DEVELOPMENT OF AN ACOUSTIC METHOD TO COLLECT STUDDED TIRE TRAFFIC DATA

FINAL PROJECT REPORT

by

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for

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16. Abstract

Travel during winter months remains particularly problematic in the Pacific Northwest due to the regular occurrence of inclement weather in the form of snow and ice during freezing and sub-freezing conditions. For travelers and commuters alike, vehicle traction in the form of studded tires serves to provide an added level of driving confidence when weather conditions deteriorate. However, recurring studded tire usage causes damage to the roadway infrastructure in the form of surface wear and rutting over time. Left unattended, this damage contributes to challenging and potentially dangerous driving conditions in the form of standing water and the increased potential for hydroplaning.

Currently, an efficient and automated method to collect site-specific studded tire traffic volumes is lacking. While studded tire usage can be locally estimated based on manual roadway traffic counts, parking lot counts, or household surveys, the lack of real-world traffic volumes prevents the fine-tuning of roadway deterioration models that measure performance and estimate infrastructure life. This project tested the use of off-the-shelf sound meters to determine if an acoustic method could be developed to measure studded tire volumes. Based on the results, a prediction model was developed to allow for data-driven solutions that will benefit local transportation officials, planners, and engineers responsible for managing highways and roadways.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
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EXECUTIVE SUMMARY

Vehicular travel during winter months is a concern in the Pacific Northwest due to the regular occurrence of snow and ice during freezing and sub-freezing conditions. For travelers and commuters alike, vehicle traction in the form of studded tires serves to provide an added level of driving confidence when such weather conditions are present. However, studded tire usage causes damage to the roadway infrastructure in the form of surface wear and rutting over time. This damage contributes to challenging and potentially dangerous driving conditions in the form of standing water and the increased potential for hydroplaning. While many drivers may not seem to be particularly concerned with the impacts associated with studded tire usage, transportation agencies recognize that the roadway damage caused by studded tires will accelerate the need for pavement surface maintenance or replacement. For this reason, there is an inherent benefit to accurately determine studded tire usage on highways or roadways. This information can help to support life cycle cost analysis and assign appropriate maintenance and roadway resurfacing timelines.

Current estimates for studded tire usage are typically based on parking lot counts or household surveys. The lack of real-world traffic volume data limits the precision of roadway deterioration models that measure roadway performance and estimate infrastructure life. As a response to this need, this study explored the use of off-the-shelf sound meters to serve as an effective way to collect studded tire volumes in the field.

Based on the study results, it was determined that while vehicles with studded tires generate a higher decibel reading when matched with comparable vehicles without studded tires, the decibel reading alone could not be relied upon to definitively determine whether or not a vehicle was using studded tires. Some pick-up trucks and semi-trucks generated similar decibel readings due to factors such as engine noise and tire-pavement interaction. There were also incidences when more than one vehicle passed the sound meter at the same time, or when multiple vehicles passed the sound meter in quick succession as a platoon. In these cases, isolating the sound generated by each individual vehicle was not always possible.

The use of video as a supporting medium allowed a predictive model to be developed. For this study, during targeted time windows, the sound meter collected data while a video simultaneously recorded activity at the study site. This pairing allowed the research team to identify the cause or causes whenever decibel readings changed. Using this logged data, a model was developed and applied to longer time periods when video was not recorded. The accuracy of the model was then compared with actual Idaho Transportation Department volume data.

Based on the results, the study outcomes yielded results that were similar to previously established methods (e.g., parking lot surveys to determine approximate studded tire vehicle percentages). The study concluded that the use of off-the-shelf sound meters alone was not sufficient to definitively collect volume data. However, the insights from this study will support future research efforts that provide new data-driven solutions for local transportation officials, planners, and engineers responsible for managing highways and roadways.

CHAPTER 1. INTRODUCTION

Studded tires are used by drivers during winter months to increase vehicle traction and performance. While the use of studded tires provides drivers with an added level of reassurance, the contact and interaction between the studded tire and the roadway surface contributes to pavement rutting and the potential for hydroplaning. The process of determining when a roadway needs to be resurfaced can be improved upon if studded tire vehicle volumes, and other contributors such as heavy vehicle volumes, are accurately measured. To date, studded tire usage has typically been approximated at a local or regional level based on parking lot surveys and phone surveys.

The objective of this research was to determine if sound could be used as a parameter to determine studded tire vehicle volumes along a highway. Sound data for different time durations were collected on two separate highways in the surrounding area of Moscow, Idaho for analysis purposes. The data were collected in shorter and longer durations. The shorter segments were accompanied by a video recording to compare with actual traffic conditions, while the longer segments were used to apply a prediction model after analyzing the shorter ones. The video footage was used to analyze vehicle types and identify decibel ranges, especially for vehicles with studded tires. By general observation, the presence of the metal studs protruding from the tires increased sound (e.g., decibel levels) when compared to non-studded tires. To further investigate the sound data collected, an ANOVA analysis was conducted to explore how different variables affected the data. In addition, a model was created to predict the probability of a vehicle being either a passenger vehicle, truck, passenger vehicle with studs, or another vehicle type.

In Chapter 2, the literature review describes previous sound-related research and topics of interest. Chapter 3 describes the methods for data collection and a new method for measuring studded tire vehicle volumes using sound data. Chapter 4 describes the results from the data collection and includes an analysis exploring how different variables influenced the data collection process. A probability prediction model for the sound data is also described in this chapter. Lastly, Chapter 5 details the conclusions from this study and highlights the key findings and areas for future work.

As part of this study, a survey was conducted to assess user perspectives and travel behaviors of Idaho drivers who use and do not use studded tires. This survey captured data including, but not limited to, driver demographics, safety perceptions, and perceived damage to roadways caused by studded tires. Since the survey complemented the main objective of this study, additional details of the survey and its results are found in the Appendix of this report.

CHAPTER 2. LITERATURE REVIEW

The literature review examined previous studies that focused on the varying effects of studded tires. The content has been divided into six sections, and these sections include a description of the rutting damage and pavement wear caused by studded tires, studded tire data collection methods, defining sound and the sound effects produced by studded tires, AASHTO guidance for collecting sound data, and a summary of state-level legislation, specifically for Idaho and Washington, as it relates to studded tires.

2.1. Rutting Damage and Pavement Wear

Studded tires contribute to pavement rutting damage during the winter months wherever snow and ice are common. Pavement materials such as hot mix asphalt and portland cement concrete tend to contract with low temperatures. The binding materials within these pavement surfaces also weaken with low temperatures which decreases ductility (Das, 2013). The process of freezing and thawing results in surface cracks which weakens the pavement. When studded tires are introduced, the metal studs from the tires cause a higher impact force on the road surface which contributes to greater cracking damage. In a previous study, the rutting damage caused by passenger vehicles with studded tires was compared with heavy truck wheel axial loads; the wear rates were 0.0116 inches per 100,000 studded vehicles compared with average rut rates due to heavy wheel loads of 0.0049 inches per 100,000 trucks (Abaza, 2019). Rutting damage caused by vehicles with studded tires can be remedied in a timely manner if both the location and volume of these vehicles are known. Mitigation practices include strengthening the pavement surface by increasing its thickness or introducing additional binding materials.

Angerinos (1999) explored the characteristics of studded tires that contributed to pavement wear. Some of the characteristics were stud protrusion, stud weight, driving speed, number of studs per tire, and stopping effectiveness. Wear rates ranged from 0.4 inches per million studded tire passes for California AC to less than 0.1 inches for Oregon PCC. Stud protrusion was one of the characteristics that directly impacted pavement wear, and mainly depended on the characteristics of the stud.

The structure of wheel studs has evolved over time to reduce the overall protrusion effect on pavement. Research work performed in Finland concluded that pavement wear increased with heavier stud weights (Unhola, 1997). Stud weights start at 1.0 grams which resulted in 0.25 cm^3 of wear and increased up to 0.80 cm^3 of wear at a stud weight of 3.0 grams.

Brunette (1995) examined the relationship between vehicle speeds and pavement wear and concluded that vehicle speed is a contributing factor to the stud dynamic force, which in turn affects the pavement wear rate. As an example, vehicle speeds at 50 miles per hour contributed to 0.02 in^3 of pavement wear per million studded tire passes.

2.2. Studded Tire Data Collection Methods

Previous collection methods for studded tire volumes have been based on phone surveys and parking lot surveys. The purpose of a phone survey is to approximate the number of vehicles with studded tires based on the verbal responses provided by the recipients of the call. An initial set of questions is formed, and responses are then collected over the phone. For example, a study conducted by Portland State University in partnership with the Oregon Department of Transportation (ODOT) used the phone survey collection method to conclude that the use of studded tires in Oregon declined over time (Shippen et al., 2014). The study determined that 16% of registered vehicles were equipped with studded tires in 1995, but that value dropped to 7.9% nearly two decades later.

By comparison, parking lot surveys are based on field work where a data collector analyzes and counts vehicles by sight. The chosen sites are typically larger commercial store parking lots or shopping malls in which several hundred vehicles are simultaneously present. Based on an analysis by Malik (2000), phone surveys were more efficient than parking lot surveys as phone surveys were able to collect more winter driving data such as the number of studded tires on vehicles and when users prefer installing studded tires. The phone surveys yielded use patterns and studded tire percentages, and also deduced usage growth rates by Oregon residents. Based on the phone survey, cars with studded tires typically have studs installed on all four wheels while earlier studies had indicated a mixture of installation preferences (Shippen et al., 2014).

2.3. Defining Sound

Sound is transmitted through waves and these waves can travel through air, water, and other surfaces. A sound wave has five main properties including wavelength, time period, amplitude, frequency, and speed. Human beings process these waves based on their frequency and frequency refers to the way in which sound waves oscillate while travelling to our ears (Attune, 2021). In this form, sound is typically measured in decibel units. Sound frequency refers to the number of waves produced in one second and is measured in Hertz units. If ten complete waves are produced in one second, then the frequency of the waves will be ten Hertz (Hz), or ten cycles per second. Low frequency sounds are typically measured at 500 Hz or below, and include earthquakes, elephant roars, and noise caused by severe weather. High frequency sounds are comparably measured at about 2000 Hz or higher, and include whistles, sounds caused by mosquitos, and fingernails on a chalkboard. A high frequency does not necessarily mean a louder noise, but louder noises tend to have higher intensities and equate to higher decibels (Encyclopedia Britannica, 2021).

Vehicle noise sources are mostly attributed to tire and pavement noise and the vehicle engine (Sandberg, 2002). The exhaust stack or pipe, muffler, drivetrain, air intake, and cooling fans are all potential contributors, along with vehicle (or heavy vehicle) type, tire tread patterns, and pavement and operating conditions (Donavan and Janello, 2017; Lodico and Donavan, 2018).

2.4. Sound Effects from Studded Tire Vehicles

The sound resulting from studded tires is based on its interaction with the pavement surface, and differentiating the sound effects is useful for data collection. Johnsson (2013) explored the effects of stud patterns and wheel types since some studded tires have more studs than others which affected the sounds produced. Also, the number and placement of tire studs depended on tire tread pattern. To simulate the sound of a stud contacting the pavement surface, Johnsson (2013) used an impact hammer with a steel tip. Multiple tests with different tires were conducted, and the recordings used a free field microphone positioned 0.5 meters from the center of the rim. The study concluded that there was a significant difference on sound pressure inside the car compartment based on the stud tire response and the stud pattern. Vehicle speed also had a significant effect on the perceived annoyance from different studded tire patterns.

A similar study recorded studded tire sound using acoustic emission and piezoelectric sensors (Schumacher, 2010). An experiment was performed on a bridge with acoustic sensors placed beneath it. The study concluded that studded tire stress waves can be differentiated from trucks and passenger vehicles. Studded tires were found to produce a unique recording on the acoustic emission sensing system which was at a higher amplitude versus trucks and passenger vehicles without studs. Rebar strain detectors were also placed under the bridge to detect load magnitude, and studded tires had smaller rebar strain values compared to trucks and passenger vehicles without studs.

A study from Sweden examined the noise aspect caused by studded tires on pavement surfaces. Noise measurements were carried out by a close proximity method where a measurement trailer was used with microphones close to the tires (Vieira, 2018). The results indicated that studded tires are roughly 6 to 10 decibel (dB) units louder than regular tires. A separate study determined that at speeds between approximately 40 and 55 miles per hour (mph) the effect of the studs produced a noise increase of approximately 2 to 6 (dBs) in the frequency range of 500-5000 Hz and 5 to 15 dB above 5000 Hz (Kongrattanaprasert, 2010).

Zhang (2014) examined the frequency level of vehicles with noises connected to road features and tried to separate out other parameters such as engine noise. Sound pressure from studded tires and all-season tires were compared and frequency levels were recorded. Test vehicles were driven at 20 mph, 30 mph, and 40 mph over 200 feet. The study concluded that studded tires were higher in sound pressure versus all season tires at all test speeds, and the increased sound emission from studded tires was concentrated at high frequencies above 6 kHz.

2.5. Federal Guidelines for Wayside Sound Measurements

The Federal Highway Administration released a handbook in June 2018 that provided guidelines on how to plan for a noise measurement program. The handbook provided guidance on how to measure noise effects from highways in urban communities, appropriate measurement methods based on different projects, and measurement instrumentation (FHWA, 2018). The guidelines were designed to capture noises relative to buildings off the highway and recommended horizontal placement of the microphones 25 feet from the fog line of the nearest lane and then another 10 feet away from the first microphone moving toward the building of interest. FHWA recommended microphones to be vertically placed at 5 feet above the ground surface to be representative of ear height for a standing person.

The handbook recommended taking video footage for traffic counts and synchronizing time between any acoustic instruments and video cameras. External factors that could affect the data collection process such as wind and temperature were also discussed. The handbook provided wind condition classes that would affect the results from the sound meters, and discouraged taking sound measurements when wind exceeded 11 mph regardless of direction. Measuring the temperature at two heights above ground was also recommended to precisely find parameters that could affect the data collection process.

2.6. Studded Tire Legislation (in Idaho and Washington)

Studded tire legislation for the states of Idaho and Washington was reviewed for comparison purposes. Some similarities between the states were observed regarding permitted dates, tire structure restrictions, and highway restrictions. In the state of Idaho, where this study was carried out, studded tires are permitted for use from October 1st to April 30th each year. Studded tires are permitted for use in Washington from November 1st to March 31st, and these dates can be extended if there is a crisis that prevents people from having access to changing their tires. Also, the severity of winters and how much snow falls during the season can affect this legal period.

In terms of the physical tire structure, Title 49 of the Idaho Statutes states that no vehicle tire on a highway “shall have on its periphery any block, stud, flange, cleat, spike, or any other protuberance of any material other than rubber which projects beyond the tread of the traction surface of the tire”. However, under Title 49-948 (Motor Vehicles), Chapter 9 (Vehicle Equipment), the Idaho statute states that studded tires on vehicles can be used when required for safety because of snow or rough winter conditions. There is also a list of conditions that the Idaho legislature enforces on retailer shops that install studded tires. These conditions include type of tire, size of tire, and the weight of studs depending on tire size.

CHAPTER 3. METHODS

For this study, two highway locations were chosen for data collection (see Figure 3.1). The locations were selected because they were representative examples of area highways and Idaho Transportation Department (ITD) collected traffic volume data in the immediate vicinity.

The first location was located between Moscow, ID and Troy, ID on ID-8. This facility is a two-lane highway with a posted speed limit of 60 miles per hour. The second site was located between Moscow, ID and Lewiston, ID on US-95. This divided highway has two lanes in each direction and the southbound direction was chosen for data collection purposes. The posted speed limit at this site is 65 miles per hour.

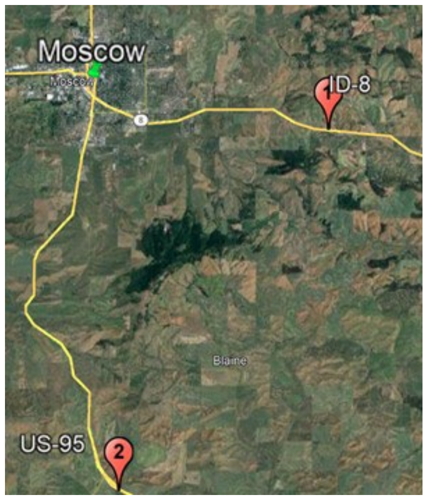

Figure 3.1 Data Collection Sites

Several data sets were collected during both the winter and summer seasons:

- Two one-hour data sets with video footage on ID-8 (collected on Thursday, March 4, 2021 and Wednesday, June 9, 2021)
- Two one-hour data sets with video footage on US-95 (collected on Thursday, December 10, 2020 and Thursday, June 17, 2021)
- Two seven-hour data sets without video footage on ID-8 (collected on Wednesday, January 20, 2021 and Wednesday, June 9, 2021)
- Two seven-hour data sets without video footage on US-95 (collected on Tuesday, January 12, 2021 and Thursday, June 17, 2021)

Each one-hour data set was collected with video footage so that each passing vehicle could be identified and associated with the decibel readings from the sound meter. The video footage included a sound recording to identify the vehicles with studded tires. Data were collected on days when wind speeds were minimal, and when there was no precipitation in the air or on the ground.

3.1. Field Setup

Since the wayside sound measurement guidelines described in the literature review focused on measuring noise levels that affected nearby residential areas, the recommended microphone distances from those guidelines were referenced but not replicated. The goal of this research was to collect sound from each vehicle as closely and as safely as possible. For this study, the sound meter device was placed approximately five feet from the fog line of the highway (see Figure 3.2) with a camera placed adjacent to the sound meter. Microphones were placed on instrument stands which lifted the microphones not more than one foot off the ground. The camera captured video quality in 1080p (Full HD) definition. For each one-hour data set, a manual count of the vehicle volumes was also conducted, and there were at least two people present on site to assist with the counting process.

Figure 3.2 Sound Meter Field Setup (Along US-95)

An off-the-shelf sound level meter (PCE-322A professional Class II) with built-in data-logging functionality was used for this study (see Figure 3.3). While there were many device options to choose from, the research team sought to use a device that was both economical and portable. This particular sound level meter provided a user-friendly interface, an ability to record data up to 30 hours, and the flexibility to transfer data. The sound level meter recorded a decibel reading each second and had a maximum storage capacity of 32,700 readings, which well exceeded the needs of this study.

Two sound level meters were used at each site. During initial testing, it was determined that relying on one meter to collect data was not always reliable. For this reason, two meters were used in tandem and the average decibel reading from both meters was then used for analysis purposes.

Data from the sound meters were exported to Excel files for analysis. A picture of the info display on the sound meters was taken to synchronize the time between the sound equipment and the video camera.

3.2. Vehicle Classifications

For this study, each vehicle was classified into one of four categories which included passenger vehicles, trucks, other vehicles such as semi-trucks, and passenger vehicles with studded tires. Passenger vehicles consisted of sedans, sport utility vehicles, coupes, hatchbacks, and compact vehicles. Trucks represented all vehicles with an open cargo area. Other vehicles were comprised of recreational vehicles and semi-trucks. Lastly, vehicles with studded tires represented all passenger vehicles with studded tires. Based on FHWA classifications, the vehicles observed in the field closely matched up with Class 2 (passenger cars), Class 3 (four tires single unit), and Class 9 (5-axle tractor semi-trailer) and Class 10 (six or more axle, single trailer) vehicles (Federal Highway Administration, 2013).

Figure 3.3 Sound Meter Display

3.3. Decibel Readings

Using the sound level meter data and the corresponding video footage, the one-hour data sets were reviewed to determine decibel reading values and vehicle type for each passing vehicle.

The highest decibel reading was recorded during an approximate time window of three to five seconds when the vehicle approached and then passed the sound level meter. A typical increase and decrease in the decibel reading as recorded by the sound meter is shown in Figure 3.4.

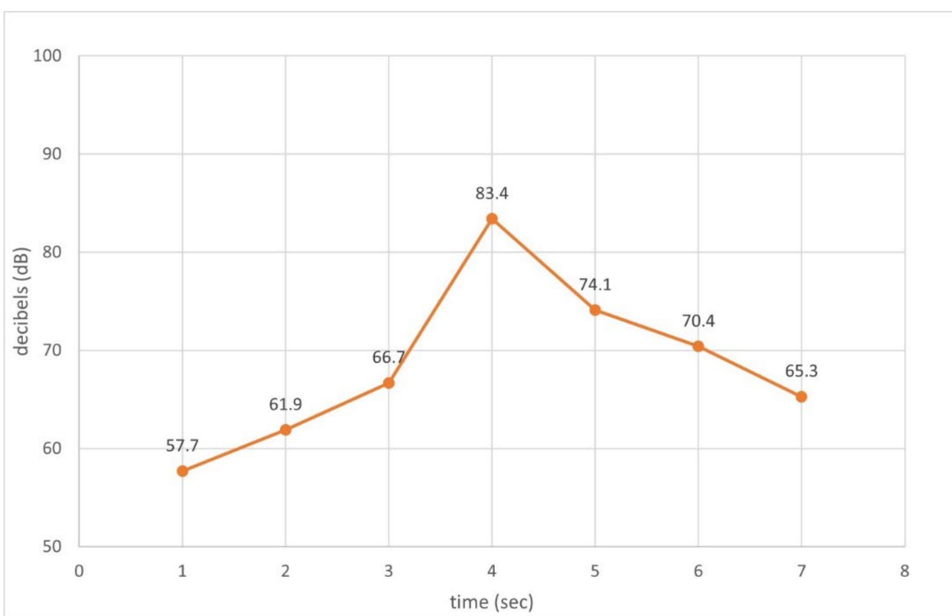

Figure 3.4 Sound Meter Recording (Passenger Vehicle With Studded Tires)

This figure illustrates how a representative decibel reading was chosen for each passing vehicle. For a single passing vehicle, one defined peak was typically present with lower decibel readings before and after the peak. Based on this pattern the highest decibel reading within the time span was used.

There were other observed scenarios when associating a decibel reading for each passing vehicle was more challenging. Some of these scenarios included two vehicles simultaneously passing by in different lanes and two or more consecutive vehicles passing by in the same lane. By synchronizing the video with the sound meter, it was easier to identify when a vehicle passed the sound meter and to assign an approximate decibel reading.

Figure 3.5 represents a sound recording of two vehicles passing by the sound meter at almost the same instant, with one truck in the near lane (closer to the sound meter) and one passenger vehicle in the far lane. Some assumptions were made in order to analyze this data. Vehicles in the near lane and Class 9 and Class 10 vehicles were assumed to be louder. For instance, the highest decibel reading (i.e., 81.2 dB) in Figure 3.5 was assumed to represent the truck passing by in the near lane, and the two data points that followed (i.e., 78.3 dB and 76.7 dB) represented the passenger vehicle in the far lane.

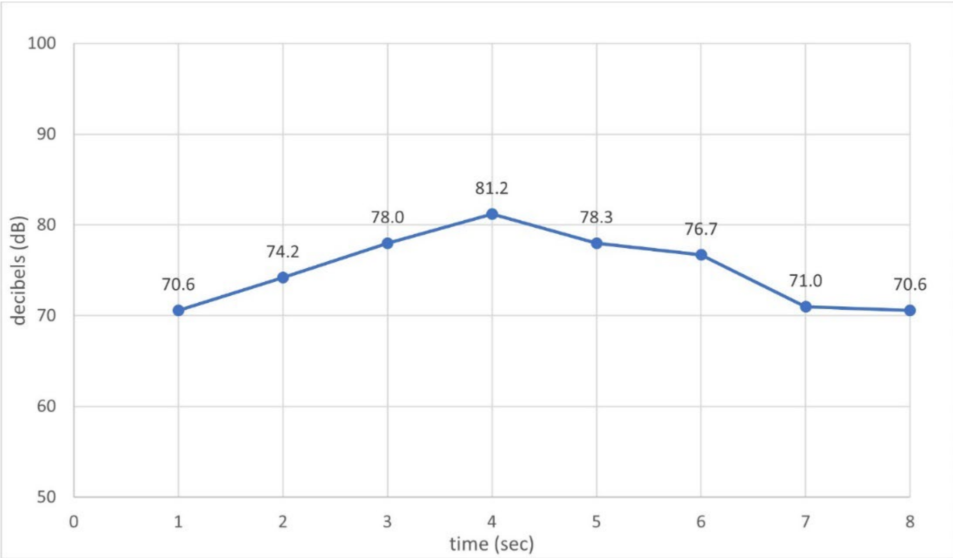

Figure 3.5 Two Vehicles Simultaneously Passing Sound Meter (Example)

Figure 3.6 shows an example of three vehicles passing by within one to two seconds of each other. Based on the video, the first vehicle was a passenger vehicle in the far lane followed by a truck in the near lane and a passenger vehicle with studs in the near lane. The passenger vehicle with studs in the near lane recorded the highest decibel reading (i.e., 85.1 dB), and that point was used as a reference. By relying on the assumption that vehicles in the near lane were generally louder than those in the far lane, the second highest decibel reading (i.e., 82.3 dB) was associated with the truck in the near lane.

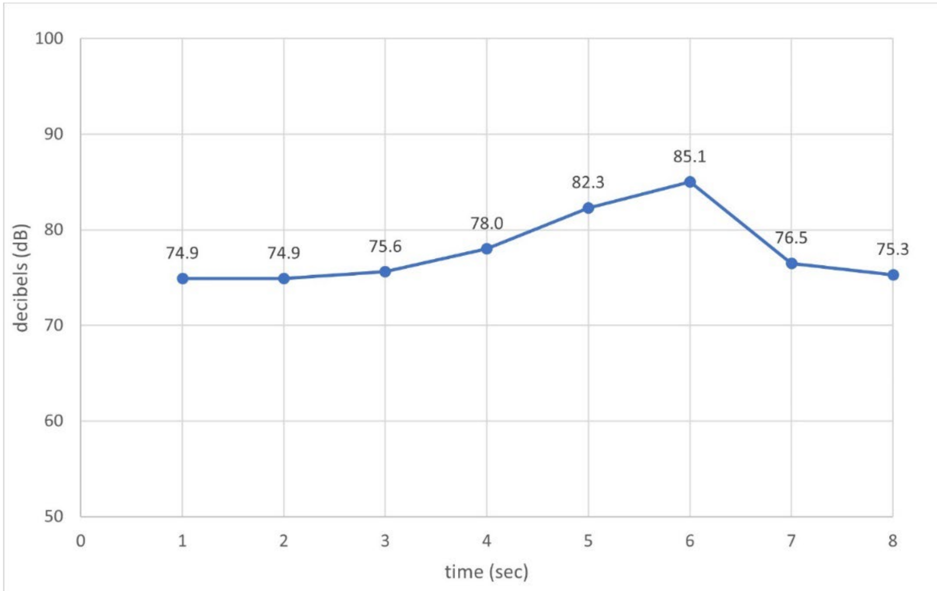

Figure 3.6 Multiple Vehicles Passing Sound Meter (Example)

3.4. Parking Lot Survey

To compare and to determine the percentage of vehicles with studded tires in the local area, a parking lot survey was conducted at several University of Idaho parking lots and at Eastside Marketplace, a small urban shopping complex, during the study period.

The University of Idaho sites included one of the largest parking lots (#60) on campus and other high traffic locations (i.e., Greek System parking). All of the parking lots shown in Figure 3.7 were visited during the parking lot survey. The totals from these parking lots were then combined into a single representative sample.

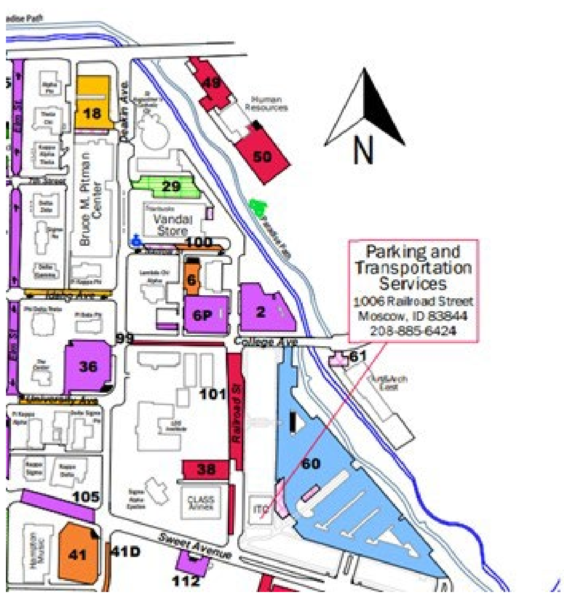

Figure 3.7 University of Idaho Campus Parking Map, the different colors represent different parking zones (i.e., short-term parking, student parking, etc.).

This study initially targeted parking lots at grocery stores, like WinCo, and commercial retailers, like Walmart. However, these locations did not allow surveys to be performed due to store policy restrictions. As a result, other locations were considered. After contacting the Eastside Marketplace's manager, permission was granted. The Eastside Marketplace is a shopping center with multiple restaurants and other shops. As shown in Figure 3.8, the parking lot to the right of the concrete divider island was used for the survey and consisted of nine parking rows. The Safeway parking lot was not used for data collection to avoid potential store policy concerns.

Figure 3.8 Eastside Marketplace Parking Lot

The parking lot surveys were performed based on visual observation. The total number of vehicles was recorded along with vehicles that had installed studded tires. Vehicles with studded tires on either axle or both axles of the vehicle were counted equally. In other words, a vehicle with studded tires installed on only the front or rear axle was treated the same as a vehicle with studded tires on both axles. The survey dates and vehicle counts are presented in Table 3.1.

Table 3.1 Parking Lot Survey Results

	Date	Vehicles	Vehicles with studs	% of vehicles with studs
Eastside Marketplace	Jan 8th 2021	69	20	28.90%
U of I	Feb 18th	202	42	20.80%

The results from Table 3.1 concluded that the overall percentage of studded tire vehicles from the two sites was 22.8%, or 62 out of 271 vehicles.

3.5. ITD Data Collection Stations

The Idaho Transportation Department has two ways of keeping highway traffic count records, automatic traffic recorders (ATR) and Weigh-In-Motion (WIM) sensors. The automatic traffic recorders are roadside systems that use different sensors and electronics to record vehicle volume, length, speed, and classification data. According to ITD, there are approximately 175 ATRs located in the state of Idaho.

The automatic traffic recorders collect daily traffic for each month throughout the year. A monthly hourly traffic volume report was used to compare vehicle volumes with the results from this study. Volume data were available for each lane and for each hour. The southbound hourly lane volumes were used for US-95, and the westbound and eastbound lane volumes were used for ID-8. Figure 3.9 shows the ITD's automatic traffic recorder locations (#98 and #127) that were used for this study. By comparison, the field data collection sites for this study, as shown in Figure 3.1, were located to the north and to the east of these automatic traffic recorder locations, respectively.

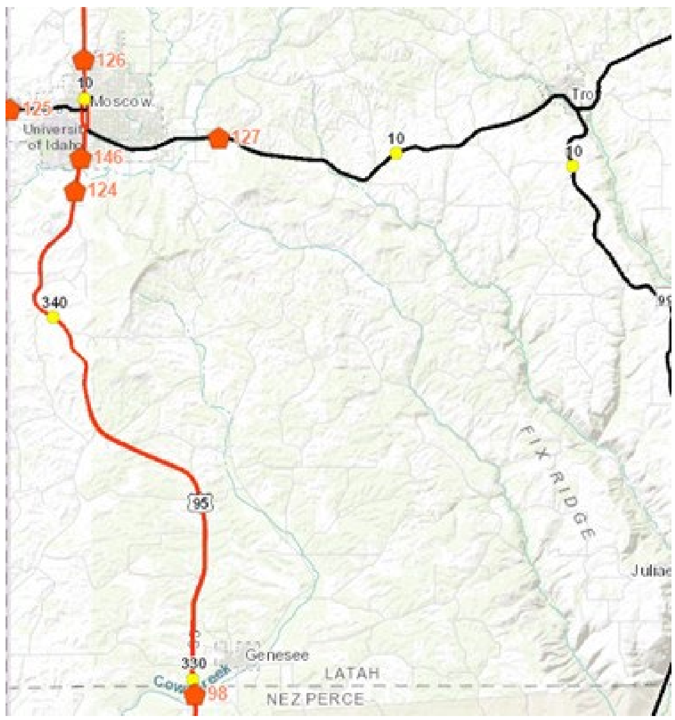

Figure 3.9 ITD Automatic Recorder Stations

The weigh in motion sensors collect vehicle weight data, specifically axle weights to identify vehicle volume, and classification data. Monthly and specialty reports are available on the ITD website. WIM reports were not used for this study.

CHAPTER 4. RESULTS AND ANALYSIS

This chapter describes the results obtained from the studded tire data collection during the winter and summer seasons on US-95 and ID-8 and summarizes the resulting decibel value data of different vehicle types. Comparisons of the sound data collected during the two different seasons and of vehicles with and without studs will be presented, followed by an analysis that determined how different variables (e.g., highway type, season) affected the results. Lastly, the outcomes from two prediction models will be shared. These models were used to forecast vehicle volumes and determine the likelihood probability of vehicles with studded tires.

The sound results from the winter and summer seasons along US-95 are provided in Table 4.1a, based on the one-hour sound meter and video recordings. Similar sound data collected along ID-8 are provided in Table 4.1b. In addition to the average decibel reading for each vehicle type, a standard deviation was calculated along with the standard error (to illustrate how far this sample mean deviated from the true sample mean).

Table 4.1 a) US-95 Results (Winter vs. Summer), b) ID-8 Results

a)

	Type	Lane	Sample Size	Avg dB	St. Dev.	Error (±)
Winter	Pass veh	Far	22	76.3	2.54	0.80
	Pass veh	Near	25	80.7	2.43	0.49
	Pickup	Far	12	78.7	2.22	0.74
	Pickup	Near	37	82.4	3.46	0.84
	Other	Far	3	84.8	1.48	0.66
	Other	Near	7	86.3	4.59	1.73
	Veh W studs	Far	10	*79.2*	2.08	0.69
	Veh W studs	Near	23	*83.0*	2.74	0.57
		Total	139			

	Type	Lane	Sample Size	Avg dB	St. Dev.	Error (±)
Summer	Pass veh	Far	68	76.3	2.91	0.65
	Pass veh	Near	75	81.7	3.69	0.67
	Pickup	Far	30	79.8	3.84	1.06
	Pickup	Near	50	85.5	4.61	1.06
	Other	Far	5	87.5	4.79	2.39
	Other	Near	10	95.7	4.43	1.48
		Total	238			

b)

	Type	Lane	Sample Size	Avg dB	St. Dev.	Error (±)
Winter	Pass veh	Far	19	75.7	1.91	0.44
	Pass veh	Near	38	82.7	2.89	0.47
	Pickup	Far	16	79.9	2.41	0.60
	Pickup	Near	20	84.8	3.61	0.81

	Other	Far	5	85.9	2.66	1.19
	Other	Near	8	91.4	3.54	1.25
	Veh W studs	Far	16	*80.7*	3.02	0.75
	Veh W studs	Near	30	*85.4*	3.94	0.72
		Total	152			

	Type	**Lane**	**Sample Size**	**Avg dB**	**St. Dev.**	**Error (±)**
Summer	Pass veh	Far	158	74.8	3.18	0.25
	Pass veh	Near	67	79.4	3.38	0.41
	Pickup	Far	35	77.1	3.21	0.54
	Pickup	Near	42	80.8	3.76	0.58
	Other	Far	9	81.9	1.79	0.60
	Other	Near	9	87.9	2.77	0.92
		Total	320			

During the winter data collection period on US-95, there were 23.7% studded tire vehicles (33 studded tire vehicles out of 139 total vehicles). Along ID-8, there were 30.3% studded tire vehicles (46 out of 152). For comparison purposes, the parking lot survey yielded 22.9% studded tire vehicles (62 out of 271).

Two independent two-sample t-tests were conducted to evaluate the average decibel readings between the winter and summer results and between passenger vehicles with and without studded tires. The main assumption (i.e., null hypothesis) for this hypothesis testing was that the means of these data sets were equal. In other words, the test assumed that the mean for winter data did not vary from the mean of the summer data, and also did not vary for passenger vehicles with and without studded tires. As a result of the t-tests, the null hypotheses were rejected. For both scenarios, the t-values were larger than the t-critical two-tail values (see Table 4.2)

Table 4.2 T-Tests a) Winter vs. Summer; b) Passenger Vehicles With (PWS) and Without (Pass veh) Studded Tires

a)

t-test: Two-sample assuming equal variances (95% confidence interval)						
	Sample size	**Mean**	**St. Dev.**	**P-value**	**t-value**	**t-critical two tail**
Winter	257	82.5	19.9	9.84E-22	9.9	1.9
Summer	335	78.6	25.1	9.84E-22		

b)

t-test: Two-sample assuming equal variances (95% confidence interval)						
	Sample size	**Mean**	**St. Dev.**	**P-value**	**t-value**	**t-critical two tail**
PWS	72	82.7	12.5	8.85E-08	5.6	2.00
Pass veh	106	79.4	16.6	8.85E-08		

There was a significant difference between the winter (M=82.5, SD=19.9) and summer (M=78.6, SD=25.1, t (592) = 9.9) data sets. The t-value was greater than the t-critical two tail (1.9) which meant a rejection to the null hypothesis that the two samples had equal variances. Passenger vehicles with studded tires (M=82.7, SD=12.5) also had a significant difference compared to passenger vehicles without studded tires (M=79.4, SD=16.6, t (178) = 5.6) with the t-value greater than the t-critical two-tail (2.0). These t-tests concluded that vehicles were collectively louder in the winter compared to the summer (likely attributed to the increase in studded tire vehicles), and passenger vehicles with studded tires were comparably louder than passenger vehicles without studded tires.

To further examine these results, a statistical analysis to calculate and summarize the variances of multiple variables was conducted using the R software package. In Figure 4.1, the average decibel reading for the different vehicle categories along ID-8 and US-95 were examined. The figure lists vehicle types along the x-axis and dB (decibel units) along the y-axis. The vehicle types are passenger vehicles (P), pickup trucks (TR), passenger vehicles with studded tires (PWS), and other vehicles (O). Each boxplot is a vehicle type associated with a road. For instance, the third box plot from the left represents passenger vehicles with studs on ID-8. Each box plot represents 100% of the data, where 50% of the data lies within the box, and the upper and lower whiskers (dotted lines) represent maximum and minimum values, respectively. Outliers are noted with an open circle.

Based on Figure 4.1, the “other” vehicle category recorded the highest decibel reading for both highways. The mean for the other (O) vehicles was 88.4 dB on ID-8 and 90.3 dB on US-95. Passenger vehicles with studs (PWS) were louder than pickup trucks (TR) on ID-8 but slightly quieter on US-95. The mean for PWS was 84.9 on ID-8 and 83.3 dB on US-95. The mean for pickup trucks was 81.1 dB on ID-8 and 83.8 dB on US-95. Finally, passenger vehicles (P) had a mean of 78.3 dB on ID-8 and 78.8 dB on US-95.

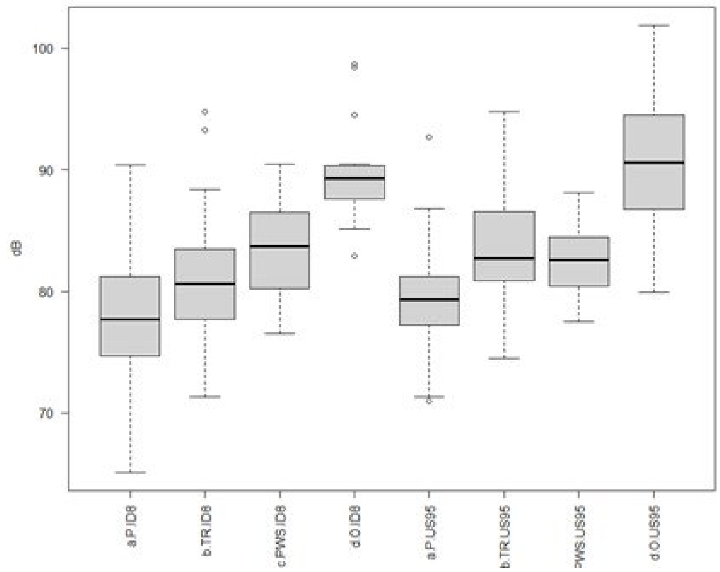

Figure 4.1 Effects of Vehicles Type and Highway Location

Another analysis examined the effects of lane proximity. In Figure 4.2, the results show that vehicles traveling along the far lane were recorded to have a lower decibel reading when compared with vehicles traveling in the near lane. For this study, all travel lanes were twelve feet in width and the sound meters were placed approximately five feet away from the fog line (e.g., white edge lane marking) of the nearest lane.

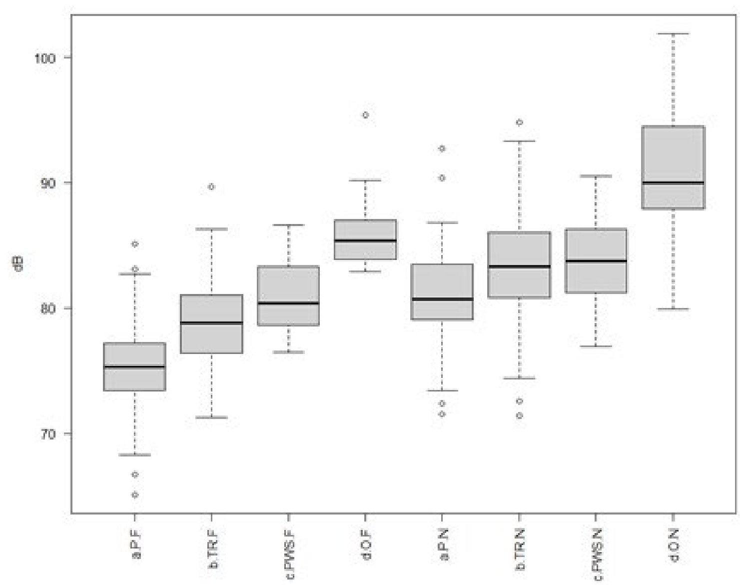

Figure 4.2 Effects of Vehicle Type and Lane Position

Passenger vehicles with studded tires (PWS) had a mean of 84.7 dB in the near lane, and 82.6 dB in the far lane. By comparison, passenger vehicles without studded tires (P) averaged 80.3 dB for the near lane and 74.6 dB for the far lane. Pickup trucks (TR) averaged 83.1 dB and 77.6 dB for the near and far lanes, respectively, and other vehicle types (O) averaged 91.9 dB in the near lane and 87.3 dB in the far lane.

Figure 4.3 summarizes the decibel readings of different vehicle types based on whether the data were collected in the winter or summer. Passenger vehicles with studded tires collectively averaged 82.6 dB. No data for this category, of course, were collected during the summer months. By comparison, passenger vehicles without studded tires had a mean of 77.7 dB in the summer and 81.6 dB in the winter, pickup trucks had a mean of 82.3 dB in the summer and 83.7 dB in the winter, and other vehicle types had a mean of 92.1 dB in the summer and 89.5 dB in the winter.

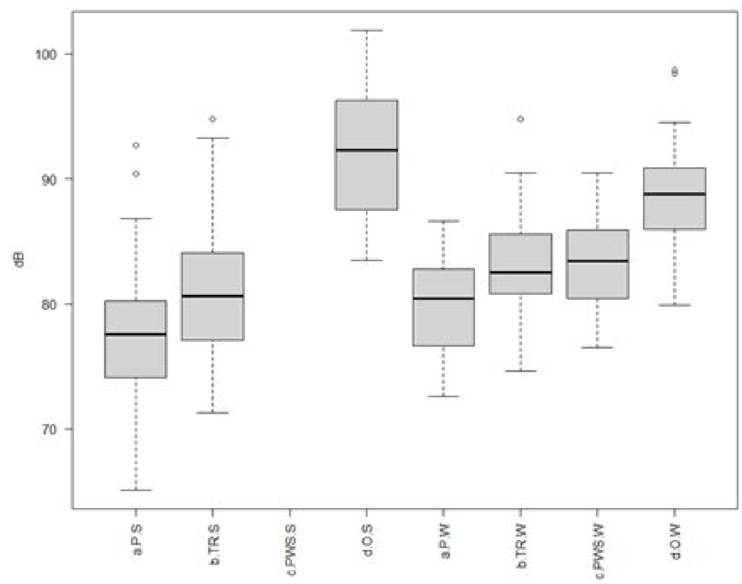

Figure 4.3 Effects of Vehicle Type and Season

An analysis of variance (ANOVA) was conducted to observe the significance of variance between the main variables (first order effect) and the main variables associated with other factors (second order effect). Tables 4.3 and 4.4 list the variables used for this test along with the ANOVA results. The analysis of variance tested whether the effects of vehicle type, lane, season, or highway had differences in their mean decibel levels. The ANOVA also tested for interactions among the factors in which the effects of one factor changed depending on the level of another factor.

Table 4.3 Analysis of Variance (ANOVA) Test Variables

Variable	Description
Vtype	Vehicle type (Passenger, Pickup (Truck), Passenger with studs, Other)
Lane	Lane being either close or far
Season	Winter and summer
Road	US-95 and ID-8
Vtype:Lane	Vehicle type associated with Lane (close or far)
Vtype:season	Vehicle type associated with Season (Winter or summer)
Vtype:Road	Vehicle type associated with Road
Season: Road	Season associated with road

Table 4.4 Analysis of Variance (ANOVA) Test Results

Variable	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Vtype	3	5679.2	1893.1	155.3	< 2.2e-16
Lane	1	3305.4	3305.4	271.2	< 2.2e-16
Season	1	95.3	95.3	7.8	0.005346
Road	1	36.3	36.3	3.0	0.084796
Vtype:Lane	3	103.6	34.5	2.8	0.037708
Vtype:Season	2	181.4	90.7	7.4	0.000645
Vtype:Road	3	99.9	33.3	2.7	0.043088
Season:Road	1	354.4	354.4	29.1	1.02E-07
Residuals	574	6996.2	12.2		

This model analyzed factors instead of independent variables, main effects instead of one-way effect variables, and interaction effects instead of two-way effect variables. The null hypothesis assumed that these independent variables would have no effect on the dependent variable. For instance, the null hypothesis for the first variable (Vtype) was that all vehicle types had equal average decibel readings, and the p-value was used to either accept or reject the hypothesis. The first four variables were one-way effect variables and the remaining four variables were two-way effect variables.

Based on the analysis, interactions between vehicle type and lane (p-value=0.0377), vehicle type and season (p-value=0.001), vehicle type and road (p-value=0.043), and season and road (p-value=1.02E-07) were all significant since their values were less than 0.05. In addition, the independent variables of vehicle type, lane, and season were also significant.

4.1. Prediction Model

A prediction model was developed using a special package in R to extract “features” from a smoothed curve based on discretely sampled functional data (e.g., decibel reading over time). The model extracted key features such as the mean, first and second derivatives, critical points (e.g., local maxima and minima), and outliers. The model counted specific elements including the number of critical values with above average decibel values, and the negative second derivatives represented by local maxima. Figures 4.4 to 4.7 illustrate the analysis steps performed by the R prediction model using a 100 second sample data set. This same process was applied to the seven-hour data sets which consisted of approximately 25,000 decibel readings each.

The prediction model initially plotted all of the decibel readings for a specific data set. Figure 4.4 shows the decibel readings for the 100 second data set used as an initial test. The x-axis represents the time a reading was recorded, and the y-axis represents its decibel value.

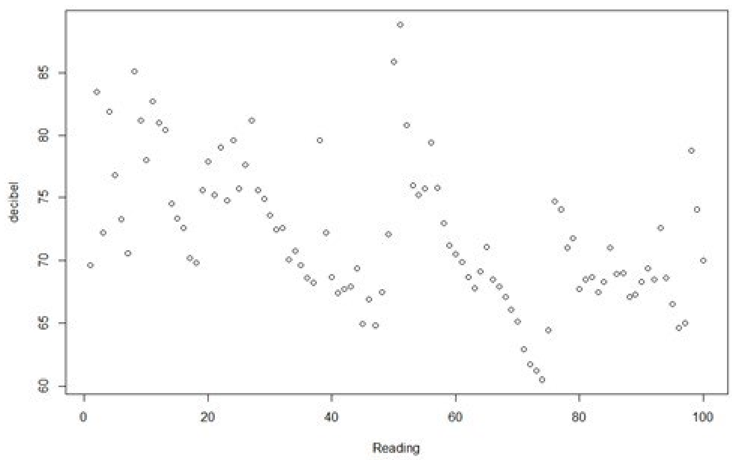

Figure 4.4 Prediction Model Plotted Data Readings

The model then fit a smooth curve function using the decibel readings (see Figure 4.5).

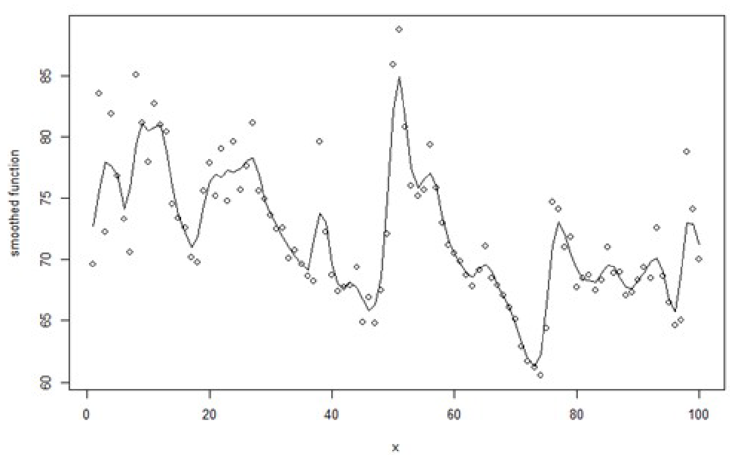

Figure 4.5 Fitted Function of Prediction Model

Next, the model extracted features of the smoothed function which included the first and second derivatives, mean values, and critical points. The first derivative identified points on the dotted line (see Figure 4.6). The second derivative used the points initially identified to find the local maxima (see Figure 4.7).

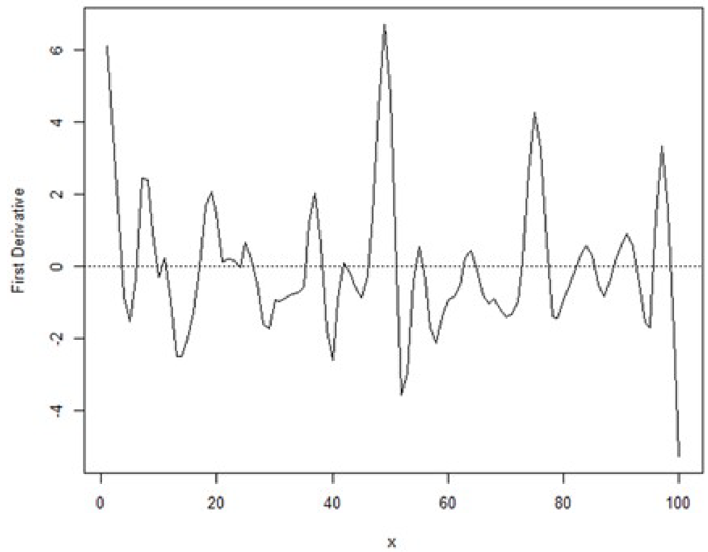

Figure 4.6 First Derivatives From Smoothed Function

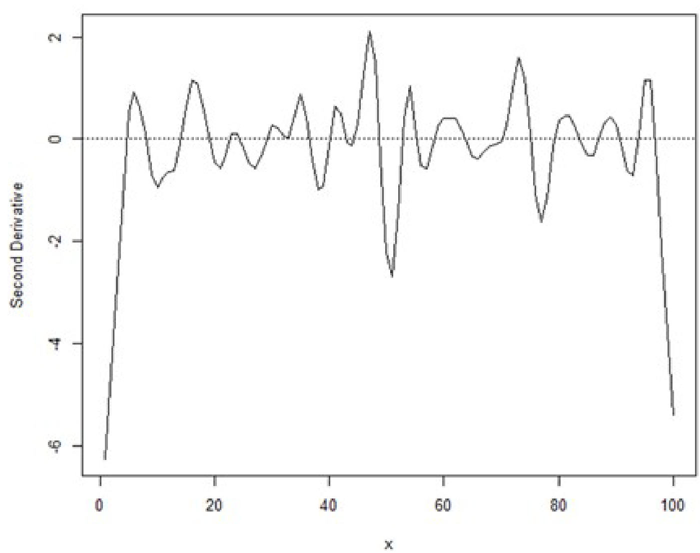

Figure 4.7 Second Derivatives From Smoothed Function

This method was used to estimate the number of vehicles passing by the sound meter, and the estimated result was then compared with ITD ATR data. The error percentages were calculated using the predicted model results and the recorded ITD volume results using the following equation:

$$\text{Absolute percentage error} = \left|\frac{\text{Actual} - \text{predicted}}{\text{Actual}}\right| * 100$$

Table 4.5 shows the results from the prediction model and the ITD results for each road and season. The US-95 prediction model underestimated winter results by 42 vehicles (3.2% error rate) and underestimated summer results by 255 vehicles (15.5% error rate). The winter data from ID-8 was the only scenario where the model overestimated, by 190 vehicles, the total volume (15.4% error rate). The model underestimated summer data for ID-8 by 74 vehicles (5.2% error rate).

Table 4.5 Comparison of Prediction Model Results with ITD Data

	Vehicle Volumes		
Road/season	**Prediction model results**	**ITD results**	**Error %**
US-95/Winter	1270	1312	3.2
US-95/Summer	1390	1645	15.5
ID-8/Winter	1421	1231	15.4
ID-8/Summer	1342	1416	5.2

A flowchart summarizing the process used to develop the prediction models is shown as Figure 4.8.

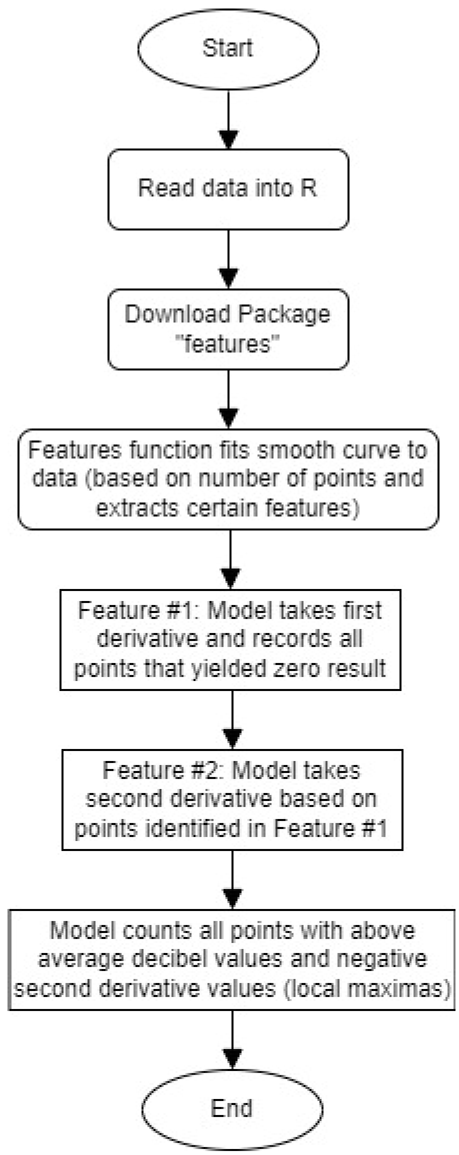

Figure 4.8 Flowchart of Vehicle Volume Prediction Model

4.2. Probability Likelihood

To associate a probability likelihood for vehicle types based on the different decibel ranges, a multinomial logistic regression was performed in R. The model used explanatory variables (e.g., characteristics) to identify the possible outcomes and their probabilities, with the characteristics represented by the different vehicle types and their average decibel readings. This model then used an algorithm to predict the categorical vehicle types and applied the rule that all probabilities for a specific outcome equaled one. This approach was carried out for each decibel reading range, and likelihood probabilities for each vehicle type based on decibel readings were generated based on the winter data sets when vehicles with studded tires were present.

Probabilities for vehicle types falling in the same decibel range and traveling in either the near or far lane were combined as the model could not associate traffic with a particular lane. The model predicted vehicle type based on decibel reading, and these likelihood probabilities are shown in Table 4.6.

Table 4.6 Likelihood Probabilities of Different Vehicle Types

Decibel Range	Pass Veh	Pickup	Pass Veh w/ studs	Other
70 - 75 dB	0.90	0.05	0.05	0.00
75 - 80 dB	0.58	0.22	0.19	0.01
80 - 85 dB	0.26	0.36	0.31	0.07
85 - 90 dB	0.04	0.34	0.30	0.32
90 dB and above	0.00	0.14	0.13	0.73

The model determined that there was a 90% probability that a vehicle in the 70 to 75 dB decibel range was a passenger vehicle without studded tires. All of the other vehicle types registered significantly lower percentages. In the 75 to 80 dB range the passenger vehicle without studded tires remained the category with the highest probability but the pickup and passenger vehicle with studded tire categories registered noticeable percentage increases. The vehicle type with the highest probability in the 80 to 85 dB range was the pickup and was followed by passenger vehicles with studded tires. This decibel range also represented the highest percentage likelihood for vehicles with studded tires. In the 85 to 90 dB range the pickup had the highest probability and was followed by passenger vehicles with studded tires. In the highest decibel range of 90 db or above, the highest probability belonged to the other vehicles category, with much smaller percentages for the other three vehicle types. As shown in Table 4.6, the probability values of passenger vehicles with studded tires tended to closely mirror the probability values of pickup trucks. A flowchart of the prediction model is shown in Figure 4.9.

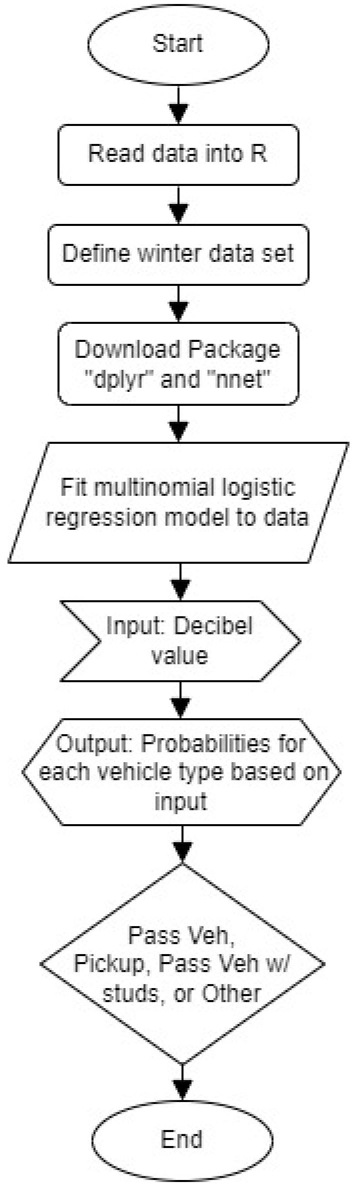

Figure 4.9 Flowchart of Vehicle Type Prediction Model

Table 4.7 summarizes the studded tire vehicle percentages based on the different methods used in this study. The parking lot surveys were added together to obtain their total percentage. Video recording percentages were represented by the one-hour data sets during the winter season. The studded tire vehicle percentage using the prediction model, based on the likelihood probability values, were calculated using the following equation:

$$\text{Percentage} = \frac{V_v * L_p}{P_d} * 100$$

where:

V_v = Predicted vehicle volume for a decibel range
L_p = Likelihood probability for a decibel range

P_d = Total vehicle volume from prediction model

Table 4.7 Studded Tire Vehicle Percentages by Method

Method	Location	Total Vehs	Studded Tire %
Parking Lot Surveys	in city	271	22.9%
Video Recordings	US-95	139	23.7%
Video Recordings	ID-8	152	30.3%
Prediction Model	US-95	1270	14.2%
Prediction Model	ID-8	1421	23.9%

Based on these outcomes, the parking lot surveys and video recording of US-95 yielded similar studded tire vehicle percentages although the parking lot surveys represented a larger vehicular volume when compared with the video recordings. The prediction model results for ID-8 were also similar to these other methods but represented a significantly higher vehicular volume.

A comparison of the video recording data versus the prediction models concluded that the video recordings consistently yielded higher percentages. On US-95, the measured studded tire vehicle percentage for one hour during the winter was 23.7%, which was almost ten percentage points higher than the prediction model outcome of 14.2%. On ID-8, the video recording tallied 30.3% vehicles with studded tires, which was just over six percentage points higher than the prediction model.

CHAPTER 5. CONCLUSIONS

This research explored a method of using sound data to quantify studded tire volumes on highways. Based on the results using an off-the-shelf sound meter device, it was determined that while vehicles with studded tires generate a higher decibel reading when matched with comparable vehicles, the decibel reading alone could not definitively determine a vehicle using studded tires, in part because the decibel reading of some pick-up trucks and semi-trucks were comparable to passenger vehicles with studded tires. For this reason, a secondary method such as video capture of the travel environment or a field observer was necessary for verification purposes.

This study confirmed several expected findings, including higher vehicle decibel readings in the winter versus the summer, and noticeable differences in the decibel readings depending on whether a vehicle was traveling in the lane nearest the sound meter or one lane away in the far lane. Based on an analysis of variance, the study concluded that the interactions between a particular vehicle type and lane, season, or highway were statistically significant.

The results from both prediction models showed that sound data can be utilized to approximate studded tire vehicle volumes and to differentiate vehicle types. The accuracy of predicting vehicle volumes proved to be better than exclusively predicting studded tire vehicles. Studded tire vehicles and pickup trucks yielded similar decibel values, and from the probability likelihood values of vehicles with studded tires frequently fell in the 80 to 85 dB range. The vehicle volume prediction model had similar results to actual field volumes recorded by ITD, though the model did not consistently overestimate or underestimate results.

An examination of specific frequency levels is recommended for future study as this factor could help differentiate studded tires from other vehicles. This study only used the sound pressure levels as the differentiating factor and there are more advanced sound meters available that could be used to analyze the frequency spectrum of studded tires. One of the challenges encountered during this research study was separating individual vehicles when two or more vehicles passed the sound meter simultaneously.

There is an inherent value to determining actual studded tire vehicle volumes on each highway. The wear and tear on the roadway surface caused by studded tire usage is not insignificant over time and providing detailed information to local and state departments of transportation supports life cycle cost analysis on specific facilities. Parking lot and phone surveys yield local results, but site-specific data, when available, is more beneficial. This study has concluded that if highway-specific data are needed, manual field observations may, in fact, remain a practical alternative until a more refined acoustic method, likely requiring more sophisticated and expensive sound meter devices, is established.

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CHAPTER 7. APPENDIX

To gather driver perspectives regarding studded tire usage and the impact on the roadway surface, an online user survey was administered to 423 Idaho residents who owned at least one vehicle. Qualtrics was hired to enlist participants and collect survey data.

In terms of general demographics, females represented 59.7% (n=252) of the sample, while males represented 39.8% (n=168), and non-binary individuals represented 0.5% (n=2). The age ranges were divided between 18 to 49 years old (56.4%, n=238) and 50 years old and over (43.6%, n=184), and 83.6% (n=353) said they had “5 or more years” of driving experience. An overwhelming number of the respondents were Caucasian (90.3%, n=381) and 84.8% (n=358) had household incomes of less than $99,000 per year.

Each household owned between one and three vehicles. The vehicle categories were defined as “passenger car”, “SUV”, “truck”, and “other”. Some respondents owned more than one vehicle at their place of residence. Most people owned one passenger car (53.8%, n=227), while the second most popular vehicle type was an SUV (43.1%, n=182). In a typical week, most of the respondents reported traveling between 1 and 199 miles (88.3%, n=373), though 39.1% (n=165) worked from home or did not work.

On their travels during winter months, few respondents said they would “rarely encounter compact snow or ice” (4.5%, n=19). While most respondents have snow driving experience, 73.2% (n=309) had not been “involved in a crash as a driver when snow and ice are present.” Conversely, 26.8% (n=113) had been involved in a crash. For those involved in a crash when snow and ice were present, 16.8% (n=19) recalled having studded tires. Of the entire sample, 40.4% (n=170) had installed studded tires “in the last three winters.”

Survey respondents were asked a series of questions about their driving behavior. Only 2.6% (n=11) self-identified as being “somewhat aggressive”, and no one identified themselves as an “aggressive driver.” The rest of the drivers all self-identified between “cautious” and “neutral.” When asked about driving on snow, ice, and fresh snow, drivers were more comfortable on fresh, unplowed roads (46.9%, n=198) versus compact snow or ice (37.0%, n=156). Most people chose to avoid less-traveled roads, with 68.2% (n=288) agreeing or strongly agreeing that they stay on major routes or roads in the winter. Additionally, 91.5% (n=386) of respondents drive slower and 63.0% (n=266) intentionally drive less when snow or ice are present. For 36.3% (n=153) of the respondents, they agreed with the statement, “When snow or ice are present on the roadway, I prefer not to drive unless the roads have been cleared.”

Driving With Studded Tires

The survey examined responses provided by drivers who used studded tires (n=170) versus those who did not (n=252). Of the respondents who used studded tires, 80.0% (n=136) said they “feel safer when driving a vehicle with studded tires.” For their primary vehicle, 74 (43.5%) respondents said they had front-wheel drive and 69 (40.6%) said they had all-wheel or four-wheel drive vehicles. A majority (71.8%, n=122) installed studded tires “most years” or “every year.” Most drivers (74.8%, n=127) installed studded tires on all four tires, and 59.4% (n=101) do not carry snow-chains in the winter months. Of those who carry chains, most respondents (76.8%, n=53) used or installed chains between zero to two times in the last three winters.

Driving Without Studded Tires

Of the respondents who did not use studded tires (n=252), a majority owned all-wheel or four-wheel drive vehicles (58.0%, n=146). All-season tires (82.1%, n=207) represented the predominant tire in winter months for a respondent's primary vehicle, with all-terrains accounting for 11.9% (n=30). Eighty-nine percent (n=225) did not replace their vehicle tires in preparation for winter driving. Figure A.1 summarizes the reasons why a driver chose not to install studded tires. The respondents were able to choose more than one option, so the total percentage exceeds 100%.

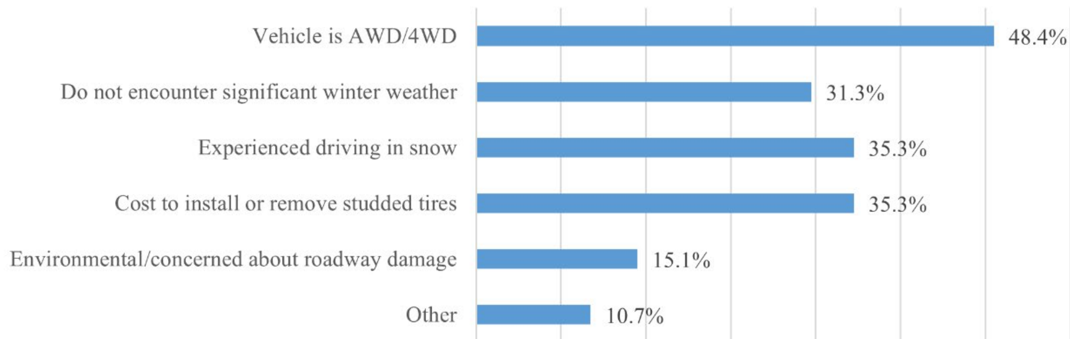

Figure A.1. Reasons Why Drivers Do Not Install Studded Tires.

Only 18.3% (n=46) of non-studded tire users carry snow-chains in their vehicles, and those who carried snow-chains used them less than once on average (0.51) over the last three winters.

Perceived Studded Tire Impacts

When asked about the kind of impact studded tire usage has on roadway surface deterioration, 41.2% (n=70) of drivers who use studded tires thought studded tires had a "moderate impact" (see Figure A.2). Only 8.2% (n=14) said that there was a "major impact". Eighty-six respondents (50.6%) said that there was "no impact", "minor impact", or was "neutral" (see Figure A.2). Exactly 100 (58.8%) respondents said that they "rarely encounter winter driving conditions where … studded tires negatively impacted…driving experience," and another 61 (35.9%) people said that they "occasionally" or "sometimes" encountered an occasion when studded tires negatively impacted their driving experience.

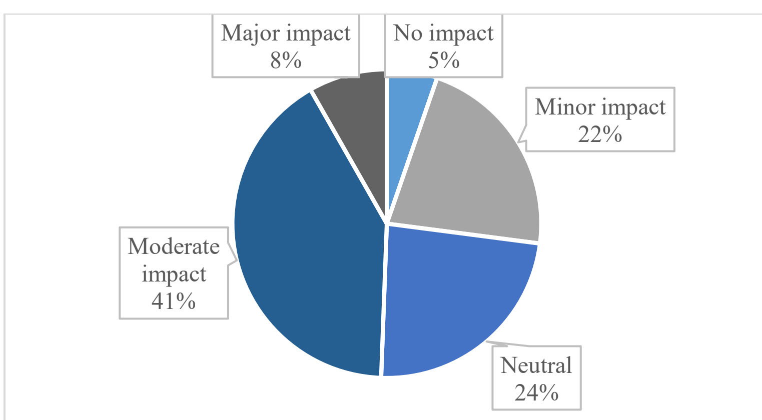

Figure A.2. Roadway Deterioration Impacts (Studded Tire Users)

Similar to respondents who used studded tires, 46.0% (n=116) of those who did not use studded tires thought that studded tire usage had a “moderate impact” on roadway surface deterioration. A higher percentage of those that do not use studded tires (13.9%, n=35) thought that there was a “major impact” on roadway deterioration when compared to those that used studded tires. The remaining respondents (40.0%, n=101) chose the options “neutral”, “minor impact”, or “no impact”. Figure A.3 shows the opinions of non-studded tire users on roadway deterioration.

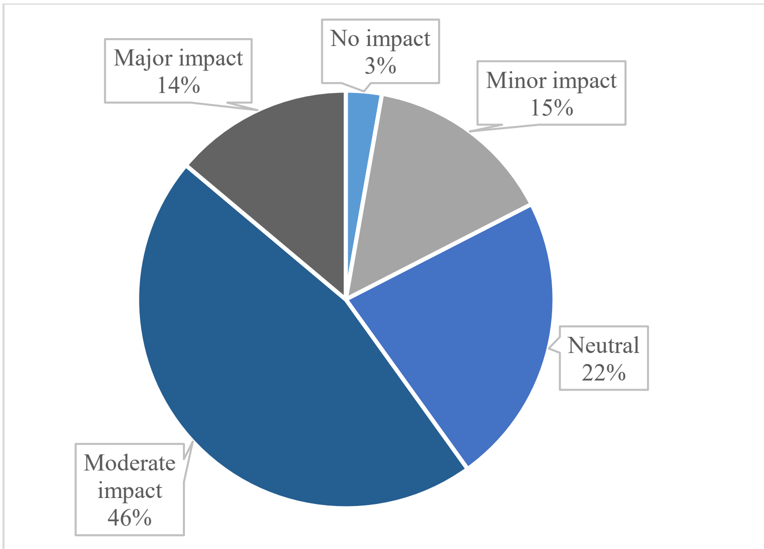

Figure A.3. Roadway Deterioration Impacts (Non-Studded Tire Users)

A chi-square test of independence was performed to examine the relationship between perceptions of roadway deterioration and studded tire usage. The relationship between these variables was not significant (χ^2 (4, N = 422) = 7.97, p = .093). In other words, the perceptions of roadway damage caused by studded tires was not viewed differently by drivers who used studded tires and those who did not.