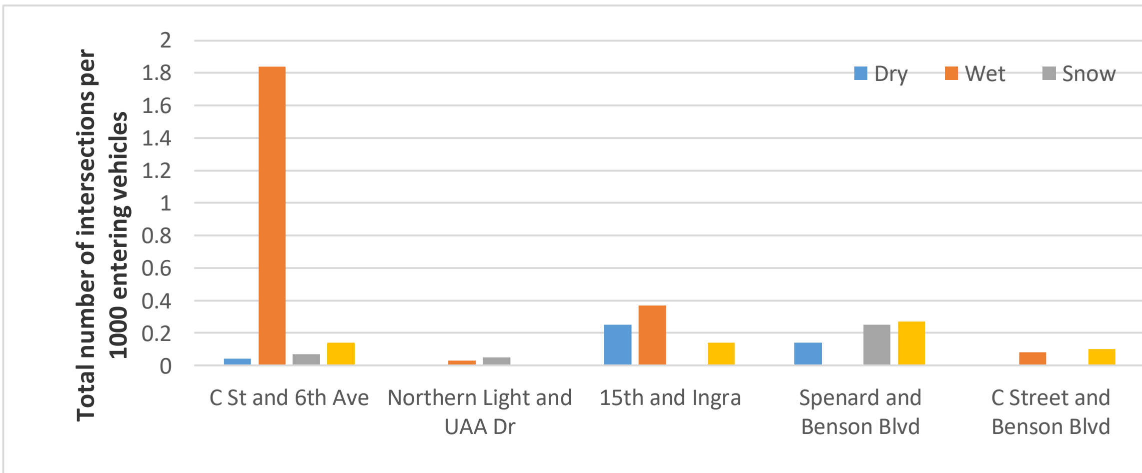

Figure B63: Total number of greater than 3-second severity-based red light violations for different pavement conditions.

Phasing

The average green time interval and the average of RLR violations for each pavement surface condition were taken into account. Red light running violations followed the pattern of traffic volume up to the end of the peak afternoon traffic period for dry pavement conditions (Figure B64). As ADT was too low after midnight, few RLR violations were recorded for dry pavement conditions. The ADT started picking up in early morning (6:00 a.m.), with green time interval increased (6:45 a.m.) to about 50 seconds until 3:30 p.m. Red light running violations increased during the morning peak traffic flow, followed by fluctuations until the afternoon peak. Though green time interval increased during the morning peak period, spikes of RLR violations were observed. A decrease of green time interval was observed from evening to late evening, with more spikes of RLR violations even after the traffic volume started to decline around 5:00 p.m. Higher rates of violations were observed even with an increase of the green time interval. Red light running violations are more related to traffic volume than to green time interval. This phenomenon is associated with the rushing behavior of travelers particularly in the afternoon period.

Figures B65 and B66 represent the frequency of average red light violations, ADT, and green time throughout a day for wet and snowy pavement conditions. Spikes of RLR violation are more noticeable in the afternoon period compared to dry pavement condition of Figure B64. In the case of wet and snowy conditions, traffic volume has less of an effect on RLR violation, which supports what was previously mentioned, that RLR is more associated with a driver trying to avoid slippery roadways and skidding in wet, snowy, and icy conditions. Awareness among drivers is required while heading towards an intersection at relatively high speed, especially on wet pavement, as most drivers do not consider wet pavement hazardous compared with snowy and icy pavement. Effective countermeasures for limiting RLR violations in the afternoon and late afternoon period are required for snowy pavement conditions. In addition, driver awareness a distance away from the intersection as the amber period changes to red can limit low-level as well as high-level severity of RLR violations.

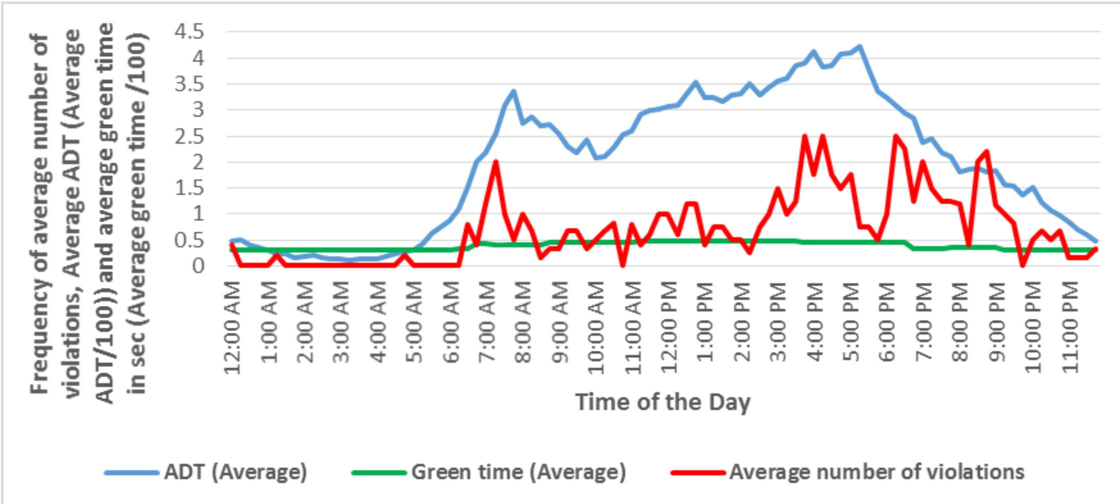

Figure B64: Frequency of average red light violations, ADT, and green time throughout a day for dry pavement conditions.

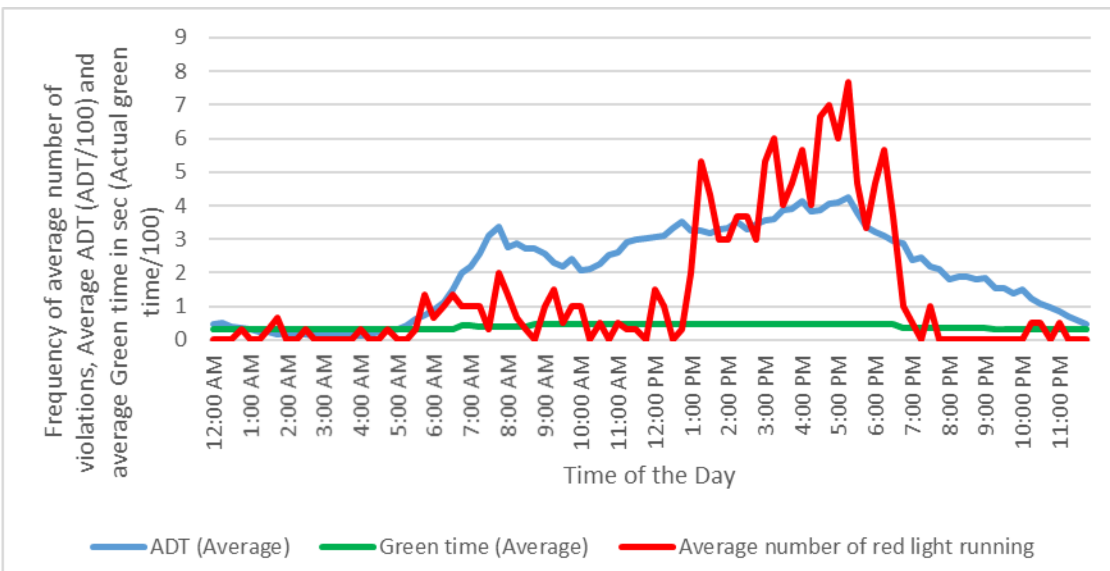

Figure B65: Frequency of average red light violations, ADT, and green time throughout a day for wet pavement conditions.

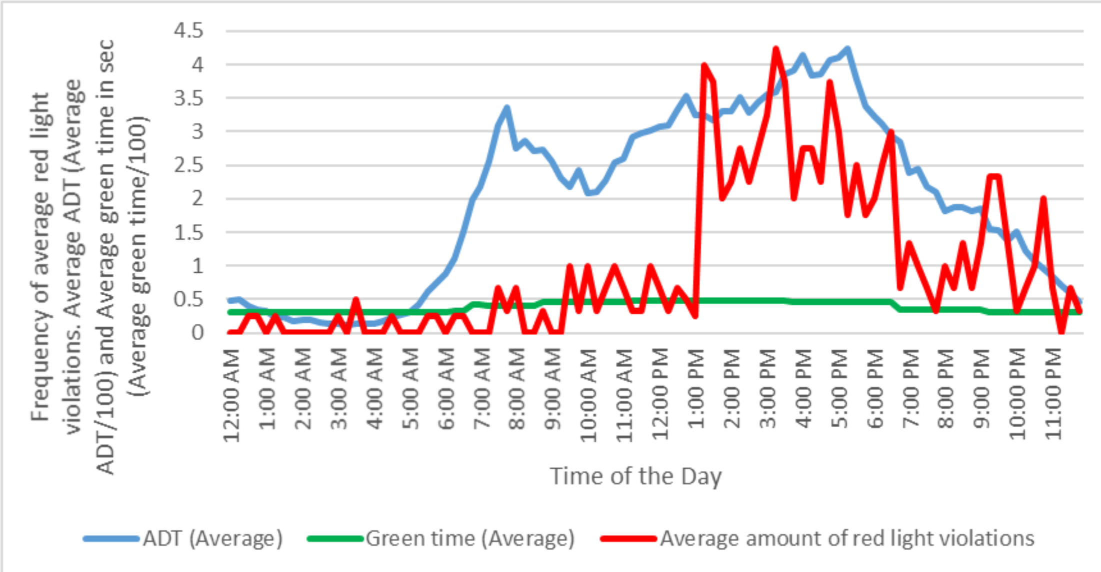

Figure B66: Frequency of average red light violations, ADT, and green time throughout a day for snow pavement conditions.

We noticed further fluctuation in RLR violations with respect to changes in ADT for icy pavement conditions (Figure B67). Higher rates of RLR violations were recorded after midnight, when traffic counts were low. This observation supports the previous statement concerning drivers' avoidance of skidding into the intersection when a yellow light is changing to red or is just red. Drivers tend to drive at higher speeds during off-peak hours and eventually have limited ability to stop under icy conditions as the signal turns red. Figure B68 shows a comparative analysis of RLR violations versus the four pavement surface conditions.

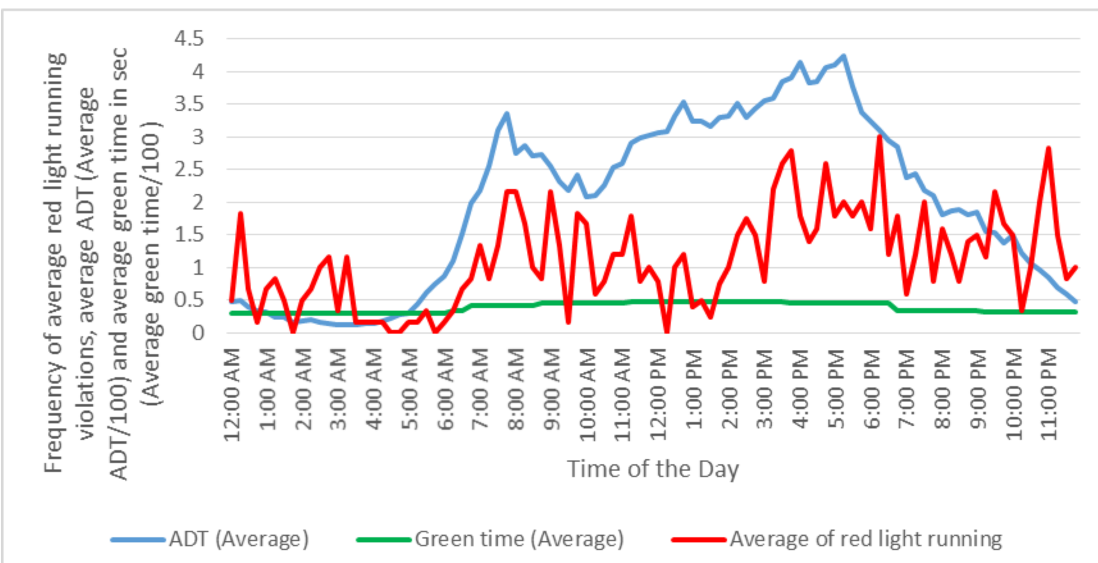

Figure B67: Frequency of average red light violations, ADT, and green time throughout a day for icy pavement conditions.

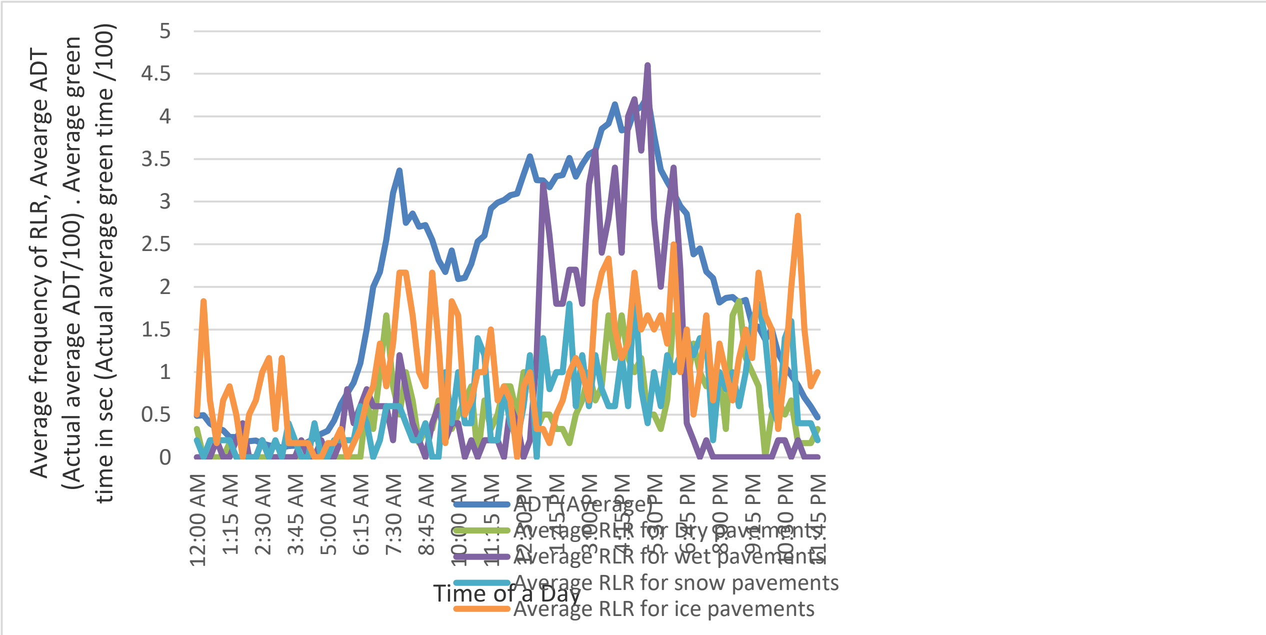

Figure B68: Frequency of average red light violations, ADT, and green time throughout a day for the four pavement conditions.

Analyzing Countermeasures for RLR in Anchorage

Significant rates of RLR violations were recorded in the studied six intersections of Anchorage. Pavement conditions were found to be a contributing factor for RLR violations in the intersections. Traffic volume was a factor in the rate of RLR violation, but not the sole factor. Effective countermeasures are required for limiting RLR violations and increasing safety at the intersections. Several countermeasures to reduce RLR violations/behavior in Anchorage were taken into consideration based on the literature review conducted as part of this project. Countermeasures used and might be applicable to this project to reduce RLR can be summarized as follows:

- Red light camera enforcement
- Green extension period
- Green signal countdown device
- Increased visibility of signal
- Increased yellow interval duration
- Use of flashing green
- Use of a flashing yellow
- Pavement markings
- Adding advance warning signs
- ITS solution like confirmation light

A red light camera is an effective countermeasure for reducing RLR in certain states of the U.S., although significant drawbacks are identified in the literature. Though red light cameras are an effective countermeasure, their use is not a sustainable countermeasure for Alaska, which has no state law or programs involving the use of red light or speed cameras.

Public opinion among drivers tends to be conservative when disclosing self on a red light camera at an intersection. Many states are in the process of eliminating red light cameras or have already done so, such as California. Moreover, installing red light cameras would be an expensive measure for a state like Alaska. Red light cameras have not proven 100% efficient, and an objectionable outcome can result. Thus, red light cameras are not a feasible option for reducing RLR violations in Anchorage. This countermeasure could be an option for high crash rate intersections pending legislative approval.

The extension of the green time interval also proved questionable as a countermeasure. In some intersections, particularly during the morning off-peak period, green time extension with declining traffic volume was combined with significant increase in violations. Under wet and icy conditions, the key factor in RLR violations is drivers' avoidance of skidding on roadways; thus, extension of green will not be an effective countermeasure.

The green signal countdown device proved effective in the first few months of implementation, but effectiveness fades as time progresses. People grow accustomed to the countdown green interval with time, and RLR violations rise again. In addition, RLR violations were occurring after termination of the yellow interval. Alaska is a "permissive yellow" state (Article 13 AAC 02.010, Traffic-Control Signal Legend). In the NCHRP Report 731, Guidelines for Timing Yellow and All-Red Intervals at Signalized Intersections (McGee et al., 2011), drivers may enter the intersection during the entire duration of the yellow change interval and legally can be in the intersection while the red signal indication is displayed, so long as entrance to the intersection occurred before or during the yellow signal indication. Thus, the green countdown can be effective, but drivers will tend to use all the green interval into the yellow interval to enter the intersection. This countermeasure may not be an effective solution for Alaska.

Visibility is an important criterion in crossing an intersection effectively. Increased visibility of the yellow LEDs (signal-head) and signal back plate proved effective in some cases at reducing RLR violations. Based on data collected, visibility is not the cause of RLR violations at the intersections we studied in Anchorage; five of the six intersections had no issues in this regard. In addition, DOT&PF utilized the signal back plates on many interactions in Anchorage.

Increasing the yellow interval duration proved an effective option in limiting RLR violations. We found that rates of less than 1-second RLR violations at the intersections studied were significant. Increasing the yellow period for 1 or 2 seconds may reduce RLR violations effectively. Extension of yellow/red by 1 and 2 seconds may theatrically result in a 78% and 95% reduction based on the data collected in this project, respectively, in RLR violation on average for the through movement, but might not be effective over time. Some studies show that as drivers grow accustomed to the extended yellow period, they use more of it to enter the intersection. This countermeasure can be applicable only at locations where RLR is observed through studies or crash history. Table B2 shows the periods of yellow and all red at the study intersections.

Table B2: Overview of yellow and all red for study intersections.

Intersections	Yellow Period (Sec)	All Red (Sec)
C Street & 6th Avenue	3.2	1.8
Northern Lights & UAA Drive	3	3.5
15th Avenue & Ingra Street	4.3	1.4
Spenard & Benson Blvd.	4	1.7
C Street & Benson Blvd.	4	1.5
Boniface & Mountain View Drive	4.4	1.5

In Alaska, right turning is permissible for vehicles during all red periods if there is no opposing traffic. Thus, countermeasures should be predominately effective in reducing through-movement RLR. An increase in yellow/red interval of 1 second at all study intersections might theoretically reduce RLR violations significantly (see Figure B69). A reduction of 70% or more in through-movement RLR violation might be achieved at the studied intersections. More than an 80% reduction would result at C Street and 6th Avenue and 15th Avenue and Ingra Street. Overall, more than 60% reduction in RLR violation was observed at each intersection except at 15th Avenue and Ingra Street, where the rate of reduction was close to 60%. As a result, an increase of 1 second in the yellow period would significantly reduce RLR violations at each of the intersections studied.

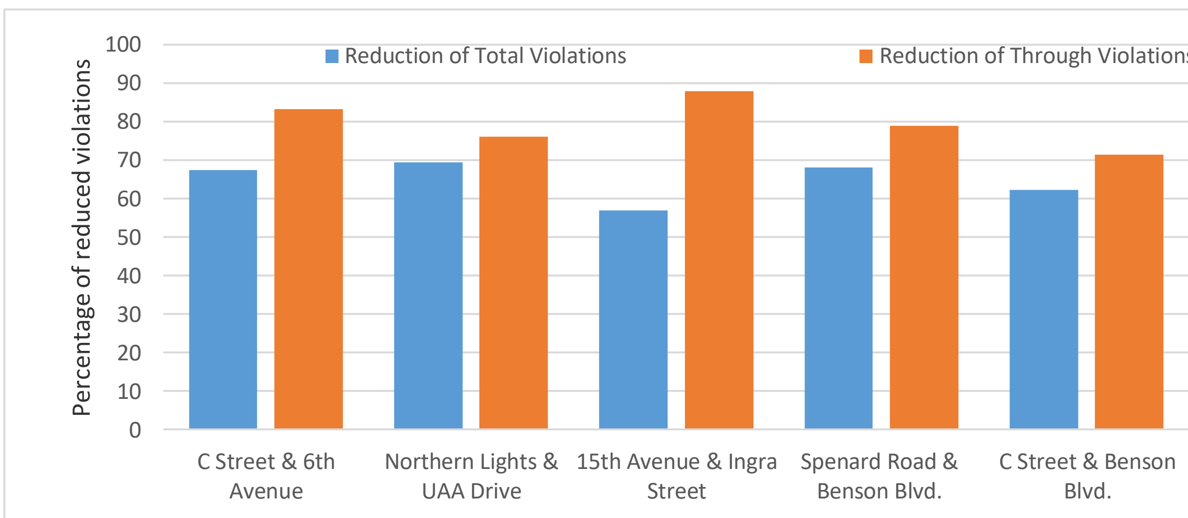

Figure B69: Percentage of violations reduced at all study intersections

Considering all the pavement conditions, a reduction in RLR violations of 60% or more will occur if the yellow period increase of 1 second is implemented (Figure B70). In wet conditions, a 90% reduction in through-movement RLR would result, which confirms our finding of driver avoidance behavior to skidding at intersections. Red light running violations on icy pavement, which are more critical than on wet pavement, will be reduced by about 70%. More than 70% of through-movement RLR violation would be observed in dry and snowy pavement conditions.

Though RLR violations would be significantly reduced by extending the yellow period by 1 second, a few violations would still occur, which could cause dangerous intersection crashes (Figure B71). Thus, initiating a 2-second increase in the yellow period may result in greater reduction of RLR violations. All intersections will experience more than 93% reduction in through RLR violations if the yellow period extension of 2 seconds is observed. The C Street and 6th Avenue intersection, where we found that more RLR violations occur, may see a 97% reduction in through RLR violations and overall violations. At Boniface and Mountain View Drive, where the highest number of through-movement RLR violations occurs, the new implementation could result in a 98% reduction of RLR violations. Moreover, C Street and Benson Blvd. and 15th Avenue and Ingra Street will experience 96% and 97%, respectively, through-movement RLR violation reduction. At 15th Avenue and Ingra Street, a 97% reduction of through RLR violations would occur.

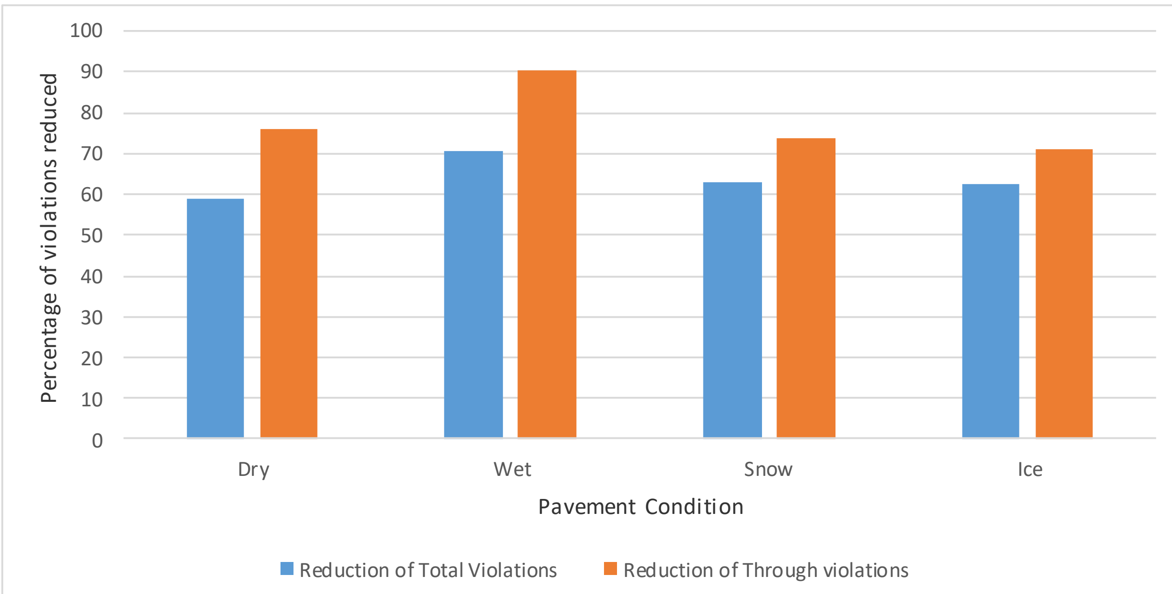

Figure B70: Percentage of violations reduced in all pavement conditions.

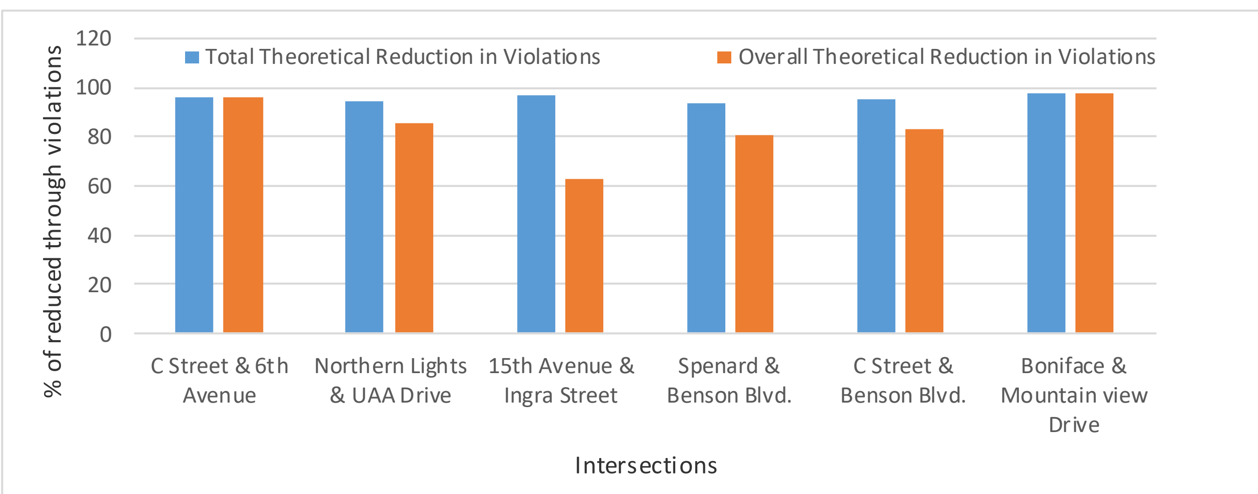

Figure B71: Percentage of through violations reduced at all the study intersections.

A more interesting outcome emerged in the analysis of RLR reduction in each of the pavement conditions, as shown in Figure B72. A 92% reduction in through-movement RLR violations would occur in dry pavement conditions, and a 96% reduction in through-movement RLR would occur in wet, snowy, and icy conditions. More than 80% reduction of RLR would be observed for wet, snowy, and icy conditions. The forced conditions (wet and icy) we discussed earlier, in which significant RLR violations occur, would be reduced to 95% confidence intervals, as data suggests, but RLR violations would still occur in normal, dry conditions, as statistics point out the lowest reduction of overall RLR. Red light running in dry conditions suggests that people intentionally violate the red light at the intersections. Thus, driver awareness is required to avoid the RLR violator and violent crashes at intersections in Anchorage.

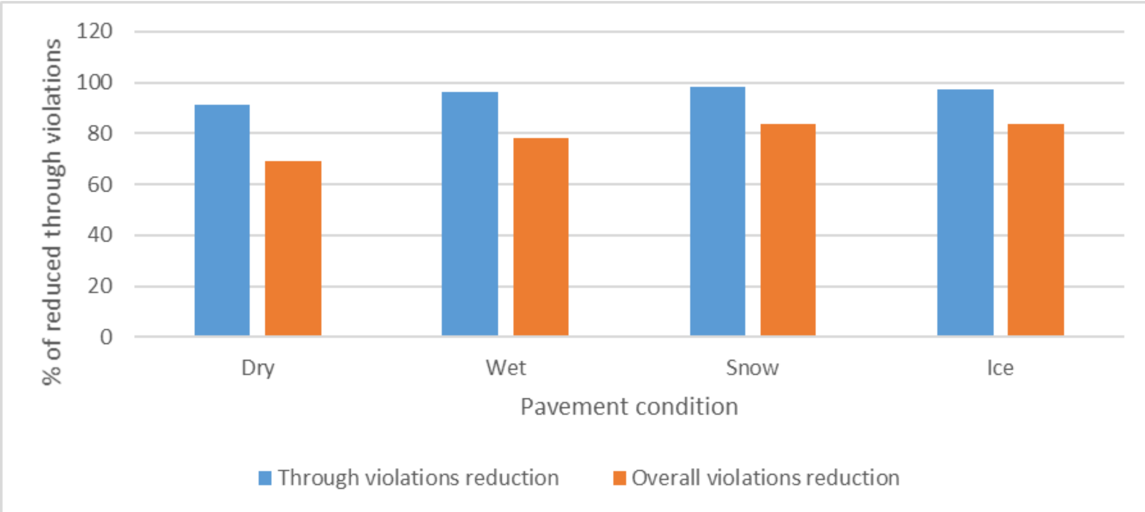

Figure B72: Percentage of through violations reduced at all pavement conditions.

An extension of the yellow period by 2 seconds may reduce RLR violations significantly, but as time passes, drivers will become accustomed to the extension and start running the red light again. This outcome was observed in different states. Other countermeasures can be considered per the discussion outlined in chapter two of this report.

The use of flashing green proved to be effective countermeasure for RLR. This mostly used in Europe and Asia with no supporting literature of the effectiveness in the United States. In addition, it requires provisional backup from in the local codes like MUTCD and ITE.

Using the flashing yellow for the through movement might create issues for drivers who confuse the concept of flashing yellow arrow for left turn signals, already in place, and the above-mentioned flashing yellow signal for through movements. Since the suggested approach of using the flashing yellow for the through movement is only for hotspots or high RLR violation intersections, it might be a good practice to test such countermeasures before full implementation.

Pavement markings in the dilemma zone warning drivers of signal "SIGNAL AHEAD" is an effective tool to reduce RLR but the condition of snow cover in the winter time might hinder the use of this countermeasure.

The use of advance warning signs proved to be effective in reducing RLR violations and crashes. Several techniques are used with advance warning signs resulting in about 27-67 percent reduction in RLR. Some of these techniques are addressed in the literature review (Appendix A). Some of these techniques include “Signal Ahead sign”, “Be Prepared to Stop When Flashing assembly” (MUTCD 2009), Advance Warning for End of Green System (AWEGS),

The use the ITS technique of a blue confirmation light or simply a confirmation light might be the better countermeasure. This system gives an indication to law enforcement when a RLR violation is in effect (a driver is in violation of the red light). It is worth to note such a system are in place in some intersection in Anchorage but needs activation to measure its effectiveness. Other ITS countermeasures such vehicle detection for traffic signal programing are considered effective but adaptability and cost might hinder the use of such countermeasure.

Analysis of RLR crashes in Anchorage

Crashes related to RLR was analyzed for the available crash data of 2008-14 and 2015-16. Table B3 represents the hierarchy of intersections based on recorded RLR crash severity per 1000 and per million entering vehicles. C Street and 6th Avenue experience the most RLR crashes for property damage only (PDO) and incapacitating injury crashes while Northern Lights Boulevard and UAA Drive intersection led in the non-Incapacitating injury crashes. Please note the intersection at Northern Lights Boulevard and UAA Drive was rehabilitated in 2014 and the RLR crash rates drastically reduced based on the 2015-16 crash data and it is reflected in the rates address in table B5.

For comparative analysis Table B4 and B5 gives the overall summary of the hierarchy of intersections based on RLR violations per 1000 and per million entering vehicles.

Case studies of red-light running in localities in the United Sates are shown in Table B6. The tables addressed rates of RLR per 1000 and million entering vehicles as well as the recorded crashes. Results shows higher rates of RLR for Anchorage compared to these locations with the exception of Milwaukee, Wisconsin experiencing very few violations. For violations per 100 entering vehicles in the Iowa study found an average of 5.03 RLR violations per 1000 entering vehicles and the data shows Anchorage has an average of 5.90, slightly higher than the Iowa rate. Per Phase I of this project the rates in Anchorage was way less as the study was limited to summer time. Looking at violations in Sacramento, California, this study shows less overall average with 4.2 compared to Anchorage’s 5.90 average. With the exception of Anchorage other studies didn’t report daily changes in RLR. Note that the RLR behavior we observed differs from RLR behavior observed in other states, where this violation mostly occurs during peak hours. RLR behavior occurs during peak as well as off-peak hours with fewer violation during the night hours while in Anchorage most of the RLR violations are in the afternoon hours and later at night. Though in Anchorage violations are in alignment with traffic volume but later in the night violations needs further evaluation as the numbers are significantly higher compared with the national trend. Note in other states and in Anchorage, the majority of RLR violations occur within 1 second of the red light interval.

Table B-3: Hierarchy of intersections based on recorded RLR severity crashes per 1000 and per million entering vehicles (2008-14)

Property damage only (**PDO**) crashes			
Rank	Intersection	Crashes per 1000 entering vehicle	Crashes per million entering vehicle
1	C street and Benson Blvd.	0.0028	2.799
2	Spenard and Benson Blvd	0.00213	2.127
3	Northern Lights and UAA drive	0.00197	1.967
4	C street and 6th Avenue	0.0012	1.221
5	15th and Ingra	0.00097	0.966
6	Boniface and Mount view drive	0.00034	0.338
Incapacitating injury crashes			
Rank	Intersection	Crashes per 1000 entering vehicle	Crashes per million entering vehicle
1	C street and Benson Blvd.	0.000079	0.08
2	Northern Lights and UAA drive	0.00006	0.058
3	C street and 6th Avenue	0.000034	0.034
4	15th and Ingra	0.000031	0.031
5	Boniface and Mount view drive	0	0
6	Spenard and Benson Blvd	0	0
Non-Incapacitating injury crashes			
Rank	Intersection	Crashes per 1000 entering vehicle	Crashes per million entering vehicle
1	Northern Lights and UAA drive	0.00101	1.0052
2	C street and Benson Blvd.	0.00097	0.973
3	C street and 6th Avenue	0.00077	0.774
4	Spenard and Benson Blvd	0.00069	0.694
5	15th and Ingra	0.00054	0.537
6	Boniface and Mount view drive	0.00016	0.158
Fatal crashes			
Rank	Intersection	Crashes per 1000 entering vehicle	Crashes per million entering vehicle
1	15th and Ingra	0.000015	0.0153
2	Spenard and Benson Blvd	0	0
3	C street and Benson Blvd.	0	0
4	C street and 6th Avenue	0	0
5	Northern Lights and UAA drive	0	0
6	Boniface and Mount view drive	0	0
Overall crashes			
Rank	Intersection	Crashes per 1000 entering vehicle	Crashes per million entering vehicle
1	C street and Benson Blvd.	0.0039	3.892
2	Northern Lights and UAA drive	0.0029	2.894
3	Spenard and Benson Blvd	0.0028	2.821
4	C street and 6th Avenue	0.0020	2.03
5	15th and Ingra	0.0016	1.55
6	Boniface and Mount view drive	0.00049	0.5

Table B-4: Hierarchy of intersections based on recorded RLR severity crashes per 1000 and per million entering vehicles (2015-16)

Property damage only (**PDO**) crashes			
Rank	Intersection	Crashes per 1000 entering vehicle	Crashes per million entering vehicle
1	C street and Benson Blvd.	0.00211	2.114
2	15th and Ingra	0.00175	1.75
3	Spenard and Benson Blvd.	0.00125	1.25
4	C street and 6th Avenue	0.00103	1.032
5	Northern Lights and UAA	0.00995	0.995
6	Boniface and Mount view drive	0.00020	0.203
Incapacitating injury crashes			
Rank	Intersection	Crashes per 1000 entering vehicle	Crashes per million entering vehicle
1	C street and 6th Avenue	0.00021	0.21
2	Spenard and Benson Blvd.	0	0
3	C street and Benson Blvd.	0	0
4	15th and Ingra	0	0
5	Northern Lights and UAA	0	0
6	Boniface and Mount view drive	0	0
Non-Incapacitating injury crashes			
Rank	Intersection	Crashes per 1000 entering vehicle	Crashes per million entering vehicle
1	Spenard and Benson Blvd.	0.00111	1.11
2	C street and 6th Avenue	0.00093	0.929
3	Northern Lights and UAA	0.00069	0.688
4	C street and Benson Blvd.	0.00059	0.596
5	15th and Ingra	0.00046	0.459
6	Boniface and Mount view drive	0.00014	0.135
Fatal crashes			
Rank	Intersection	Crashes per 1000 entering vehicle	Crashes per million entering vehicle
1	15th and Ingra	0	0
2	Spenard and Benson Blvd	0	0
3	C street and Benson Blvd.	0	0
4	C street and 6th Avenue	0	0
5	Northern Lights and UAA drive	0	0
6	Boniface and Mount view drive	0	0
Overall crashes			
Rank	Intersection	Crashes per 1000 entering vehicle	Crashes per million entering vehicle
1	C street and Benson Blvd.	0.00274	2.74
2	Spenard and Benson Blvd.	0.00236	2.36
3	15th and Ingra	0.00221	2.21
4	C street and 6th Avenue	0.00196	1.96
5	Northern Lights and UAA	0.0017	1.683
6	Boniface and Mount view drive	0.0004	0.36

Table B5: Hierarchy of intersections based on RLR violations per 1000 and per million entering vehicles

Rank	Intersection	Average RLR Violations per 1000 entering vehicles	Average RLR Violations per one million entering vehicles
1	C street and 6th Avenue	14.1	14097
2	Boniface and Mount view drive	6.99	6994
3	15th and Ingra	5.4	5362
4	Spenard and Benson Blvd	4.41	4406
5	C street and Benson Blvd.	3.2	3153
6	Northern Lights and UAA drive	1.3	1290

Table B6: Comparative analysis of RLR and crash rates with other localities in the United Sates.

State	City	RLR violations per 1000 entering vehicles	RLR violations per million entering vehicles	Recorded RLR crashes per 1000 entering vehicles	Recorded RLR crashes per million entering vehicles
Iowa		5.03	5026.2	X	X
Wisconsin	Milwaukee	4.0	4000	0.000427	0.43
California	Sacramento	4.2	4150	.000642	0.642
Alaska	Anchorage	5.9 **(2016-2017)**	5900 **(2016-2017)**	0.002281 **(2008-2014)**	2.2812 **(2008-2014)**
				0.0019 **(2015-16)**	1.886 **(2015-16)**

Red Light Running Enforcement

Table B7 addresses the detailed Hierarchy of intersections based on recorded RLR violations per hour by time of day. Law enforcement can use this information as a guide for enforcement. In addition, Table B8 provides the Hierarchy of intersections based on RLR recorded crashes per hour by time of day. Please note the research team recommends using the Hierarchy based on RLR violations for enforcement as a preventive measure for any potential crashes.

Table B7: Hierarchy of intersections based on recorded RLR violations per hour

Morning hours up to noon		
Rank	Intersection	RLR Violations per hour
1	15^{th} and Ingra	6.623
2	Spenard and Benson Blvd	5.6
3	C street and 6^{th} Avenue	4
4	C street and Benson Blvd.	3.2
5	Boniface and Mount view drive	2.24
6	Northern Lights and UAA drive	0.913
Evening hours up to 7:00 pm		
Rank	Intersection	RLR Violations per hour
1	C street and 6^{th} Avenue	13.8
2	C street and Benson Blvd.	5.7
3	15^{th} and Ingra	4.76
4	Spenard and Benson Blvd	4.6
5	Boniface and Mount view drive	2.75
6	Northern Lights and UAA drive	2.22
Late evening and night time		
Rank	Intersection	RLR Violations per hour
1	C street and 6^{th} Avenue	5.2
2	Spenard and Benson Blvd	4.5
3	Northern Lights and UAA drive	1.13
4	Boniface and Mount view drive	0.88
5	C street and Benson Blvd.	0.8
6	15^{th} and Ingra	0.75
Overall average per hour		
Rank	Intersection	Average RLR Violations per hour
1	C street and 6^{th} Avenue	7.7
2	Spenard and Benson Blvd	4.9
3	15^{th} and Ingra	4.04
4	C street and Benson Blvd.	3.23
5	Boniface and Mount view drive	1.96
6	Northern Lights and UAA drive	1.421

Table B8: Hierarchy of intersections based on recorded RLR crashes per year (2008-14)

Morning hours up to noon		
Rank	Intersection	Crashes per year
1	Northern Lights and UAA drive	10.33
2	C street and Benson Blvd.	6
3	C street and 6th Avenue	5.83
4	15th and Ingra	4
5	Spenard and Benson Blvd	3.7
6	Boniface and Mount view drive	1.83
Evening hours up to 7:00 pm		
Rank	Northern Lights and UAA drive	21
1	C street and Benson Blvd.	20.83
2	Spenard and Benson Blvd	12.83
3	15th and Ingra	9.5
4	C street and 6th Avenue	7.2
5	Boniface and Mount view drive	4.5
6	Northern Lights and UAA drive	21
Late evening and night time		
Rank	Intersection	Crashes per year
1	C street and 6th Avenue	6.7
2	C street and Benson Blvd.	5.83
3	Northern Lights and UAA drive	4.83
4	Spenard and Benson Blvd	3.83
5	15th and Ingra	3.2
6	Boniface and Mount view drive	1
Overall average crashes per year		
Rank	Intersection	Average Crashes per year
1	Northern Lights and UAA drive	36.2
2	C street and Benson Blvd.	32.66
3	Spenard and Benson Blvd	20.36
4	C street and 6th Avenue	19.73
5	15th and Ingra	16.7
6	Boniface and Mount view drive	7.33