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Survey and Economic Analysis of Pavement Impacts from Studded Tire Use in Alaska

Abaza 2017

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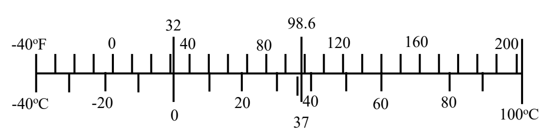
METRIC (SI*) CONVERSION FACTORS

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

In cold regions, such as Alaska, using studded tires is common among the public when driving in icy and snowy conditions. However, studded tires cause extensive wear to asphalt pavement, reducing pavement life. Almost 22 years have passed since the Alaska Legislature completed an analysis of the impact on Alaska's roadways from studded tire use. The Alaska Department of Transportation and Public Facilities initiated the present research effort to update the previous research results, determine the actual cost of roadway resurfacing due to studded tire use, and analyze fees collected from studded tire purchases versus costs incurred because of maintaining roadways damaged by studded tire use. A parking lot survey and a household survey were employed to examine the extent of studded tire use in the state and alternative cost-effective solutions for the Alaska roadway network. A pavement life cycle cost review was established based on an overall number of statewide road segments considering a number of variables to discover a realistic cost of roadway resurfacing and rehabilitation. This project's economic analysis is a planning level analysis based on 3,025 statewide road segments' resurfacing cost, road classifications, studded tire use, growth in traffic, studded tire season length, the adoption rate of non-studded tires, proportion of heavy load vehicles, average rut rate due to studded passenger vehicles and rut rate due to heavy wheel loads. Wear rates due to studded tires and rut rates due to wheel loads were found for different highway classes. Results show higher average wear rates due to studded passenger vehicles on freeways (0.0116 in. per 100,000 studded vehicles) than the average rut rates due to heavy wheel loads (0.0049 in. per 100,000 trucks) and lower average wear rates on arterial and collector roads (0.0062 in. and 0.0045 in. per 100,000 studded vehicles, respectively). The annual damage cost associated with studded tires statewide was found to be \$13.7 million—42 times the state's fees from studded tire sales and stud installations not considering the cost of crashes and other safety aspects caused by ruts. Policies are suggested to address future action on studded tire use, reduce resurfacing costs, and minimize roadway damage.

SUMMARY OF FINDINGS

In order to quantify the degree of pavement damage caused by studded tire use in Alaska, rut measurements and traffic data were collected from a sample of the state's freeways and arterial and collector roads. Data were classified per directional split, lane split, and vehicle classifications including passenger vehicles and heavy trucks. A parking lot survey and an online household survey were employed to determine an approximate value of studded tire use. A total of 1226 vehicles were surveyed in the parking lots throughout the Anchorage area where studded tire use was found to be 35%. More than 800 households, altogether owning 1531 vehicles, responded to the household online survey.

Data were analyzed and tabulated to differentiate between rutting caused by passenger vehicles using studded tires and rutting caused by trucks with heavy wheel axial loads. Results from the freeway segments show significantly higher average wear rates due to studded passenger vehicles—0.0116 in. per 100,000 studded vehicles—compared with average rut rates due to heavy wheel loads on the right lane—0.0049 in. per 100,000 trucks. Results also show significantly lower average wear rates due to studded passenger vehicles on arterial and collector roads, reaching 0.0062 in. and 0.0045 in. per 100,000 studded vehicles, respectively.

Wear rate results show significant resistance by stone mastic asphalt (SMA) and HMA Type R compared with other mixes used in structural sections of various projects. It may be observed cost savings using SMA and it should be further investigated.

The pavement costs of resurfacing were calculated from as-builts of 20 similar historical projects. The average cost of pavement resurfacing ranged from $2.06–$3.24 per square foot, based on the pavement structural section. Estimates show that studded tire use reduced asphalt surface life on the selected freeway sample by about 7 years, which is about 47% loss in pavement life based on the initial design life of 15 years.

An economic analysis on the planning level was conducted using base-case assumptions and based on 3,025 statewide road segments' resurfacing cost, road classifications, studded tire use, growth in traffic, studded tire season length, the adoption rate of non-studded tires, proportion of heavy load vehicles, average rut rate due to studded passenger vehicles and rut rate due to heavy wheel loads. The estimated total cost of mitigating road damage from studded tire use in Alaska over the next 20 years will amount to $203.2 million in 2019 USD. The effective annualized damage cost associated with studded tires still amounts to $13.7 million/year.

Historical data for tax revenue statewide were collected. Comparing the effective annualized damage to the annualized studded tire fees of $318,000, the resurfacing cost associated with road damage from studded tire use is more than 42 times the state's fees from studded tire and stud-installation sales.

CHAPTER 1 – INTRODUCTION AND RESEARCH APPROACH

Background

In cold regions, studded tire use is considered a factor that contributes to pavement rutting and damage. In Alaska, just like in other cold environments, pavement deterioration leads to increased cost associated with pavement resurfacing. The heavy wheel loads of trucks cause noteworthy damage to highway pavement as well. The Alaska Department of Transportation and Public Facilities (DOT&PF) is concerned about this issue and looking for feasible solutions to mitigate the damage.

Alaska is well known for its extreme temperatures. In Interior Alaska, winter temperatures have been recorded as low as -80°F, and summer temperatures have been recorded as high as 100°F. This extreme temperature range makes construction of roadways and transport challenging. Due to its northern latitude, Alaska, in some locations, experiences 24 hours of daylight in summer, and far less daylight in winter, adding further challenges. Alaska's immense size, coupled with high mountain ranges and huge glacier fields, increases the cost of building roads, making it prohibitive in much of the state, particularly in villages and towns in rural Alaska (AFHCP, 2018).

One common pavement defect caused by excessive use of studded tires is "rutting." The leading countries in studded tire use are Nordic countries, especially Finland and Sweden. Studded tire use estimates range from 95% in Finland (Leppänen, 1997) to 49% in Alaska (Hicks et al. 1990). In Alaska, historical studded tire use was 73% in 1970 and decreased to 49% in 1990 (Hicks et al. 1990). Then the percentage has remained about the same from 1990 to 2003 (Zubeck et al., 2004). Sweden has mandated winter tire use and lately asserted use during winter months. A 1996 study in Oregon estimated the annual cost to repair damage caused to its highways by studded tires, prior to lightweight stud regulations, at $37 million (1994 USD) (Brunette and Lundy, 1996). Another study in Oregon quantified the current use of studded tires, wear rates, and associated costs. Several techniques were used to account for the extent of studded tire use, from parking lot surveys to household surveys. That study showed a decline in studded tire use from 16% (1995) to 4% (2013) for registered vehicles during winter months and calculated an asphalt pavement wear rate of 0.0295 in. per 100,000 studded tire passes (Shippen et al., 2014). The present study has conducted a comparable cost-benefit assessment of studded tire use on roads in Alaska to quantify the net cost benefit as it relates to wear of pavement surfaces.

Problem Statement and Research Objective

Studded tires contribute to rutting of roadways in Alaska and contribute partially to the wear of marking stripes. In Alaska's central and south coast regions, the lifespan of pavement subject to studded tire wear is unspecified but is far shorter than the lifespan of pavement in the Lower 48. Based on the past construction projects in Anchorage, pavement resurfacing life due to rutting ranges from 7 to 9 years with an average of 8 years for freeways and higher for other road class such as arterials and collectors. Various states spend millions of dollars annually on repairing pavement damage due to studded tires, but in Alaska it was not clear whether the inflow of tax revenue generated from purchasing studded tires covers the damage caused by their use.

A pavement life cycle cost analysis was needed, one that includes the costs of pavement marking wear, traffic control, and design and construction engineering, to mitigate the damage caused by studded tire use. The study would identify the actual cost of pavement damage due to studded tire use not considering the cost of crashes and other safety aspects caused by ruts. In addition, the study explores alternative types of winter tires available in the market. A comparison was needed to correlate tax revenue with the impact of studded tire use on Alaska's roads. The study examine the extent of studded tire use in the state, as well as alternative cost-effective solutions for the Alaska roadway network.

The objectives of this study include the following:

1. Collect comprehensive studded tire tax revenue data based on the Alaska State Department of Revenue database and compare revenue data with pavement damage costs associated solely with studded tire use.
2. Conduct a comprehensive pavement resurfacing cost review from as-builts for 20 projects to establish a realistic cost of construction, which includes overall resurfacing costs, pavement marking wear, traffic control, and construction engineering costs.
3. Estimate winter tire options in Alaska to draw conclusions as to the ratio of studded tires/non-studded tires currently on the road system.
4. Conduct surveys to explore the current use of studded tires and alternative solutions that might be cost-effective for the Alaska roadway network.

5. Conduct an economic analysis to estimate the total cost of mitigating road damage from studded tires in Alaska over the next 20 years.

Literature Review

As part of this research project, a state-of-the-art literature review was conducted to find published research and statistical reports or articles relevant to the project. Databases used for the review included publications from state departments of transportation (DOTs), the Washington State Transportation Center, the Federal Highway Administration (FHWA), and the Transportation Research Board (TRB). Databases such as the Transportation Research Information Services (TRIS) and the National Transportation Information Service (NTIS) were also reviewed.

The main conclusion drawn from this literature review is that studded tire use, regardless of its other benefits, inflicts a certain amount of damage on road systems. Studded tires contribute to the wear of HMA (hot-mix asphalt) and concrete pavement, eventually forming ruts on the pavement surface. Studded tire laws and regulations vary by state. Some states allow unrestricted use of studded snow tires, while others set seasonal restrictions or prohibit studded snow tires.

Studded tire wear is considered one of the major distresses affecting the roadways in Alaska, especially on higher volume roads in the Central Region. The early rut monitoring programs that were carried out by Alaska DOT&PF reported that the studded tire wear rate in winter was significantly more than the rut caused by plastic deformation in summer as shown in figure 1.1.

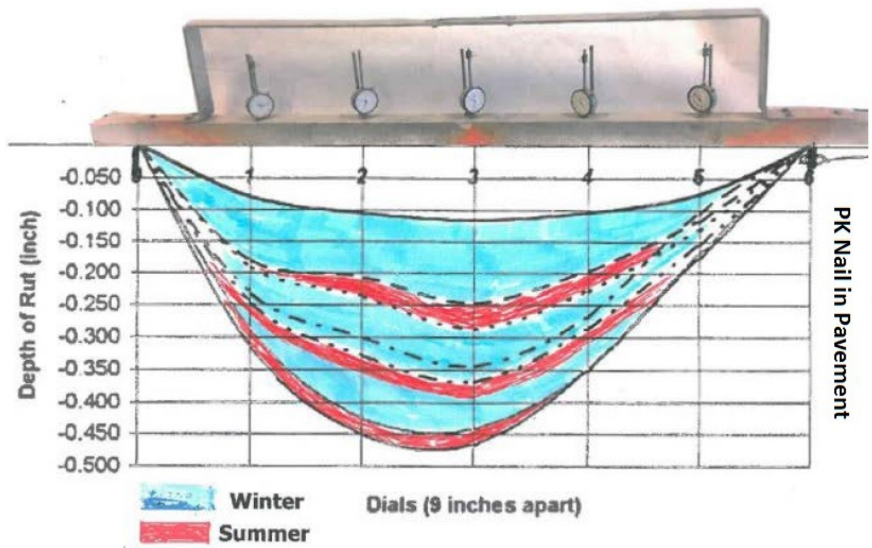


Figure 1.1 Rut Depth Progression (Iskra, 2018).

The literature review showed that different pavement wear rates were published earlier in other states like Washington and Oregon. The wear rate of PCC (Portland cement concrete) is about 0.0091 in. per 100,000 studded tire passes. The wear rate of asphalt pavement is about 0.0295 in. per 100,000 studded tire passes (Malik, 2000). The updated wear rate estimate on asphalt pavements will be considered 0.25 in. per million passes, which ranges between Alaska DOT&PF estimates in 1996 of 0.102–0.148 in. per million passes (Barter 1996), Oregon DOT estimates of 0.34 in. per million passes, and Washington DOT estimates of 0.170 in. per million passes. Damage to pavement on Washington state highways due to studded tires is estimated at $16 million annually. Damage to pavement on Oregon state highways due to studded tires is estimated at $8 to $10 million annually. Road damage caused by studded tire use also affects overall traffic safety and performance. The rutting caused by studded tires reduces road safety for all motorists when water collects in pavement ruts and creates dangerous driving conditions like hydroplaning and increased splash and spray.

Previous studies showed that there is a direct proportional relationship between pavement wear due to studded tires and traffic conditions such as traffic volumes, proportions of studded tire use, and traffic speeds. Researchers concluded that the dynamic abrasion force due to studs increases with the increased traffic speed (Arrojo, 2000). In addition, Jacobson (1998) adjusted the pavement wear models with wear factor ranges from 0.65 to 1.5 associated with different traffic speed ranges, from 30 mph to 70 mph, respectively. The impact of studded tire damage increased with the increase of traffic speeds from 50 mph to 75 mph as shown in Figure 1.2

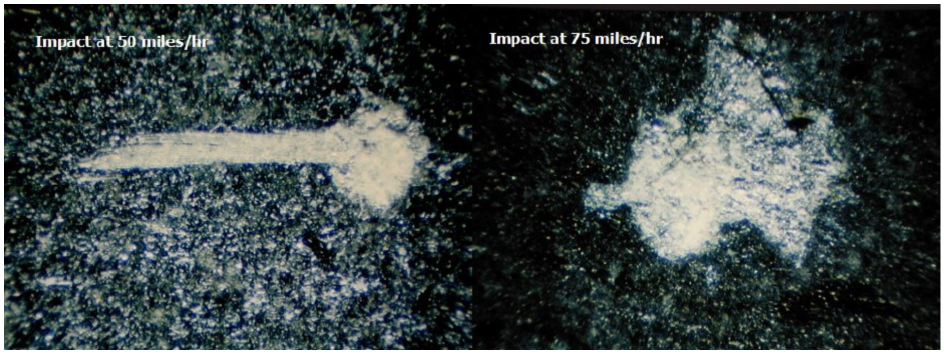


Figure 1.2 Studded Tire Impacts under different traffic speeds (Jacobson, 1999)

The performance of any HMA mix design can be enhanced by improving materials in the mix such as the binder or the aggregate. Moreover, pavement wear due to studded tires depends on the aggregate quality, aggregate size, and the binder. Arrojo (2000) reported that low quality aggregate can wear by a factor of 3 to 5 times faster than hard aggregates, and the use of modified binders enhances the properties of the asphalt and improves the wearing resistance to studded tires. Previous projects completed for Alaska DOT&PF, such as EB Tudor Road in 2005, also reported the benefits associated with the use of hard aggregate as shown in Figure 1.3. Results showed an additional improvement in the pavement life by 3 years when using hard aggregates rather than local aggregates.

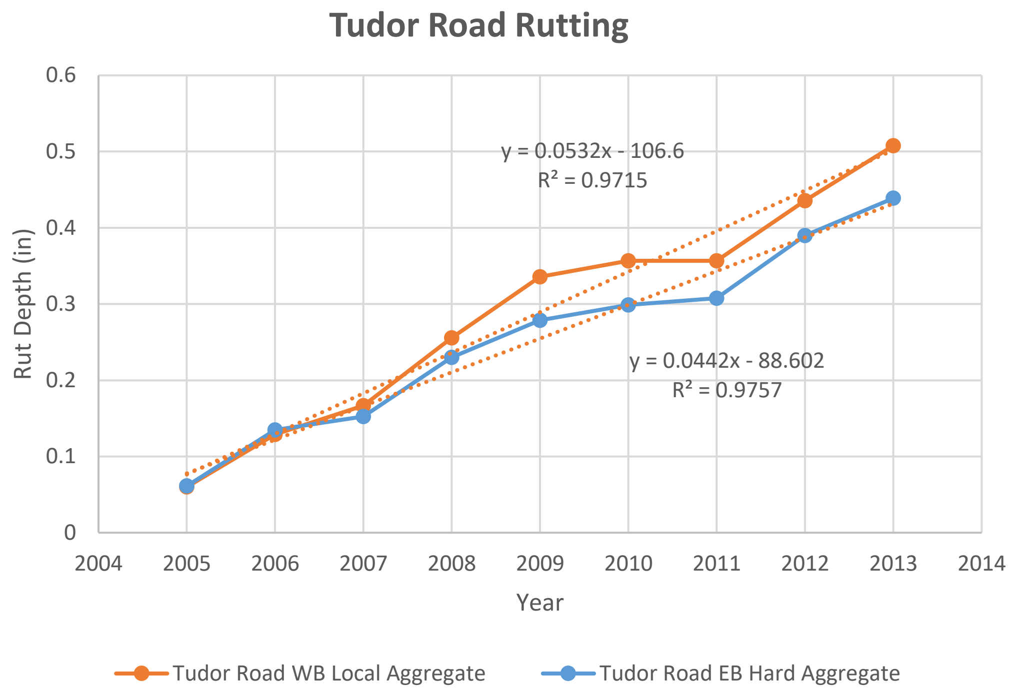


Figure 1.3 Tudor Road wearing rates (Iskra, 2018).

In an attempt to compare studded and studless winter tire performance, researchers have shown that tires with studs perform better on glare ice than non-studded tires, but are not as effective on snow- and slush-covered or wet pavement. In addition, vehicles equipped with studded tires require a longer stopping distance on wet or dry pavement than do vehicles equipped with standard tires, and in comparing the contact area between the tire and the pavement structure, tire studs reduce full contact between the tire rubber compound and the pavement (Zubeck, et.al, 2004).

In general, based on evidence from past research, the Federal Highway Administration (FHWA) support efforts to prohibit the use of studded tires (WSTC, 2013). Other countries like Japan, Poland, and Germany have banned studded tires use. The use of metal studs was banned in Japan because during winter months the use of metal studs leads to increase the dust along highways that cause health and environmental hazards. A detailed literature review can be found in Appendix A; it covers all topics needed to finalize the research methodology.

Research Approach

The literature review (see Appendix A) helped determine the final methodological approach. The methods and procedures described here are based on a methodology used by the Oregon State Department of Transportation (Malik, 2000), calibrated for Alaska local conditions, traffic volumes, and current studded tire use estimates.

The first step was to estimate the percentage of studded tire use in Alaska. A parking lot survey and an online household survey were conducted by the Department of Civil Engineering at the University of Alaska Anchorage.

The second step was to select sites for rut depth measurements and traffic data from several samples, including freeways, arterials, and collectors. Data were collected from the Pavement Management and Statewide Planning teams at the Alaska DOT&PF.

The third step was to identify pavement wear rate models. Wear rate estimates from studded tire traffic and truck traffic were calculated for each freeway sample. After establishing the theme from freeways and determining the contribution of stud wear on pavement, a comparable methodology was applied for arterial and collector roads.

The fourth step was to determine the pavement rehabilitation life cost. Pavement repaving/resurfacing cost was estimated from a list of as-builts for 20 similar historical projects. Then the cost of total pavement damage from studded tire use was estimated.

Finally, an economic analysis was conducted to compare Alaska's resurfacing costs associated with road damage from studded tire use with the state's tax fees from the sale of studded tires and stud installations.

CHAPTER 2 – FINDINGS

State-of-the-Art Summary

Rut depth measurements and traffic data were collected from the Alaska DOT&PF Pavement Management and Statewide Planning teams. Studded tire traffic data were collected through the surveys. Tax revenue data were defined based on the Alaska State Department of Revenue database. Rut depth measurements and traffic data were classified and tabulated for each highway segment per directional and lane split. Wear rate estimates from studded tire traffic, as well as from truck traffic, were calculated for each highway and for each lane. Pavement damage costs associated with studded tire traffic were determined for the various highway classifications, including freeways, arterials, and collectors. Finally, a comprehensive economic analysis was implemented to correlate pavement damage costs with annualized studded tire fees.

Survey Results

The extent of studded tire use in Alaska was examined to learn the percentage of studded tire traffic statewide. A comprehensive parking lot survey was conducted by the Department of Civil Engineering at the University of Alaska Anchorage. A total of 1226 vehicles from eight parking lots throughout Anchorage were surveyed covering public, private, and commercial parking lots. From the parking lot survey, the average studded tire use was found to be 35% with a standard deviation of 5%. This percentage was used to simulate actual studded tire traffic during wintertime. Details of the parking lot survey, including methodology and procedures, are described in Appendix B.

A comprehensive household survey was also conducted with a sample of more than 800 households, including ones in Anchorage, Palmer, Wasilla, Fairbanks, Juneau, and Kenai. Detailed survey questions, responses, results, and interpretation are given in Appendix B.

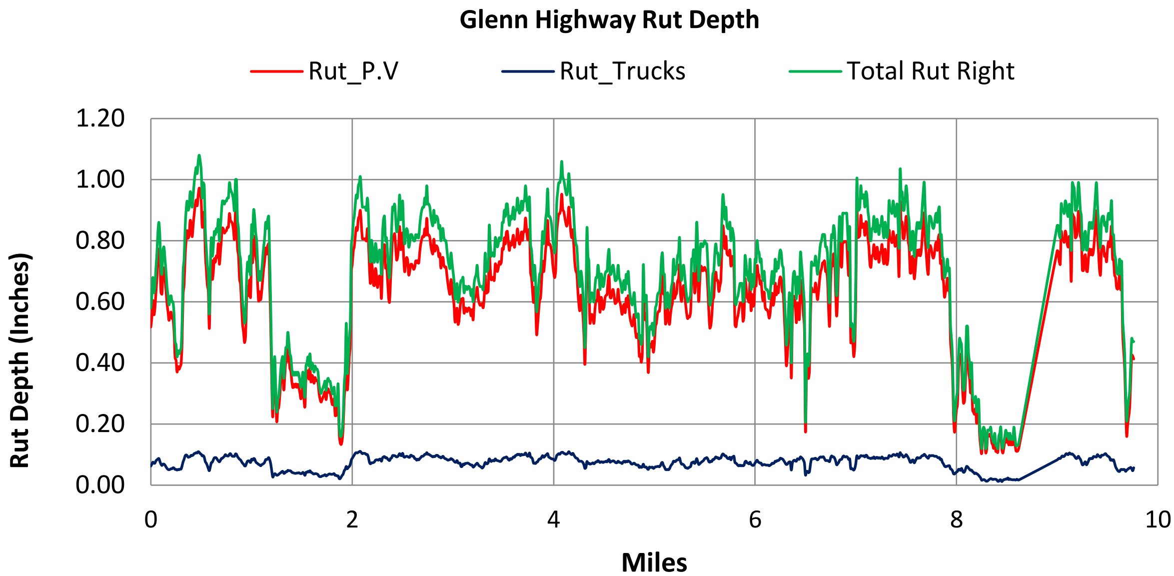
Traffic Data Analysis

Data on annual average daily traffic (AADT) was provided by the Alaska DOT&PF Transportation Data Program. Highway traffic data were collected from permanent stations located on different highway segments. Other characteristics for traffic, such as growth rates and average monthly daily traffic, were taken from the Alaska DOT&PF Traffic Volume Reports (Alaska DOT&PF, 2016), which are published annually on the department’s website. Traffic data were derived from a sample of Alaska's freeways, arterials, and collectors. Roadway condition data were referenced from the Alaska DOT&PF Pavement Management database. A balanced sample size was considered from each highway classification. Local roads were excluded from the analysis because of their long pavement rehabilitation life and because they are damaged less by studded tires due to low speed limits. Detailed information regarding sample size, permanent stations examined, and length of miles selected for each site can be found in Appendix C.

Rut Depth and Wear Rate Analysis

Data sets of rut depth measurements were collected by the Alaska DOT&PF Pavement Management and Preservation Office from several sections of the Alaska Highway system. These sections represent a statistically significant sample size from several highway classifications. The data sets were gathered from profiler measurements that were averaged every 0.01 miles (52.8 ft). Each average reading constitutes one observation. Each data set in the rut measurements was combined with the traffic data and current estimates of studded tire use to generate wear rate models. Wear rates were expressed as a function of the rut depth over the average daily traffic. Two wear rate models were generated for each highway sample, one representing damage as a result of studded tires and the other representing damage as a result of heavy trucks. The freeway samples showed significant wear rates on the right lane as a result of studded tires, higher than the rut rates from wheel loads. Figure 2.1 shows a sample distribution of wear rates over segments of the Glenn Highway. Other highway wear rates and the models can be found in Appendix D.

Results from the freeway segments showed significantly higher average wear rates due to studded passenger vehicles, reaching 0.0116 in./100,000 studded vehicles, compared with average rut rates due to heavy wheel loads on the right lane that reach 0.0049 in./100,000 trucks. These results show evidence to support the claim that studded tires contribute to pavement deterioration, more so than heavy wheel loads. In addition, average wear rates due to studded passenger vehicles are significantly lower on arterial roads, reaching 0.0062 in./100,000 studded vehicles. Results showed a significantly lower average wear rate due to studded passenger vehicles on collector roads, reaching 0.0045 in./100,000 studded vehicles, compared with average wear rates on freeway and arterial segments, respectively.



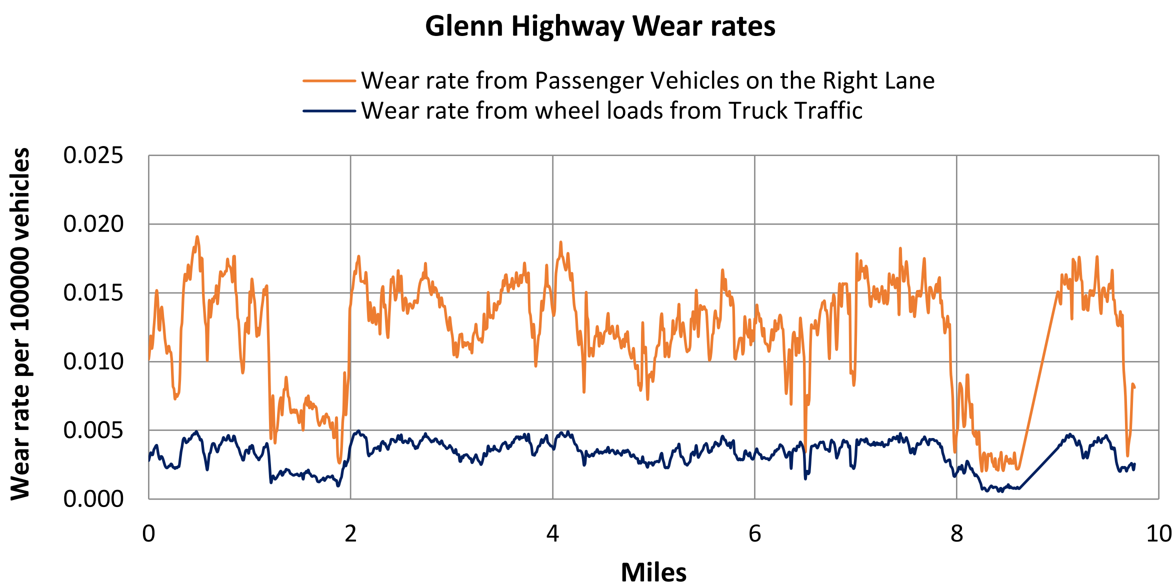


Figure 2.1 Distribution of wear rates for the Glenn Highway

Cost Estimates

A life cycle cost analysis was conducted, comparing pavement annual expenditures statewide with annual tax revenues from the purchase of studded tires. Large-scale projects that have at least 6 to 10 miles of mill and fill were selected for estimating the cost of pavement resurfacing and rehabilitation per square foot. Pavement direct costs such as structural section price, milling/filling price, marking/ striping, traffic maintenance, and construction signing were included in the total price. The average cost of pavement resurfacing ranged from \$2.06–\$3.24 per square foot based on the pavement structural section.

The pavement damage cost due to studded tires was then defined per vehicle miles of travel. The methodology was based on estimating the average rut threshold for every roadway classification. This rut threshold was assumed to be the cut-off point, which ranges from 0.5–0.81 in. in rut depth that should require resurfacing and rehabilitation. The average estimated cost of damage due to studded tires on freeways amounted to \$116,867 per lane mile. A detailed cost analysis can be found in Appendix E.

Finally, the cost due to reduction in pavement life as a result of studded tire traffic was estimated. Using the estimated percentage of studded tire use statewide and the average rut threshold, the level of studded tire traffic equates to a certain value of damage per year. The results suggest that the effect of studded tires reduces the asphalt surface life by 6–8 years with an average of 7 years, which represents about 47% loss of pavement life.

Economic Analysis

All paved roads statewide, excluding unpaved or gravel roads, were analyzed for resurfacing and rehabilitation needs. The cost of pavement rehabilitation from as-builts of 20 similar projects was used as an estimate of the total resurfacing cost of mitigation. The estimate of the cost took into consideration studded tire use, growth in traffic, studded tire season length, the adoption rate of non-studded tires, proportion of heavy load vehicles, average rut rate due to studded passenger vehicles and rut rate due to heavy wheel loads. Representation of these variables were selected based on statewide numbers or representation from central region to reflect a specified level of confidence. In addition, the effective annualized damage cost was assumed equal to the annualized present value. Using base-case assumptions, the estimated total cost of mitigating road damage from studded tires in Alaska over the next 20 years is \$203.2 million in 2019 USD in present value terms, discounting any future damages by 3%. The effective annualized damage cost associated with studded tires still amounts to \$13.7 million annually. The Alaska Department of Revenue tire fees for the past 6 years were analyzed (ADOR, 2018). Published annual fees from studded tire sales and stud installations were divided by the tire fee of \$5 to calculate the number of studded tires and stud installations sold each year. Comparing the effective annualized damage to the annualized studded tire fees of \$318,000, the resurfacing cost associated with road damage from studded tire use is more than 42 times larger than the state's fees from the sale of studded tires and stud installations. A detailed economic analysis can be found in Appendix F.

CHAPTER 3 – INTERPRETATION, APPRAISAL, AND APPLICATIONS

Alaska's studded tire regulations are in a state of change. As of 2010, it is not mandatory for Alaska drivers to install winter tires on their vehicles. The Alaska Legislature is taking into consideration steps to enforce installing winter tires, whether studded or non-studded. Based on Alaska Statute 28.35.155, studs should not exceed 0.25 in. and must only be used between September 15 and May 1 because of related pavement damage. Studded tires, regardless of their advantages and driving performance enhancement, inflict significant damage on Alaska roadways. The Alaska DOT&PF has made many efforts to quantify and reduce the risk of pavement damage associated with studded tires. Below are important interpretations and results from this research.

- Based on annual published reports by the Alaska DOT&PF on traffic volume and vehicle classification, the percentage of trucks is not significant in total traffic volume compared with passenger vehicles. Most rutting on Alaska roadways is caused by studded tires on passenger vehicles. Though some trucks use studded tires, trucks are not considered in this research because the percentage of trucks using the roadway is small relative to passenger vehicles.

- Results from the household survey of Alaska households show that 21% use studded tires more than 6 months of the year; 1.34% use studded tires the whole year. Based on an Alaska DOT&PF report (Barter et al., 1996), the 3–6% of motorists who use studded tires during the summertime are directly responsible for $1 million in damage per year (1996 USD). According to the Bureau of Labor Statistics Consumer Price Index, the dollar has experienced an average inflation rate of 2.10% per year. Prices in 2018 are 58% higher than prices in 1996. In other words, $1 in 1996 is equivalent in purchasing power to $1.58 in 2018. The result is an increase of $5.52 million in damage cost per year in 2018 on Alaska roadways, considering the growth in traffic.

- Legislatures in other states have made many attempts to prohibit the use of studded tires. Based on Barter et al. (1996) and the literature review that is part of this report (see Appendix A), lightweight studs and heavy metal studs provide the same driving performance and road traction. A ban on using heavy metal studs and switching to lightweight studs will result in a net cost savings of 50% in total pavement damage.

Furthermore, based on the research results, total pavement life will increase by 7–10%. Therefore, a ban on using heavy metal studs is encouraged. Lightweight studs are tax free by Alaska law. In addition, there is no difference in retail costs between both types of studs.

- Based on annual snowfall data published by the National Weather Service, total snowfall has decreased from 146.2 in. in 1992 to 70 in. in 2015 (NWS, 2017). Due to the warming trend in Alaska, a shortening period of studded tire use during wintertime might result in significant cost savings. It is highly recommended that, based on historic weather data, a shortened period of studded tire use be considered.

- The prototype freeway samples considered in this study were taken from actual Alaska DOT&PF resurfacing jobs. For example, SMA mixes were used for Glenn Highway improvement and resurfacing projects done in 2003, and for Northern lights & Benson Boulevard resurfacing projects done in 2001; HMA Type R and Type V were used for Seward Highway MP 115–124 resurfacing and Minnesota Drive resurfacing. Wear rate results showed significant resistance in SMA and HMA Type R compared with the resistance seen in structural sections used in other projects. Further consideration of investing research efforts in SMA is highly recommended.

- Quantifying the total number of studs embedded per tire should be regulated by Alaska law. Based on Barter et al. (1996), pavement damage is caused primarily by the total number of studs installed in a tire passing over the road surface. Studded tires have different stud numbers and arrangements. Alaska law does not regulate the number of studs per tire. Manufacturer surveys show new stud technology available in the market. With this new technology, studs have the ability to perform like steel springs, reducing raveling force once the stud hits the hard pavement surface. On ice and snow, the studs engage fully. Figure 3.1 shows the structure of the new studs. It is highly recommended that stud count per tire per tire diameter be enacted in Alaska.

Figure 3.1 New stud technology.

- Drivers consider the use of studded tires important for winter driving because of the increased sense of safety and improvement in driving performance on snow-covered and icy roads. However, research and literature show that improved traction and adjusting to winter driving is just public perception without any significant scientific evidence.

- The increased rate of crashes associated with studded tire use is related to driver confidence. Motorists with studded tires tend to drive at higher speeds because they have a sense of improved traction. The household survey questionnaire results show that people living in hilly or mountainous areas rely on studded tires during wintertime. A general ban or prohibition on using studs may not be a good idea; however, increasing public awareness of the new technology in non-studded winter tires or switching to lightweight studs may reduce pavement damage. Though the state encourages the use of lightweight studs by imposing fees on heavyweight studs, the household survey results show low interest in switching to lightweight studs.

- Based on the literature review, further consideration should be given to encourage drivers to place studded/non-studded winter tires on all four wheels rather than only two wheels to avoid slipping and enhance directional control.

- Barter et al. (1996) reported 0.13 in. of wear rates per million studded tire passes. This wear rate value is equivalent to 0.013 in. per 100,000 studded tire passes. Based on wear rate estimates from the current research, a reduction in wear rate of 0.004 in. was achieved in the period 1996 to 2018. This change in wear rate can be attributed to improved HMA, use of hard aggregate, and increasing use of lightweight studs.

In order to reduce the resurfacing costs associated with road damage caused by studded tires, below is a list of different policy options that Alaska might consider implementing.

- Option A: Phase out the allowed use of studded tires.
- Option B: Ban the use of heavy metal studs and switch to lightweight studs.
- Option C. Subsidize the sale of non-studded winter tire technology.
- Option D: Shorten the studded tire season by 2 weeks on either end, consistent with recently observed climatic changes.
- Option E: Educate motorists about the safety of non-studded winter tires.

Appendix G contains more recommendations and the detailed results from applying each policy option.

CHAPTER 4 – CONCLUSIONS AND SUGGESTED RESEARCH

Conclusions

There is sufficient evidence to conclude that the use of studded tires in Alaska is significant. Research results show that average studded traffic decreased from 49% in 1990 to 35% in 2018, but it is still significantly high. Improvements in pavement mix designs and the use of good-quality hard aggregates, modified oils, and crumb rubber have reduced pavement wear rates due to studded tire use. The pavement damage wear rate has declined by about 22% since 1996. A notable point, however, is that Alaska's traffic volume and studded tire traffic growth will likely lead to an increase of pavement damage in the future.

The purpose of this research was to quantify the degree of pavement damage caused by studded tire use. Estimates for wear rate damage due to studded tire use range from 0.0108 in. per 100,000 studded tire passes for stone mastic asphalt to 0.0122 in. for HMA Type R. Average estimated wear rates are found to be 0.0116 in. per 100,000 studded tire passes for freeways; 0.0062 in. and 0.0045 in. per 100,000 studded tire passes for arterial and collector roads respectively. Considering these wear rate estimates, an increased amount of $13.7 million in roadway damage cost occurred in Alaska based on the economic analysis. However, with the introduction of new technologies such as diamond-shaped studs, non-studded winter tires, and lightweight studs, and applying the general recommendations mentioned earlier, both the cost of stud use and the wear rates will decrease.

Alaska ranks the highest among all states in duration of time allowed for drivers to use studded tires. However, considering the warming trend and decreasing snowfall, it is highly recommended that the period allowed for studded tire use during wintertime be shortened. Past research results have shown that studs are extremely aggressive on dry pavement surfaces. It is not surprising that about 21% of studded tire users who continue to use studded tires during summertime are responsible for an additional estimated $2.0 million in pavement damage. Limiting studded tire use to wintertime only and enforcing the limit are highly recommended.

A detailed summary of research on new technology in winter tires is given in the literature review (Appendix A). Past research results have shown that new technology in winter tires and the brands available in the market are comparable in traction performance to steel studs on both ice and packed snow. The household survey results show a big gap in public awareness of non-studded winter tires. All parties in Alaska should work together to improve public awareness of the effectiveness of non-studded winter tires (retailers and manufacturers included), and the Legislature should continue increasing fees on heavyweight studded tires at the point of sale as an incentive for stores to increase the sales of non-studded winter tires or lightweight studs.

Some policy options can be considered by the Legislature and the Alaska DOT&PF to reduce pavement rehabilitation costs associated with studded tires. For example, phasing out the allowed use of studded tires would eliminate the current statewide pavement damage cost of $13.7 million. Replacing studded tires with studless winter tires is similar in cost and safety benefits for the consumer. A ban on or phasing out the use of heavyweight studs and switching to lightweight studs would reduce statewide pavement damage costs by $6.7 million. In addition, regardless of other policy decisions, the public should be encouraged to use studless winter tires through education and public awareness efforts. Tax-free or competitively priced tires should be provided at the point of sales. Detailed policy options can be found in Appendix G.

Suggested Research

The focus of this study was on the wear rate at which studded tire traffic inflicts damage on pavement; rut depth measurements were of primary interest. Safety issues related to ruts were not addressed. To further assess the cost of using studded tires and ruts in general, the International Roughness Index (IRI) could be considered in future research to correlate the rut radius of curvature to crash rates. Pavement rutting due to studded tire use affects crash severity and frequency in cold region environments. In order to support that claim, the correlation between roadway roughness and pavement surface characteristics with crash rates and severity should be determined. Safety Performance Factors (SPFs) and Crash Modification Factor (CMFs) models could be used to estimate the expected average crash frequencies related to pavement wear rates on the Alaska roadway system. Based on roadway characteristics and a collected data set of crash rates on the different highway segments studied in this project, the Empirical Bayes (EB) method could be applied for future crash prediction and estimation. These models will assist the Alaska DOT&PF and Legislature to integrate safety in the decision making process. Additional parking lot surveys could be implemented to further enhance the outcome of this research and achieve a more accurate percentage of studded tire use. Results from this study show a remarkable relation between pavement wear rates and roadway geometrical design. The effect of roadway vertical alignment and grade difference on stud wear rate should be analyzed.

Finally, a climatic study should be conducted, taking into consideration historical weather data and annual snowfall rates to support the recommendation that the studded tire season be shortened.

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APPENDIX A – LITERATURE REVIEW

Introduction

Nationwide, studded tire regulations vary greatly, including those that prohibit and restrict studded tire use seasonally to avoid rapid deterioration of pavement and reduce road wear. Thirty-three states set seasonal restrictions on metal-studded snow tire use, while seven states allow unrestricted use of metal-studded snow tires (Colorado, Kentucky, New Hampshire, New Mexico, North Carolina, Vermont, and Wyoming). Ten states prohibit metal-studded snow tires: Alabama, Florida, Hawaii, Illinois, Louisiana, Maryland, Minnesota, Mississippi, Texas, and Wisconsin (TISC and AAA, 2016).

Studded snow tires have metal studs embedded within the tread. These small, strong pieces of metal are designed to dig into ice, providing added traction. When the driving surface is not covered in ice, studded tires can damage the road. The metal studs are tough enough to dig into pavement, which is why many states limit their use during non-winter months and some states have outlawed them completely.

As a part of this research, a literature review of published research/technical reports was conducted to help determine the final methodological approach and provide insight to alternative technologies developed since the last Alaska DOT&PF study in 2004. The purpose of this appendix is to demonstrate the nature of pavement impacts and other effects caused by studded tire use. The literature review covers the following topics:

- History and background of studded tires
- States that use/ban/limit studded tires
- Types of studs being used
- New technology in winter tires
- Estimation of wear rates caused by studded tire use
- Impacts of studded tires on pavement surface life reduction
- Contribution of studs on total rut depth
- Cost estimates over pavement life cycle per tire
- Different surveys conducted in other states and level of studded tire use
- Impacts of studded tires on drivability and safety

- Comparison of studded tires, studless tires, and all-season winter tires and recent developments in this field

History of Studded Tires

In the early 1960s, studded tires were introduced in the U.S. and became popular in cold regions. The built-in traction of studded tires helped increase drivers' self-confidence and eliminated the problems associated with installing temporary aids such as tire chains. However, studded tires, though well accepted by the public as a means of enhancing mobility and safety, have long been the source of considerable controversy. In many states, studded tire use approached 30% of passenger vehicles by 1972, and in Alaska, Montana, and Vermont, approximately 60% of passenger vehicles were equipped with studded tires (Malik, 2000). Approximately 10% of passenger vehicles in western Washington use two or more studded tires and approximately 32% of passenger vehicles in eastern Washington use two or more studded tires (Scheibe, 2002). Unfortunately, the studs have caused substantial pavement damage that resulted in high maintenance costs for the road holders. In 1971, studded tires were banned in a few states in the U.S. and Canada (Angelov, 2003).

Germany, Poland, the Czech Republic, and Japan have banned studded tire use. In Japan, tires with metal studs were banned in part because of the health hazards created along highways during winter months from damaged concrete (WSTC, 2013).

In Denmark, studded tires are permitted, with 90% of all car owners using them during the winter months. A Norwegian road grip study in 1997 led to an attempt to decrease studded tire use in Norway's largest cities (Angelov, 2003).

States that Currently Use/Ban/Limit Studded Tires

In the U.S., no overlapping regulation for all states forces drivers to use winter tires in wintertime. Regulations can vary from region to region. A survey of U.S. metal-studded snow tire regulations in all 50 states and the District of Columbia was compiled by the Tire Industry Safety Council (TISC) and American Automobile Association (AAA). Table A.1 provides a list of states and their studded tire regulations as of October 2016.

Table A.1 States that currently use/ban/limit studded tire

State	Permission	State	Permission
AL	Permitted (with rubber studs)	MO	Permitted November 2 – March 31
AK	Sep 15 - May 1	MT	Permitted October 1 – May 31
AZ	Permitted October 1 – May 1	NE	Permitted November 1 – April 1
AR	Permitted November 15 – April 15	NV	Permitted October 1 – April 30
CA	Permitted November 1 – April 30	NH	Permitted – No restrictions
CO	Permitted	NJ	Permitted November 15 – April 1
CT	Permitted November 15 – April 30	NM	Permitted-No restrictions
DE	Permitted October 15 – April 15	NY	Permitted October 16 – April 30
DC	Not permitted	NC	Permitted if not projected to be more than 1/16 inch when compressed
FL	Permitted (rubber studs only)	ND	Permitted October 15 – April 15
GA	Permitted only in snow and ice conditions	OH	Permitted November 1 – April 15
HI	Not permitted	OK	Permitted November 1 – April 1
ID	Permitted October 1 – April 30	OR	Permitted November 1 – March 31
IL	Not permitted	PA	Permitted November 1 – April 15
IN	Permitted October 1 – May 1	RI	Permitted November 15 – April 1 (only if not projected to be more than 1/16 inch; no metal)
IA	Permitted November 1 – April 1	SC	Permitted if not projected to be more than 1/16 inch when compressed
KS	Permitted November 1 – April 15	SD	Permitted October 1 – April 30
KY	Permitted	TN	Permitted October 1 – April 15
LA	Permitted (with rubber studs only)	TX	Permitted as long as studs do not damage highway and are rubber
ME	Permitted October 2 – April 30	UT	Permitted October 15 – March 31
MD	Permitted restricted. November 1 – March 31. Allowed only in western counties: Allegheny, Carroll, Frederick, Garrett, and Washington	VT	Permitted – No restrictions
MA	Permitted November 2 – April 30	VA	Permitted October 15 – April 15
MI	Not permitted	WA	Permitted November 1 – March 31
MN	Not permitted	WV	Permitted November 1 – April 15
MS	Not permitted	WI	Not permitted
WY	Permitted		

(TISC and AAA, 2016)

Types of Studs Being Used

A tire stud consists of two basic parts that have varied in size, weight, and composition over the years. The outside part of the stud is referred to as the stud jacket or sleeve; a flange at the base of the stud jacket holds the stud in place. The stud core, pin, or insert is situated within the jacket and protrudes from the tire to make contact with the pavement. After insertion of a tire stud (jacket and pin) into the tire, a "breaking" period occurs, during which the tire rubber completely surrounds the stud jacket, filling any space between the jacket and the rubber. In this way, the rubber secures the jacket in place (Angerinos, 1998).

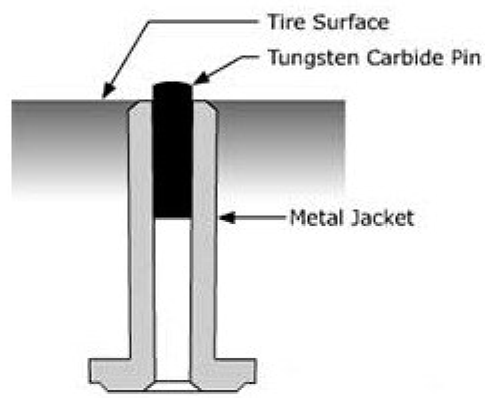

Figure A.1 Stud construction (Vermont Tire and Services, 2017)

Conventional studs in the 1960s were approximately 0.307 in. (7.8 mm) long, with a protrusion of about 0.087 in. (2.2 mm). Since the 1970s, because stud weight and protrusion length were shown to be significant factors in pavement wear rates, both weight and protrusion have been reduced. The advent of the controlled protrusion (CP) stud allowed for nearly a 40% reduction in pin protrusion—0.039 to 0.059 in. (1.0 to 1.5 mm)—by using a tapered pin that is able to move back into the stud jacket as the tire rubber wears. In the 1960s, the average weight of the conventional stud was approximately 0.081 oz. (2.3 grams), while the typical CP stud, which is the only stud in use in the U.S. today, weighs 0.059 to 0.067 oz. (1.7 to 1.9 grams) (Angerinos, 1998). In Scandinavian countries, additional efforts have been made to reduce stud protrusion and weight. Studs there now range in length from 0.047 to 0.059 in. (1.2 to 1.5 mm) and weigh approximately 0.039 oz. (1.1 grams). Testing in Scandinavia has shown reduced wear effects for studs with a lightweight plastic jacket (0.025 oz./0.7 gram), as well as studs with a lightweight metal jacket (0.033 oz. /0.95 gram) (Brunette et. al., 1996).

New Technology in Winter Tires

Studless winter tire manufacturers use advanced rubber compounds or additives to increase traction in winter driving conditions. In general, studless tires designed for passenger vehicles are constructed with soft rubber compounds. Trucks and heavier vehicles use studless tires made with hard rubber compounds that last longer under the extra weight. Among the most popular studless winter tire technologies is Blizzaks by Bridgestone Americas Tire Operations, in which a multi-cell rubber compound with microscopic pores is used to provide traction on ice. Toyo Tire and Rubber Company's Celsius tires have ground walnut shells embedded in the tire tread to dig into ice and snow. Yokohama Tire Corporation uses absorptive carbon flakes and resin-coated shelled microbubbles in its Ice Guard tires to cut through water and icy surfaces. In Michelin North America's X-Ice tires, vertical tunnel-like tubes are used in tread blocks to allow water to escape.

In the research report *"An Overview of Studded and Studless Tire Traction and Safety,"* Scheibe (2002) compiled performance-based data from a number of sources and provided 17 conclusions about winter driving traction aids. The traction of studded tires is slightly superior to studless tires only under an ever-narrowing set of circumstances: clear ice near the freezing point, a condition with limited occurrence. For the majority of test results reviewed for snow, and for ice at lower temperatures, studded tires performed as well as or worse than Blizzaks. For those conditions in which studded tires provided better traction than studless tires, the increment usually was small. The precise environmental conditions under which studded tires provide a traction benefit are relatively rare. The maximum frictional gain (in comparison with non-studded—not studless—tires) is found for new studded tires on smooth ice, where these tires have been shown to provide up to a 100% gain in certain tests Scheibe (2002). However, the relative frictional gain of studded tires diminishes or becomes negative on roughened ice, as temperatures drop, as the studs wear, or if the comparison is made with studless tires. The single best indicator of tire performance is braking distance and deceleration. Studded tires may reduce the risk of drivers misjudging the necessary braking distance they need and may improve the braking potential of anti-lock brakes. In one set of tests in Alaska, studded, studless, and all-season tires performed nearly equally on snow. On ice, stopping distances for studded tires were 15% shorter than for Blizzaks, which in turn were 8% shorter than for all-season tires. In another set of tests in Alaska, studless Blizzaks offered the best traction performance, especially for braking on both packed snow and ice in comparison with studded tires and all-season tires. Pavement rutting caused by studded tires can cause a dangerous condition called tramlining, which is the disruption of directional control by a vehicle's tendency to follow the longitudinal ruts and/or grooves in the road. Any vehicle can exhibit tramlining on certain areas of the highway because of uneven pavement or severe rutting. In addition, hydroplaning, excessive road spray, and premature damage to pavement markings are some of the problems associate with studded tires (Scheibe, 2002).

Wear Rates Caused by Studded Tires

The report *"Review of Studded Tires in Oregon"* (Shippen et al., 2014) focused on quantifying the current use of studded tires and the wear and cost caused by that use. Some results include a decline in studded tire use from about 16% of registered vehicles in 1995 to about 4% in the 2013–2014 winter seasons. The wear rate of Portland cement concrete (PCC) is about 0.0091 in. (0.2311 mm) per 100,000 studded tire passes, while the wear rate of asphalt pavement is about 0.0295 in. (0.7493 mm) per 100,000 studded tire passes.

The technical brief *"Estimate of Annual Studded Tire Damage to Asphalt Pavements"* (WSDOT, 2012) discussed the total Washington statewide asphalt cost due to studded tires. The rutting due to studs depends on the rate of wear and the number of vehicles with studded tires being driven on the road. Estimates of the wear rate on asphalt pavements range from Alaska DOT&PF's reports of 0.102–0.148 in. per million passes, to Oregon DOT's reports of 0.34 in. per million passes (Angerinos et al., 1999). From these estimates, a wear rate between that reported by Alaska and Oregon is used in Washington State: 0.170 in. per million passes. Studded tire usage rates vary from the west side of Washington (estimated at about 9% of vehicles) to the east side of Washington (estimated at 25% of vehicles).

In a published paper entitled *"An Economic Analysis of Pavement Damage Caused by Studded Tires in Oregon,"* Gray (1997) qualitatively supported the premise that there is no social or safety benefit from studded tire use in Oregon. Quantitative cost analysis was limited to pavement rutting on the state highway system that is sufficient to reduce the useful life cycle of the pavement. A range of wear rates was estimated, reflecting the numerous factors that influence rutting susceptibility of pavements. The mid-points of wear rates for asphalt and PCC were 0.0386 in. and 0.0093 in., respectively.

Brunette and Lundy (1995) reported in *"Use and Effects of Studded Tires on Oregon Pavements"* the finding that studded tire wear shortens pavement life on high-volume routes in Oregon. Asphalt pavements that experience average daily traffic (ADT) volumes of 35,000 and 20% studded tire use were found to reach the threshold rut (3/4 in.) in 7 years. Portland cement concrete pavements that experience 120,000 ADT and 20% studded tire use were found to develop the threshold rut depth of 19 mm in 8 years.

According to a study done in Sweden (Jacobson and Hornvall, 1999), wear was measured through the SPS ratio (specific wear, grams of abraded material per vehicle with studded tires, and kilometer). This measure has no constant for a certain pavement type, but an approximate estimate of actual wear in specific conditions and during a specific period. The SPS average has decreased from 30 during the late 1980s to 8 at the turn of the century. The most wear-resistant pavements have SPS ratios of 2–4. In the winter season of 1994/95, wear was calculated to be 300,000 tons; in the late 1990s, wear had diminished to around 110,000 tons.

In Minnesota, the average terminal wear rates for normal bituminous wearing courses ranged between 0.75 in. (19.05 mm) and 0.95 in. (24.13 mm) per million studded tire passes (Preus, 1971). For conventional concrete pavements, the corresponding wear rates ranged from 0.30 to 0.47 in. per million studded tire passes.

Contribution of Studded Tires to Service Life Reduction

Engineering research indicates that tire studs damage hot-mix asphalt and concrete pavements, wearing away the pavement and eventually forming ruts on the pavement surface, which decreases overall pavement service life.

Reported wear rates differ and may be explained by the varying quality of paving materials. In general, surface wear per 1 million studded tire passes is consistently higher in asphalt concrete pavements as compared with PCC pavements, and factors that affect pavement wear are stud protrusion, stud weight, driving speed, and number of studs per tire (Angerinos, 1998). Of these factors, stud protrusion and stud weight have decreased over the years, resulting in a significant reduction in pavement wear, perhaps as much as 40%. However, as allowable speeds increase, the damage from studs is expected to increase.

According to a Washington State technical brief (WSDOT, 2012), considering an average western Washington highway, with 15,000 cars per day per lane and 9% of the cars having studded tires on one set of axles, there are 1350 cars per day with studded tires. From November to March, or for 150 days, there are 202,500 cars with studded tires per year on that stretch of highway, and 202,500 passes per year. Using the wear rate of 0.17 in. per million passes, this level of traffic equates to 0.0344 in. of wear per year. The WSDOT allows up to 0.5 in. (12.5 mm) of wear before programming rehabilitation, so this roadway would need to be rehabilitated in year 15. The normal life for hot-mix asphalt on this roadway in western Washington is over 17 years; therefore, the effect of studded tires reduces the asphalt surface life by approximately 2 years, or 12%. Given the uncertainty in wear rates, a range of 10% to 14% loss of pavement life is assumed for western Washington. For eastern Washington, on a highway with 8,000 cars per day per lane and where studded tire usage is higher (estimated at 25%), the pavement surface life would be reduced from an average 11 years to 10 years, or a 10% decrease. Given this uncertainty in wear rates, a range of 8% to 12% loss of pavement life is assumed for eastern Washington.

Contribution of Studs to Total Rut Depth

Rutting in hot-mix asphalt pavement is apparent in two main forms: either deformation from wheel loads on pavement that is insufficient to support heavy truck weight, or from tire wear, especially studded tire wear. Studded tires dig into the pavement and pick out small aggregate, eventually forming ruts. Based on this literature review, no studies before have shown any practical method to reduce load rut and stud rut. Although DOT&PF tried to use polymer in reducing rut and the initial results showed positive results. Both rut forms are quite distinct in cause and appearance.

The dual wheel width of a truck exceeds the width of a studded tire groove (or rut); the wheels of a passenger vehicle lay directly within the wear pattern. The dynamics of studded tire action include three phases: as the studded tire moves over the pavement, there are “spikes” in force at the beginning and at the end of the contact. During these spikes, energy is transferred to the pavement in the form of scratching. Between these spikes, the studs have a “punching” action that breaks up aggregate and picks out the pavement surface.

Assuming that 100% of trucks are moving on the right lane, the total rut measurements on this lane are due to the axle wheel loads of heavy trucks because no studs are impeded in the truck tires. Based on this assumption, 100% of rutting in the left lane is due to studded tire passes, excluding any rut measurements wider than the normal tire of passenger vehicles (Malik, 2000).

Cost Estimates Due to Studded Tires

In the publication *"Review of Studded Tires in Oregon,"* Shippen et al. (2014) identified three cost categories of studded tire damage mitigation. The base case scenario for these estimates predicts an annual average expenditure of about $4 million from the year 2012 to the year 2022.

Gray (1997) estimated the wear rates used to approximate rutting for the Oregon state highway system and to predict resurfacing expenses attributable to studded tire traffic. The results indicate that the cost of studded tire damage on Oregon state highways in 1995 was approximately $10 million. This averages $8 per tire/year.

In a technical brief (WSDOT, 2012), Washington State DOT reported a wear rates range of 10% to 14% loss of pavement life for western Washington. For eastern Washington, pavement surface life would be reduced from an average of 11 years to 10 years, a 10% decrease. Given this uncertainty in wear rates, a range of 8% to 12% loss of pavement life is assumed for eastern Washington.

The asphalt paving budget for the 2009–2011 biennium was $170.1 million statewide. Assuming a 60/40 split (western to eastern Washington), approximately $51.1 million/year is invested in western Washington asphalt pavements and $34.0 million/year is invested in eastern Washington asphalt pavements. Using the percentage of reduction in pavement life described above, for western Washington, 10% of $51.1 million is $5.1 million and 14% of $51.1 million is $7.2 million; for eastern Washington, 8% of $34.0 million is $2.7 million and 12% of $34.0 million is $4.1 million. The total statewide asphalt cost due to studded tires can be estimated between $7.8 million and $11.3 million per year.

Surveys and Level of Studded Tire Use

A published study (Malik, 2000) entitled *"Analysis of Pavement Wear and Cost of Mitigation"* discussed the use of studded tires in Oregon. According to Malik's research approach, the level of studded tire use in Oregon was determined using two methods: parking lot surveys and household telephone surveys. During the winter of 1994/95, the Oregon DOT conducted a parking lot survey of studded tire use in Oregon. Heavily used parking areas, mostly at shopping centers, were selected at various locations to represent Oregon DOT's five regions. At each parking location and at each time, data were collected from 200 parked cars, indicating if the vehicle had 2-wheel or 4-wheel drive, and if studded tires were mounted on front, rear, or both axles. In most cases, six visits were made to each location. All of the visits took place between the last week of November and the end of March. No visits took place during April, although studded tire use was permitted during that month. The parking lot survey results indicate an average statewide level of studded tire use of 18.15%.

In *"A Survey of Vehicles Using Studded, Smooth, or Snow Tires in Michigan,"* Copple (1971) counted only vehicles with Michigan license plates. After selecting a site, a cluster containing a predetermined number of vehicles was surveyed in order of physical location. Selected sites were primarily parking lots, but in smaller towns, vehicles parked on streets were surveyed. As a result, in this survey, the percentage of passenger cars using studs was 19.5%, while the percentage of pickup and panel trucks was 18.3%, and the percentage of 4-wheel drive vehicles was 4.5%.

Preus (1971) reported in *"Effects of Studded Tires on Pavement Wear and Traffic Safety"* that data collection was carried out in Minnesota between February and May 1, 1970, and from October 15, 1970, to January 4, 1971. About 84,000 questionnaires were mailed, with a return of 47%. The questionnaire served two main functions: to determine the proportion of vehicles equipped with each type of tire and to measure the amount of tire exposure to various road cover conditions. Responses from the questionnaire, as reported by Preus, revealed the following for the total study period: 36% of autos were equipped with studded tires, but only about 1% of autos had them on all four wheels. Thirty-eight percent of driving during the study period was with studded tires, about 23% of driving was with snow tires, and about 39% of driving was with regular (All season) tires.

Bruce and Lundy (1974) undertook a relatively small data sampling and augmented some of the new Oregon DOT parking lot data to develop estimates of the level of studded tire use. For the purpose of this study, a parking lot survey and an extensive telephone survey were conducted. According to the parking lot data, approximately half of all vehicles using studded tires had them on both axles, effectively doubling the studded tire passes for those vehicles. Brunette (1995) estimates the statewide average use of studded tires at 23.8%, with regional rates ranging from 65.7% to 7.4%.

Studded Tires and Safety

In the report *"Effects on Accidents of Reduced Use of Studded Tyres in Norwegian Cities,"* Elvik and Kaminska (2011) present a study evaluating the effects on accidents of reduced use of studded tires in five Norwegian cities—Oslo, Drammen, Stavanger, Bergen, and Trondheim—based on discussion in Sweden regarding the effects of studded tires on safety, pollution, and public health. The study covers the period of January 1, 2002 to August 31, 2009. There is a concern that safety will deteriorate if the use of studded tires is reduced. A result of this study is that a clear dose-response relationship between changes in the use of studded tires and changes in the number of injury accidents was found. This pattern suggests that the changes in the number of injury accidents are mainly attributable to changes in the use of studded tires. The changes vary between a reduction of nearly 1% and an increase of nearly 10% in the number of injury accidents during the season when the use of studded tires is permitted. On average, the number of injury accidents increased by 2% during the season for studded tire use. A separate Norwegian study sent a questionnaire to drivers who reported car damage during the winter of 1994/1995 to assess the effect of studded tires on winter accident rates. The study found no significant difference in accident involvement between drivers with studded and non-studded tires when controlling for other car and driver characteristics (Fosser, 1995).

More research has been done on the relationship between studded tire use and safety factors. This topic will be addressed in future projects for Alaska DOT&PF designated for that purpose.

Studded Tires versus Studless and All-season Tires

A test study in Alaska was conducted to determine the performance of studded tires in comparison with all-season tires and Blizzaks tires on packed snow and ice and on bare pavement. The first test, conducted by the University of Alaska Fairbanks, involved the use of the same three types of vehicles used in the 1995 tests (Zubeck et. al., 2004), but for this series of tests, the Lumina had a four-wheel anti-lock braking system (ABS). Stopping distances were recorded from initial vehicle speeds of 25 mph (40.3 km/h) at a location in Fairbanks on packed snow and ice and on bare pavement. Most tests were conducted at near-freezing temperatures. Results showed that all three tire types produced the same results on packed snow. On ice, stopping distances were generally two or three times longer than on packed snow, and were shortest for studded tires followed by Blizzaks (8% longer) and all-season tires (15% longer). On bare pavement, stopping distances for Blizzaks and all-season tires were 5% and 2% shorter, respectively, than for studded tires, but the differences were deemed insignificant.

Scheibe (2002) concluded in *"An Overview of Studded and Studless Tire Traction and Safety"* that studded tires produce their best traction on snow or ice near the freezing mark and lose proportionately more of their traction ability at lower temperatures than do studless or all-season tires. On bare pavement, studded tires tend to have poorer traction performance than other tire types. This is especially true for concrete; for asphalt, there is little difference in stopping distance between studded and non-studded tires. Traction performance of studded tires is sensitive to stud wear. Studded tires may lose more of their traction ability over time (from stud wear) than studless tires. When stud protrusion diminishes to 0.024 in. (0.6 mm), the frictional effect from the studs becomes negligible. Tire tread wear (on studded tires) has relatively little frictional effect if stud protrusion is maintained at 0.039 in. to 0.043 in. (1.0–1.1 mm).

Literature Review Conclusions

The main conclusions of this literature review are that studded tire use, regardless of its other benefits, inflicts substantial damage to road systems. For many years, different road agencies have wanted to reduce that damage.

- Engineering research indicates that tire studs damage hot-mix asphalt and concrete pavements, wearing away the pavement and eventually forming ruts on the pavement surface.
- Thirty-three states set seasonal restrictions for metal-studded snow tire use. Seven states allow unrestricted use of metal-studded snow tires: Colorado, Kentucky, New Hampshire, New Mexico, North Carolina, Vermont, and Wyoming. Ten states prohibit metal-studded snow tires: Alabama, Florida, Hawaii, Illinois, Louisiana, Maryland, Minnesota, Mississippi, Texas, and Wisconsin.
- The wear rate of PCC is about 0.0091 in. per 100,000 studded tire passes. The wear rate of asphalt pavement is about 0.0295 in. per 100,000 studded tire passes.
- Damage to pavement on Washington state highways due to studded tires is estimated to be $16 million annually.
- Damage to pavement on Oregon state highways due to studded tires is estimated to be from $8 to $10 million annually.
- The road damage caused by studded tires reduces road safety for all motorists when water collects in pavement ruts caused by studded tires and creates dangerous driving conditions like hydroplaning and increased splash and spray.

- Tires with studs perform better on glare ice than non-studded tires, but are not as effective on snow- and slush-covered or wet pavement.
- Vehicles equipped with studded tires require a longer stopping distance on wet or dry pavement than do vehicles equipped with standard tires.
- Tire studs reduce full contact between the tire rubber compound and the pavement.
- The Federal Highway Administration (FHWA) supports effort to ban studded tires.
- Germany, Poland, and Japan have banned the use of studded tires. In the case of Japan, tires with metal studs were banned in part because of health hazards from dust along its highways during winter months due to damaged pavement.
- Based on the literature review, the wear rate estimate on asphalt pavements ranges between Washington DOT estimates of 0.170 in. per million passes and Oregon DOT estimates of 0.34 in. per million passes where old Alaska DOT&PF estimates in 1996 was 0.102–0.148 in. per million passes. The level of studded tire use will be determined on Anchorage, Alaska roadways using two methods: parking lot and household online surveys. Moreover, the contribution of studs to total rut depth will be considered 100% on different highways' left lanes.

APPENDIX B – SURVEYS

PARKING LOT SURVEY

Introduction

As a part of the project to identify the percentage of studded tire users in the State of Alaska, a parking survey was conducted of a sample of Alaska parking lots in Anchorage. The survey covered heavily used parking areas, mostly at shopping centers and major generators in the Anchorage area. The following sections represent the methodology, results, and analyses of the parking lot survey.

Methodology

Site selection

Seven sites were selected in Anchorage across different sections of the city to gain a diversity of respondents. The sample population represented a variety of income levels and educational levels. An additional site in Eagle River was considered to cover a broader geographic region, though this was accomplished primarily through the online survey, which covered all regions of Alaska. The selected sites include public institutions, commercial centers, private institutions, and shopping centers. The selected sites are shown on Figure B.1 and further details are given in Table B.1.

Figure B.1 Site location map for sites used in parking lot survey

Table B.1 Sites selected for parking lot survey

No.	Parking Lot	Type of business	Area in Anchorage
1	BP	Private Institution	Midtown
2	Fred Meyer	Commercial	South west
3	Lowe’s Home Improvement	Commercial	South
4	JC Penny Garage	Commercial	Downtown
5	UAA South Parking Lot	University	University-Medical District
6	Providence Hospital	Hospital	University-Medical District
7	DOT&PF Aviation Building	Govt. Institution	Airport west
8	Walmart	Commercial	Eagle River north

Sample size computation

The sample size used was determined using the following formula:

$$n = \frac{Z^2 pq}{E^2}$$

Where:

n = sample size,

Z = a number based on the confidence level,

p and q = the variance of the population, and

E = the maximum error of the estimation.

The confidence level is 95% (Z = 1.96) and the margin of error is 5%. The most conservative variance estimates for both p and q are 0.5. The calculation of sample size yielded that a minimum of 385 distinct vehicles were needed for the survey. The research team observed at least 75 vehicles at each of the eight sites, nearly doubling the minimum required for the purposes of this survey.

Survey Procedure

The parking survey was conducted in the City of Anchorage primarily in January and February of 2019. A total of eight parking lots were surveyed covering public, private, and commercial parking lots. The survey was conducted twice for each site to verify possible inconsistency of the data collection between visits for the same site. Approval to survey the sites was given by the owner of each parking lot before conducting the survey. General information of the parking site, including region within the city, type of business, parking type, parking system, and payment method, etc. were recorded. Then the following information was obtained about a minimum of 75 vehicles per site: vehicle type, drive type, types of wheel (studded or non-studded), use of studs (front, rear, or both). The form used for this survey is given at the end of this appendix.

Results and analysis

A total of 1226 vehicles were surveyed. A majority of the surveyed vehicles were SUVs (45%), followed by passenger cars (32%), then trucks (19%), and then vans (4%) (Figure B.2). Overall, 65% of the vehicles were all-wheel drive (Figure B.3). 35% percent of vehicles had studded tires (Figure B.4). The percentage of vehicles with studded tires, differentiated by location, are shown in Figure B.5. The figure indicates that the range of results between two visits are not significantly different, except that of Providence Hospital, DOT, and Walmart. The state owned vehicles at the DOT&PF Aviation Building might have biased the results because most state vehicles have studded tires. Further discussion is provided in the next section.

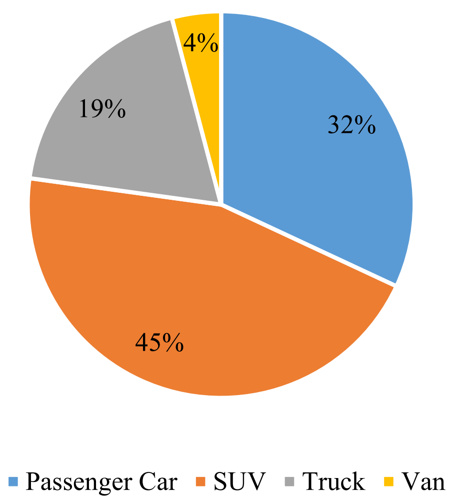

Figure B.2 Vehicle type

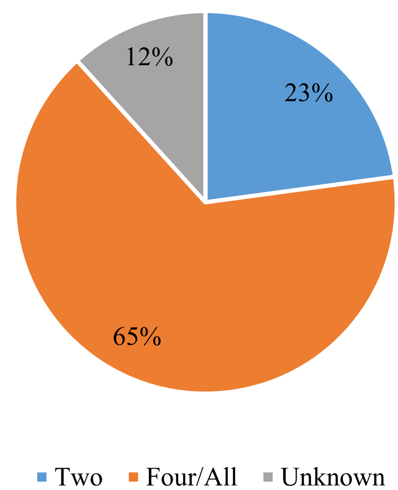

Figure B.3 Drive type of the surveyed vehicles

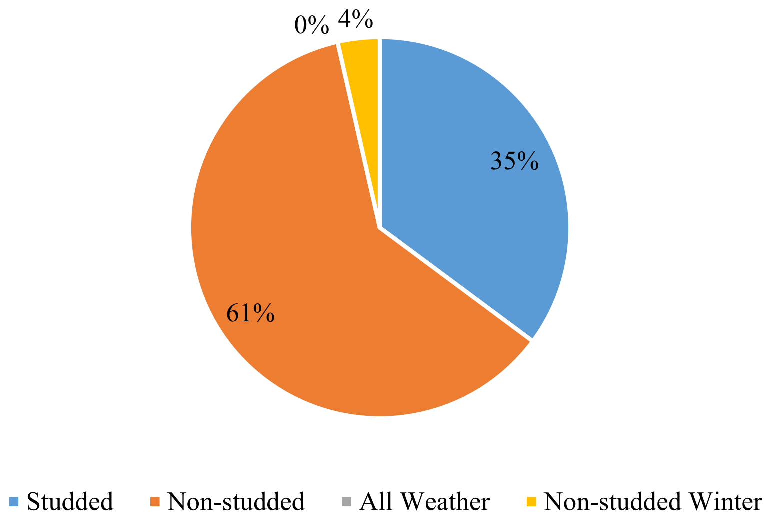

Figure B.4 Tire type of the surveyed vehicle

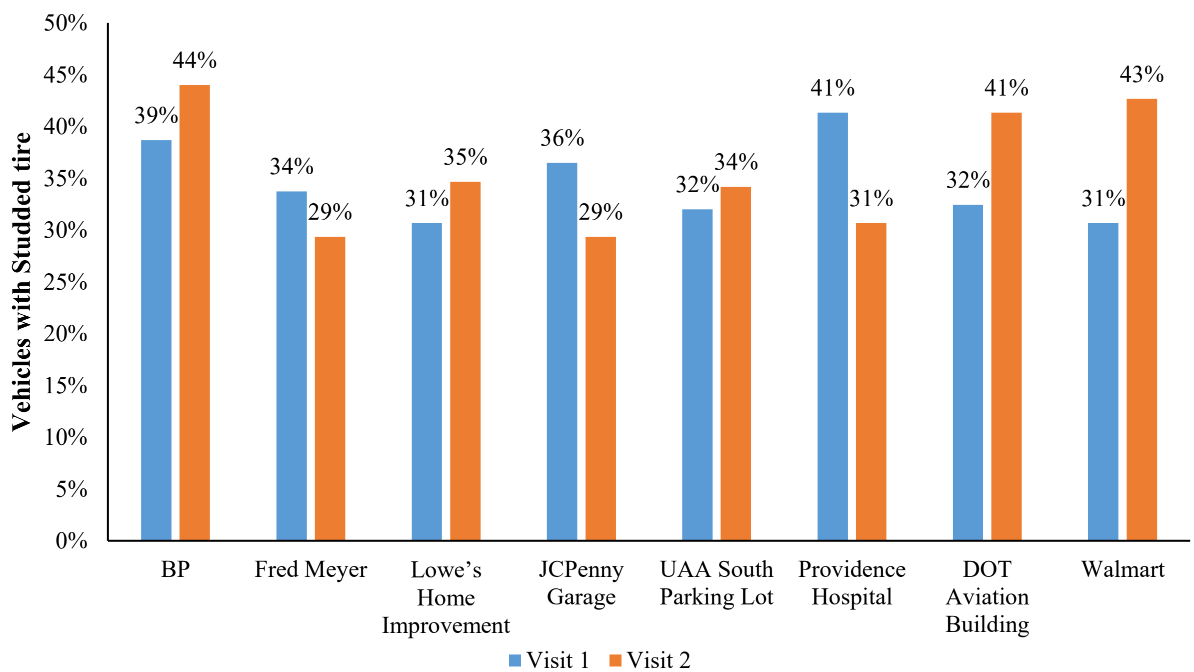

Figure B.5 Studded tire use in different parking lots

Descriptive statistics of the parking survey are given in Table B.2. On the first visit, the average studded tire use was 34% with a standard deviation of 4%, whereas the average was 36% with a standard deviation of 6% for the second visit. Overall, the average studded tire use was 35% with a standard deviation of 5%.

Table B.2 Descriptive statistics of studded tire use

	Visit 1	**Visit 2**	**Overall**
Mean	34%	36%	35%
Standard Error	1%	2%	1%
Standard Deviation	4%	6%	5%
Range	11%	15%	15%
Minimum	31%	29%	29%
Maximum	41%	44%	44%

Studded Tire Parking Lot Survey Form

General Information:

Date/Time:		Parking Site:	
Type of Business:		Parking Location:	
Parking Type:		Total Spaces:	
Parking System:		Payment Method:	

Detail Information:

Vehicle no.	**Vehicle Type** **P** = Passenger Car **S** = SUV **T** = Truck **V** = Van				**Drive Type** **2** = 2 Wheel **4** = 4 Wheel **U** = Unknown			**Tire Type** **S** = Studded **N** = Non-studded **A** = All weather/Radial **W** = Non-studded winter				**Location of Studs** **F** = Front **R** = Rear **B** = Both		
	P	**S**	**T**	**V**	**2**	**4**	**U**	**S**	**N**	**A**	**W**	**F**	**R**	**B**
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HOUSEHOLD SURVEY

A comprehensive household survey was conducted by the Department of Civil Engineering at the University of Alaska Anchorage (UAA). An online Qualtrics survey was programmed and distributed to the public through UAA Advancement, UAA student mailing lists, Alaska DOT&PF mailing lists, the 2018 Anchorage Transportation Fair, and other outlets.

The survey was programmed not only to determine the percentage of studded tire use, but also to capture the public point of view on using studded tires or alternatives. Different questions were designed to test public awareness and the public's experience with new technology in winter tires. The survey responses were received from more than 800 households, owning 1531 vehicles altogether. These households represent a balanced sample relive to population from all of Alaska's major cities including Anchorage, Palmer, Wasilla, Fairbanks, Juneau, and Kenai. The most recent collected information and studded traffic estimate by regions are summarized in Table B.3.

Table B.3 Studded tire usage in Alaska

Region	Vehicles w/stud	Vehicles w/o stud	Percentage
Anchorage	511	464	52.41
Palmer/Wasilla	66	89	42.58
Fairbanks	63	143	30.58
Juneau	19	35	35.19
Kenai	5	6	45.45
Other	80	50	61.54
Alaska	**744**	**787**	**48.60**

The household survey responses showed an average studded tire use of 48.6% per the sample population. A notable result from this survey is that 63.0% of the sample is considering switching from studded tires to new technology in winter tires, a trend that might decrease the percentage of studded tire traffic in the future. Also, 37.0% of the sample is not considering studless winter tires because of safety concerns (54.6%) and cost concerns (14.6%). The other reasons behind not considering studless tires are associated with public lack of awareness of non-studded winter tires; many drivers have no knowledge of current technology in winter tires.

Some households responded that they are aware of the performance of non-studded winter tires, but consider studded tires essential for winter driving, especially in hilly or mountainous areas to improve overall driving performance and safety, neglecting the fact that studs can cause rapid deterioration of pavement, which in itself will lead to other safety hazards. The majority of responses came from people 31–40 years of age (223 responses), 51–60 years of age (213 responses), and 21–30 years of age (201 responses). The fewest responses came from people 18–20 years of age (71 responses). Of the responses, 731 households own a first vehicle, and 455 of the vehicles are all-wheel drive and 372 have studded tires on all wheels. Also, 585 households own a second vehicle, and 386 of the vehicles are all-wheel drive and 242 have studded tires on all wheels. Based on the respondents' experience with using new technology in winter tires, 62.6% are not considering switching back to studs. Most respondents do not realize that studless winter tires, in fact, provide traction and safety performance that is comparable to studded tires.

Results of the household online survey and parking survey reported differences in the percentage of studded tire use. The online survey covered all regions of Alaska and the parking survey covered only the Anchorage area. Previous studies on studded tire use conducted multiple surveys, including parking lot surveys. The Oregon study on which the methodology was based on it compared the findings from a telephone survey and parking lot surveys. The studded tire usage from the parking lot and telephone surveys for Region 5 of Oregon State was inconsistent, with about a 20% difference, though results for other regions were reasonably consistent. Finally, the study reported the overall studded tire usage from telephone surveys, which is the lower of the two values. Therefore, a conservative value from parking lot survey for studded tires were used in the calculation for the economic study.

APPENDIX C – TRAFFIC ANALYSIS

Alaska traffic data were derived from a sample of freeways and arterial and collector roads in the state. Roadway condition data were referenced from the Alaska DOT&PF Pavement Management database (DOT&PF, 2017). Statistically, a minimum sample size of three sites for each roadway classification was considered for the significant wear rate analysis shown in Appendix D. All paved roadway segments statewide were considered for the economic analysis shown in Appendix F. The total sample size and number of sites selected are shown in Table C.1. For the purpose of this research, sites were selected based on the available actual data before any resurfacing, maintenance, or rehabilitation projects done by the Alaska DOT&PF.

Table C.1 Samples and length of miles selected

Classification	CDS Route #	Route Name	Total Miles
Freeways	135000	Glenn Highway	9.760
	130000	Seward Highway	6.000
	134300	Minnesota Drive	3.830
Arterials	133899	Tudor Road	5.728
	134750	Northern Lights Boulevard	8.160
	133700	Dimond Boulevard	4.416
	134130	Dowling Road	2.427
	133800	Intl. Airport Road	3.714
	133500	O'Malley Road	3.888
Collectors	133100	DeArmoun Road	3.735
	135225	Eagle River Road	6.486
	133710	Rabbit Creek Road	4.634
	133763	88th Ave Anchorage	0.852
	133743	100th Ave Anchorage	1.533
	134133	Brayton Drive	1.320
	133723	Hillside Drive	2.750
	133739	Lore Road	0.721
	134449	Post Road	1.640
	133755	Sand Lake Road	1.492

Data required for these sites were collected and classified by directional split, lane split, and vehicle classification, including passenger vehicles and heavy trucks.

Data on annual average daily traffic (AADT) were provided by the Alaska DOT&PF Transportation Data Program. Highway traffic data were collected from permanent stations located on various highway segments, as shown in Table C.2. Other traffic characteristics such as growth rates and average monthly daily traffic were taken from Alaska DOT&PF Traffic Volume Reports, published annually on the department's website (DOT&PF, 2013).

Table C.2 Permanent stations examined

Station ID	Road	Route Number	Description
11500420	Glenn Highway	135000	Glenn Highway – west of Bragaw
*	Seward Highway	130000	South of Dimond
13430015	Minnesota Drive	134300	North of Dimond Boulevard
10125449	Tudor Road	133899	West of Tudor Center Drive
13475037	Northern Lights	134750	East of Latouche Street
11200520	Dimond Boulevard	133700	West of Arctic Boulevard
1110538U	Intl. Airport Road	133800	West of Fairbanks Street
11100512	O'Malley Road	133500	East of Seward Highway
13522537	Eagle River Road	135225	Caribou Street

*The data from this section was used before it was removed

For each permanent counter location, data sets were tabulated and classified by directional split to define the percentage of traffic moving in each direction, by lane split to show the distribution of traffic among the right and left lanes, and by vehicle classification to indicate the percentage of passenger vehicle and truck traffic. Details for traffic volume distribution on the roadways considered are shown in Table C.3.

Table C.3 Traffic classification percentage from permanent stations

<table>
<tr><th colspan="2" rowspan="2">Road</th><th colspan="2">Directional Split</th><th colspan="2">Northbound Lane Split</th><th colspan="2">Classification</th></tr>
<tr><th>North Bound %</th><th>South Bound %</th><th>Left %</th><th>Right %</th><th>Passenger Vehicle %</th><th>Trucks** %</th></tr>
<tr><td rowspan="3">Freeways</td><td>Glenn Highway*</td><td>49.52</td><td>50.48</td><td>29.43</td><td>36.21</td><td>94.26</td><td>5.74</td></tr>
<tr><td>Seward Highway</td><td>44.25</td><td>55.75</td><td>35.27</td><td>64.73</td><td>95.95</td><td>4.05</td></tr>
<tr><td>Minnesota Drive</td><td>48.74</td><td>51.26</td><td>28.39</td><td>76.61</td><td>96.46</td><td>3.54</td></tr>
<tr><th colspan="2" rowspan="2">Road</th><th colspan="2">Directional Split</th><th colspan="2">Lane Split</th><th colspan="2">Classification</th></tr>
<tr><th>East %</th><th>West %</th><th>Left %</th><th>Right %</th><th>Passenger Vehicle %</th><th>Trucks %</th></tr>
<tr><td rowspan="4">Arterials</td><td>Tudor Road</td><td>50.00</td><td>50.00</td><td>40.00</td><td>60.00</td><td>97.00</td><td>3.00</td></tr>
<tr><td>Dowling Road</td><td>50.00</td><td>50.00</td><td>40.00</td><td>60.00</td><td>92.00</td><td>8.00</td></tr>
<tr><td>Intl. Airport Road</td><td>50.00</td><td>50.00</td><td>40.00</td><td>60.00</td><td>96.00</td><td>4.00</td></tr>
<tr><td>Dimond Boulevard</td><td>50.00</td><td>50.00</td><td>40.00</td><td>60.00</td><td>97.00</td><td>3.00</td></tr>
</table>

*The number of lane in each direction is more than two lanes

**Truck percentage is based on the total traffic on the two considered lanes for freeways

Traffic volumes were applied for each highway segment as shown in Table C.4, and traffic growth rates were used to estimate the total average daily traffic encountered over the total pavement rehabilitation life for each roadway segment. Table C.5 shows a summary of the growth rates and the total AADT for each freeway section.

Growth rates for arterial and collector roads were assumed constant throughout the pavement rehabilitation life.

Table C.4 Traffic volumes by freeway segments (continued over the next pages)

Road	MP	Feature	Lanes	AADT	Length	VMT
Glenn Highway	0.000	Beginning of Route	6	50302	0.663	28,807
	0.663	Bragaw Street overpass	6	55555	1.047	49,418
	1.710	JCT with Boniface overpass	6	53428	0.665	31,561
	2.375	JCT with Glenn Highway NB – Turpin	6	56377	0.868	43,461
	3.243	JCT with Muldoon overpass	6	65172	1.581	91,524
	4.824	JCT with Glenn Highway NB – Arctic Valley	6	59771	1.494	79,316
	6.318	JCT with D Street overpass	6	57358	3.996	205,934
	10.314	Eagle River Loop overpass	6	51117	1.756	76,948
Seward Highway	117.175	JCT with Old Seward Highway	4	10341	0.481	6,912
	117.656	JCT with DeArmoun Road	4	15085	1.115	24,630
	118.771	JCT with Huffman Road	4	34212	1.032	27,175
	119.803	JCT with O'Malley Road	4	43376	1.511	53,686
	121.314	JCT with Dimond Boulevard	4	26911	0.704	32,659
	122.018	JCT Seward Highway SB – 76th Avenue	4	34212	0.798	46,675
	122.816	JCT with Dowling Road	4	43376	1.005	58,183
Minnesota Drive	0.000	Beginning of Route	4	28834	0.76	18,855
	0.760	JCT with C Street	4	28737	0.97	20,524
	1.730	100th Avenue overpass	4	24477	0.57	13,174
	2.300	Dimond Boulevard underpass	4	37604	1	33,782
	3.300	JCT with Minnesota Drive SB	4	38147	0.53	19,052
	3.830	Raspberry Road overpass	4	50178	0.91	41,050
Tudor Road	0.209	JCT with Minnesota Drive	4	20143	0.513	11,295
	0.722	JCT with Arctic Boulevard	4	24474	0.382	9,957
	1.104	JCT with C Street	4	31910	0.612	20,629
	1.716	JCT with Old Seward Highway	4	36636	0.242	9,516
	1.958	Tudor Road Overpass	4	38143	0.761	32,360
	2.719	JCT with Lake Otis Parkway	4	33490	1.006	38,856
	3.725	JCT with Elmore Road	4	30203	1	41,999
	4.725	JCT with Boniface Parkway	4	28570	0.5	14,677
	5.225	JCT with Campbell Airstrip	4	23179	0.503	11,838

Road	MP	Feature	Lanes	AADT	Length	VMT
	5.728	JCT with Patterson Street	4	20516	0.247	5,420
Northern Lights Boulevard	0.501	JCT with Muldoon Road	4	13249	0.997	5917
	1.498	JCT with Patterson Street	4	33141	1.113	6967
	2.611	JCT with Baxter/Beaver Place	4	32349	1.098	9231
	3.709	JCT with Boniface Parkway	4	20907	0.992	8248
	4.701	JCT with Wesleyan Drive	4	30035	0.614	17498
	5.315	JCT with Bragaw Street	4	18240	0.886	27091
	6.201	JCT with UAA Drive	4	24277	0.496	11764
	6.697	JCT with Lake Otis Parkway	4	11160	0.502	22516
Dowling Road	1	JCT with Elmore Road	4	18064	0.417	7466
	1.417	JCT with Norm Drive	4	18015	0.402	6237
	1.819	JCT with Lake Otis Parkway	4	27497	0.266	12981
	2.085	JCT with Seward Highway NB	4	27497	0.342	10254
DeArmoun Road	0.000	JCT with Old Seward Highway	4	3810	0.285	1086
	0.285	JCT with New Seward Highway	4	7690	0.220	1692
	0.505	JCT with Westwind Drive	4	4394	0.844	3709
	1.349	JCT with Elmore Road	4	3750	0.353	1324
	1.702	JCT with East 140th Avenue	4	2019	1.306	2637
	3.008	JCT with Tahoe Circle	4	1350	0.727	981
88^{th} Ave.	0.407	JCT with Lake Otis Parkway	4	9340	0.445	4156
100^{th} Ave.	0.150	JCT with Minnesota Drive	4	2133	0.150	320
	0.100	JCT with Bietinger Drive	4	4145	0.100	415
Lore Road	0.219	JCT with Spruce Street	2	2430	0.502	1220
Sand Lake	0.000	JCT with Dimond Boulevard	2	2605	0.984	2563
	0.984	JCT with Kincaid Road	2	4495	0.508	2283

Table C.5 Traffic growth rates for freeways over the pavement rehabilitation life

Year	AADT	Growth %	Total AADT	AADT	Growth %	Total AADT	AADT	Growth %	Total AADT
Glenn Highway				Seward Highway			Minnesota Drive		
2016	50855	-	389717 Over 8 years	36805	-	287232 Over 8 years	38084	-	296722 Over 8 years
2015	50168	1.37		35209	4.53		39477	-3.53	
2014	49491	1.37		33161	6.18		38514	2.50	
2013	47958	3.20		36005	-7.90		37575	2.50	
2012	47836	0.26		35901	0.29		37218	0.96	
2011	48230	-0.82		35672	0.64		36202	2.81	
2010	48089	0.29		37180	-4.06		35869	0.93	
2009	47089	2.12		37299	-0.32		33782	6.18	

APPENDIX D – WEAR RATES

It is hard to identify the pavement damage from studded tires caused in a specific year, as the life of pavement spans many years and collected rut measurements are the cumulative fractions of inches that develop over time. The pavement design life is 15 years for all classes of roadways in urban Anchorage area based on Alaska flexible pavement design manual (McHattie, 2004). An estimate was derived for cumulative studded tire wear. First, the total number of years was calculated for each highway segment, from when the last resurfacing project occurred on that segment until that segment's pavement reached the rut threshold or until the segment's next resurfacing project date scheduled by Alaska DOT&PF. Then an estimate for the total number of studded tire passes was calculated for each highway segment based on the following criteria:

(1) Adjusted total traffic volume data using factors for the relative level of traffic during the studded tire season, from September 15 until May 1 (regional differences apply here for projects outside Alaska's central region).

(2) The percentage of traffic made up of total passenger vehicles and trucks.

(3) The portion of vehicles in overall traffic volume using studded tires.

Total number of traffic was calculated over the number of years, based on published traffic volumes contained in the Alaska DOT&PF website database (Alaska DOT&PF, 2013). Historic growth factors for AADT were then applied to calculate overall traffic up to the date of interest.

Rut is expressed as a function of cumulative studded tire passes over the road surface to identify the wear rate general model under the following assumptions. (a) The wear rate is constant because it stabilizes after 100,000 studded tire passes (Malik, 2000), and (b) It was assumed in the initial step of the calculation that all rutting in the left lane of a typical roadway is caused by studded tires resulting from passenger vehicles only. Then the rut rate is calculated based on actual percentage of trucks on each lane.

After establishing the theme from freeways and determining the contribution of stud wear on the pavement, a comparable methodology was applied for the arterial and collector roads.

Because many factors that affect wear rate were present, data were analyzed under the same conditions to eliminate the contribution of these factors. Variables such as speed, pavement design, and materials were constant for each highway segment. The only variables taken into consideration were traffic volume and traffic classification on highway segments. The wear rate estimate is based on the assumption that the same type of metal studs, commonly used in the U.S. tire market, are used. Types of studs and their materials are discussed in detail in the literature review in Appendix A.

Each data set in the rut measurements was combined with traffic data and current estimates of studded tire use. No information is available in the literature that shows methods to differentiate between rutting wear from studs and rutting wear from wheel loads. An assumption was made that trucks tend to travel predominantly in the right lane. A study done in Oregon (Malik, 2000) was able to resolve this challenge by summing the rut depth of each lane for every highway segment, then performing a regression of the combined depth against total directional studded tire traffic.

According to Alaska traffic law, in the state's central region, 7.5 months is the time allowed for the public to use studded tires—from September 15 to May 1. The AADT in the total number of days during that period was multiplied by the percentage of traffic split between the right and left lanes to get the total number of vehicles on respective lane. In addition, studies of studded tire rutting have shown that pavement surfaces have a higher initial wear rate. Rut rates stabilize after 100,000 studded tire passes (Malik, 2000). Therefore, wear rates were calculated per 100,000 entering vehicles and trucks for each highway segment. Wear rates were expressed as a function of rut depth over traffic volume. The wear rate models were generated for each highway sample, as shown in equations below.

First, the wear rate in left lane by passenger vehicles are calculated considering all ruts coming from passenger vehicle only using Equation D.1.

$$WR_{PV\_left} = \frac{Rut_{left}}{Traffic_{7.5month} \times Left\_lane_{split} \times \%Studs} \qquad \text{Equation D.1}$$

Where

WR_{PV_left} = Wear rate due to passenger vehicle on the left lane (in/100,000 passes),

$Traffic_{7.5month}$ = Total number of traffic during winter season of the period considered,

Rut_{left} = Rut depth observed on the left lane (inches),

$Left\_lane_{split}$ = Percentage of traffic moving on the left lane, and

$\%Studs$ = Percentage of passenger vehicles using studded tires

Since the percentage of trucks are too low in left lane, the rut depth caused by actual number of passenger vehicle are calculated using the equation:

$$Rut_{PV\_left} = WR_{PV\_left} \times Traffic_{7.5month} \times Left\_lane_{split} \times \%Studs \times \%PV_{left} \qquad \text{Equation D.2}$$

Where, $\%PV_{left}$ = Percentage of passenger vehicles moving on the left lane

Then the rut due to truck in left lane is found by subtracting passenger vehicle rut from total rut in the left lane. This remaining rut is used to estimate the truck rut rate in the left considered equal rate in the right lane for trucks.

$$Rut_{Truck\_left} = Rut_{left} - Rut_{PV\_left} \qquad \text{Equation D.3}$$

$$WR_{Truck\_left} = \frac{Rut_{Truck\_left}}{Traffic_{total} \times Left\_lane_{split} \times \%Truck_{left}} = WR_{Truck\_right} \qquad \text{Equation D.4}$$

Where

WR_{Truck_left} = Wear rate estimate due to trucks on the left lane (in/100,000 passes),

$Traffic_{total}$ = Total number of traffic during the period considered,

Rut_{Truck_left} = Rut depth due to truck on the left lane (inches),

$Left\_lane_{split}$ = Percentage of traffic moving on the left lane, and

$\%Truck_{left}$ = Percentage of trucks moving on the left lane

The rut depth by truck right lane is calculated using the wear rate found from the left lane thus the rut due to passenger vehicle is achieved by subtracting that rut from total rut in right lane.

$$Rut_{Truck\_right} = WR_{Truck\_rigt} \times Traffic_{total} \times Right\_lane_{split} \times \%Truck_{right} \qquad \text{Equation D.5}$$

$$Rut_{PV\_right} = Rut_{right} - Rut_{Truck\_right} \qquad \text{Equation D.6}$$

Where

Rut_{Truck_right} = Rut depth due to truck on the right lane (inches),

$Right\_lane_{split}$ = Percentage of traffic moving on the right lane,

$\%Truck_{right}$ = Percentage of trucks moving on the right lane, and

Rut_{PV_right} = Rut depth due to studded passenger vehicle on the right lane (inches),

Finally, wear rate due to passenger vehicle is estimated using the Equation D.7. Since the percentage of trucks in the right lane is significant compared to the left lane, the wear rate due to passenger vehicles in right lane would be more feasible than the rate in the left lane as the number of passenger car generally much higher than that of left lane. Therefore, wear rate due to passenger vehicle in right lane is considered as the ultimate wear rate due to studded passenger vehicle for freeways.

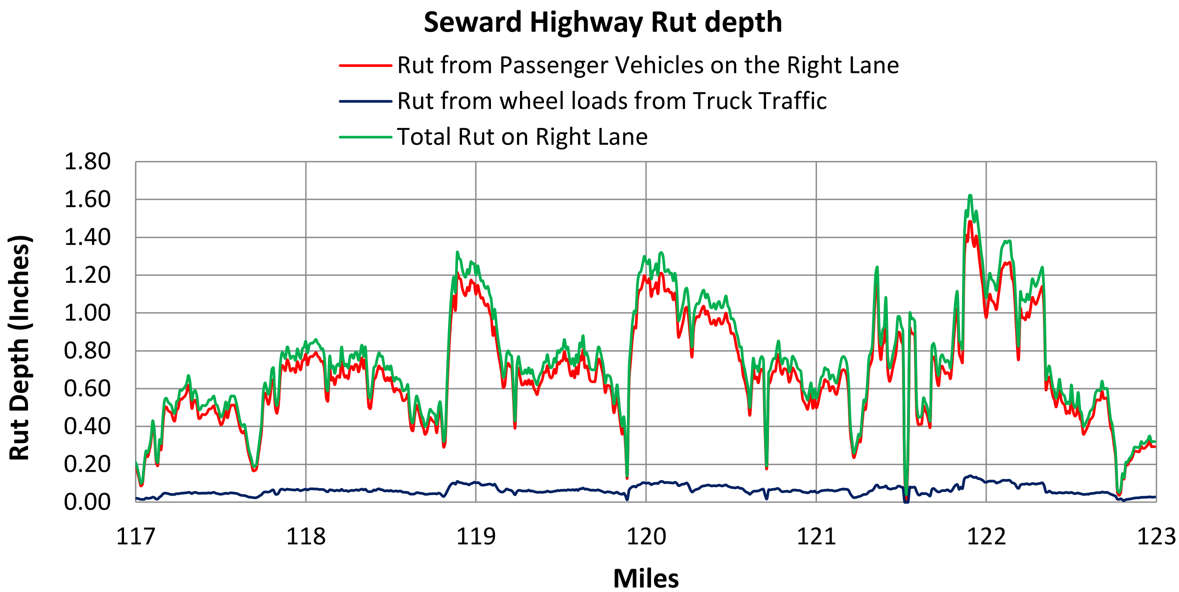
$$WR_{PV\_right} = \frac{Rut_{PV\_right}}{Traffic_{7.5month} \times Right\_lane_{split} \times \%Studs \times \%PV_{right}} \qquad \text{Equation D.7}$$

Where

WR_{PV_right} = Wear rate estimate due to studded passenger vehicle on the right lane (in/100,000 passes), and $\%PV_{right}$ = Percentage of passenger vehicles moving on the right lane

The freeway samples showed significant wear rates as a result of studded tires on the right lane, higher than the wear caused by wheel loads. Figures D.1, D.2, and D.3 show the distribution of wear rates for the freeway samples.

Figure D.1 Distribution of wear rates for the Glenn Highway



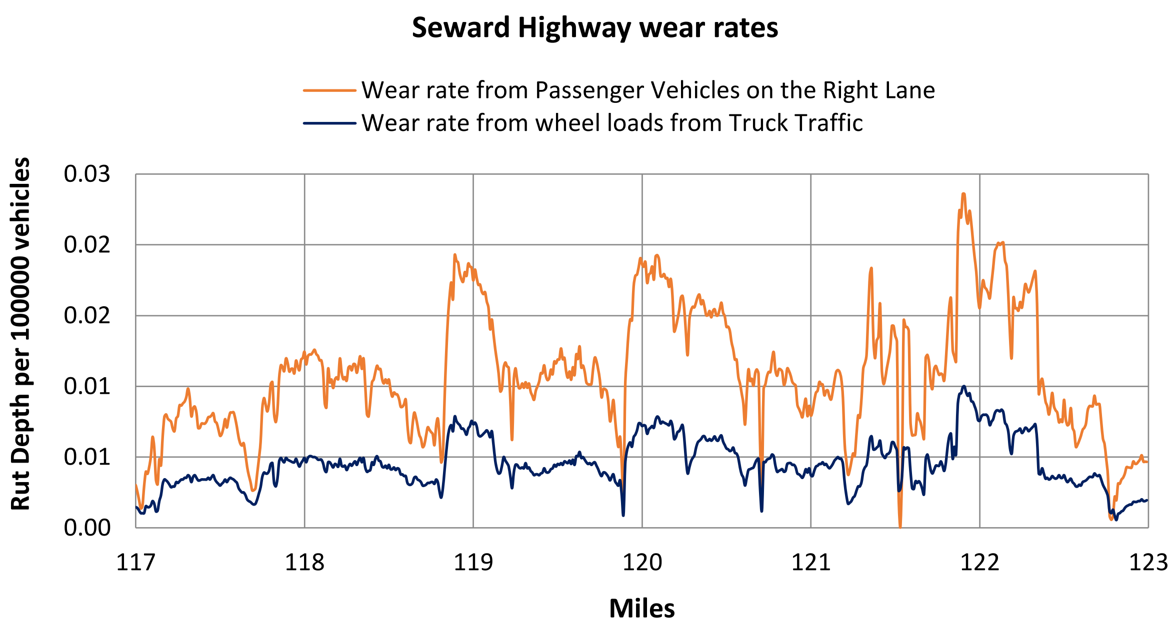
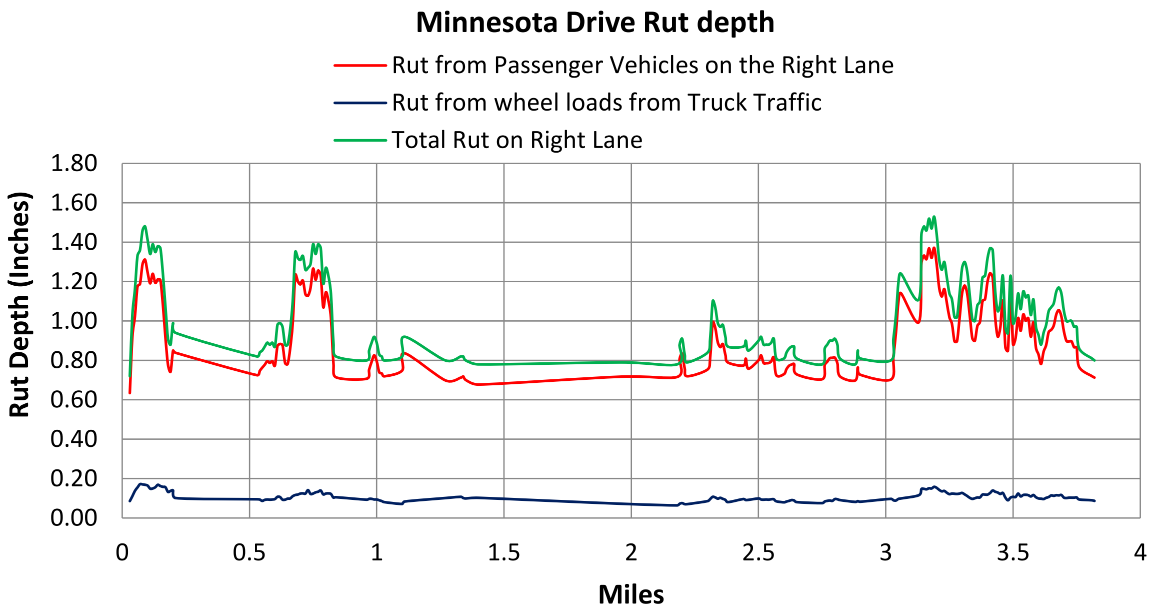


Figure D.2 Distribution of wear rates for the Seward Highway



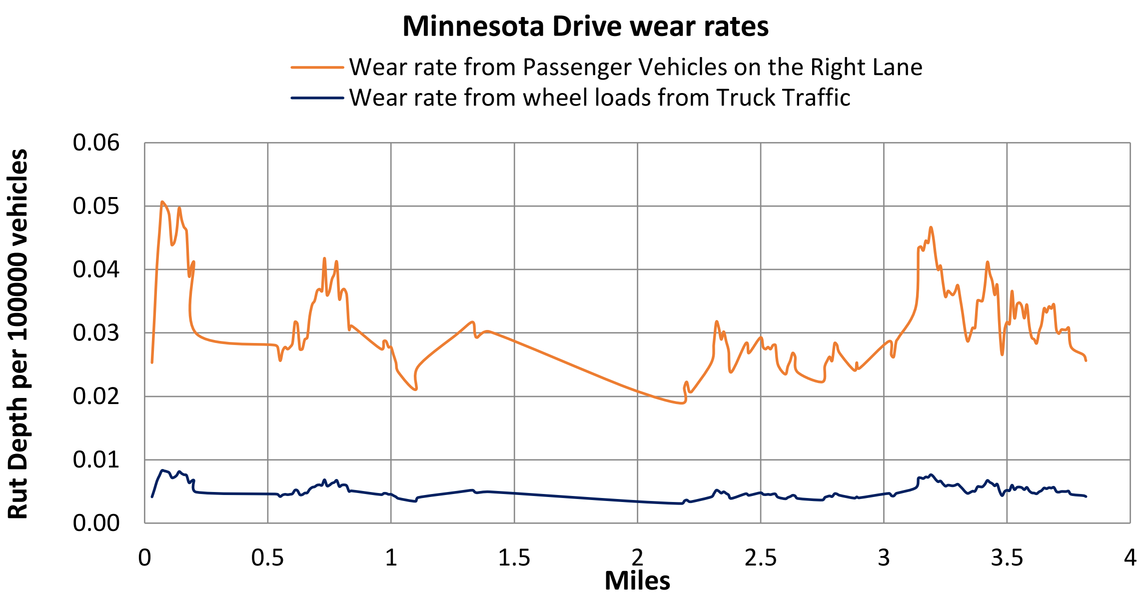


Figure D.3 Distribution of wear rates for Minnesota Drive

Results from the freeway segments showed significantly higher average wear rates due to studded passenger vehicles—wear rates that reach 0.0116 in./100,000 studded vehicles compared with average rut rates on the right lane due to heavy wheel loads that reach 0.0049 in./100,000 trucks. These results show evidence to support the claim that studded tires contribute to pavement deterioration more than heavy wheel loads.

In the case of arterial and collector roads, it was hard to differentiate between rutting caused by wheel loads and rutting caused by studded tire traffic by using the methodology used on the freeway segments. A comparable methodology was applied over arterial and collector roads by assuming the same truck rut rates from freeways. Note that the rut rate for heavy vehicles, considered along with type of mix used, is addressed later in this section.

An average truck rut rate of 0.0049 in./100,000 trucks was assumed for arterial samples. Then, rut measurements due to percentage of truck traffic were calculated for each arterial segment. Rut measurements as a result of passenger vehicles were estimated by subtracting the rutting caused by truck traffic from the total rut depth. Finally, wear rates due to passenger vehicles were generated for each arterial segment. Figures D.4 to D.9 show the distribution of rut rates for the arterial samples. Figures D.10 to D.18 show the distribution of rut rates for the collector samples. Results showed a significant lower average wear rate due to studded passenger vehicles on arterial roads, reaching 0.0062 in./100,000 studded vehicles, compared with an average wear rate of 0.0116 in./100,000 on freeway segments. Moreover, results showed a significantly lower average wear rate due to studded passenger vehicles on collector roads, reaching 0.0045 in./100,000 studded vehicles.

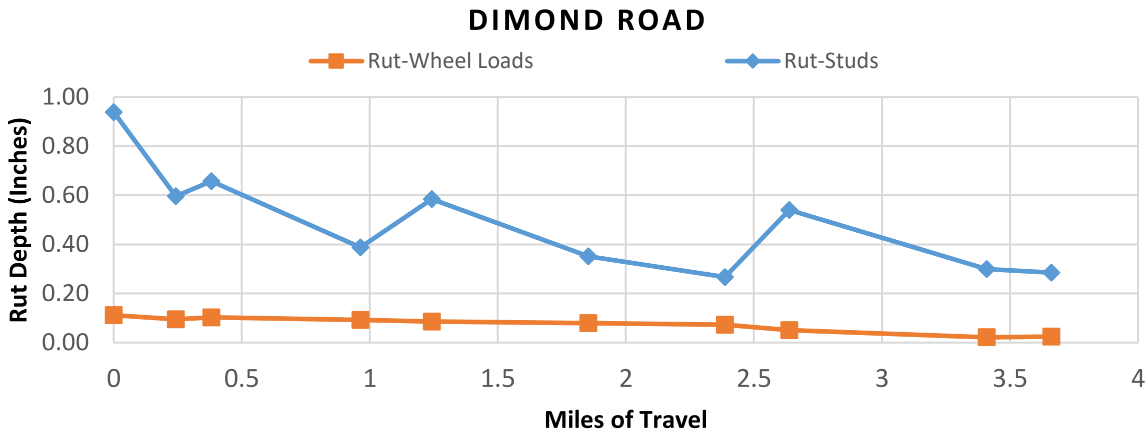


Figure D.4 Distribution of rut rates for Dimond Road

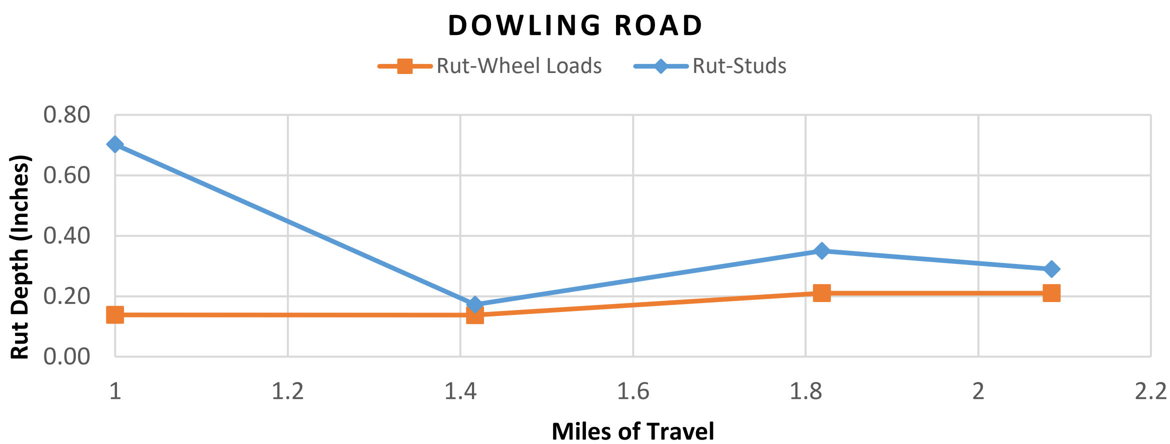


Figure D.5 Distribution of rut rates for Dowling Road

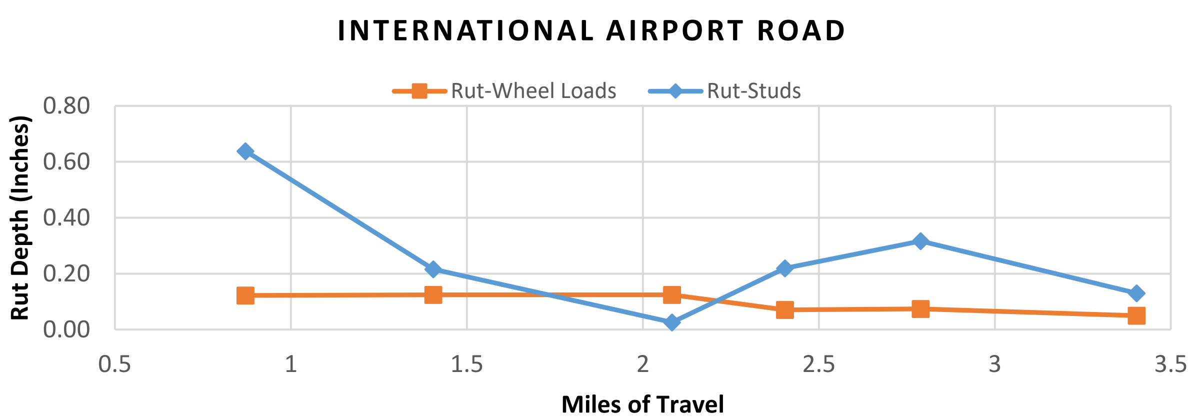


Figure D.6 Distribution of rut rates for International Airport Road

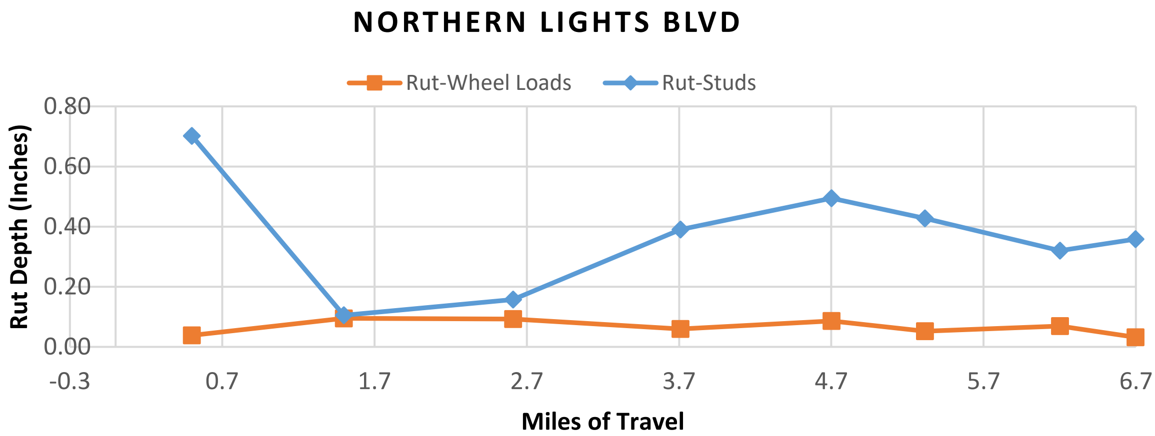


Figure D.7 Distribution of rut rates for Northern Lights Boulevard

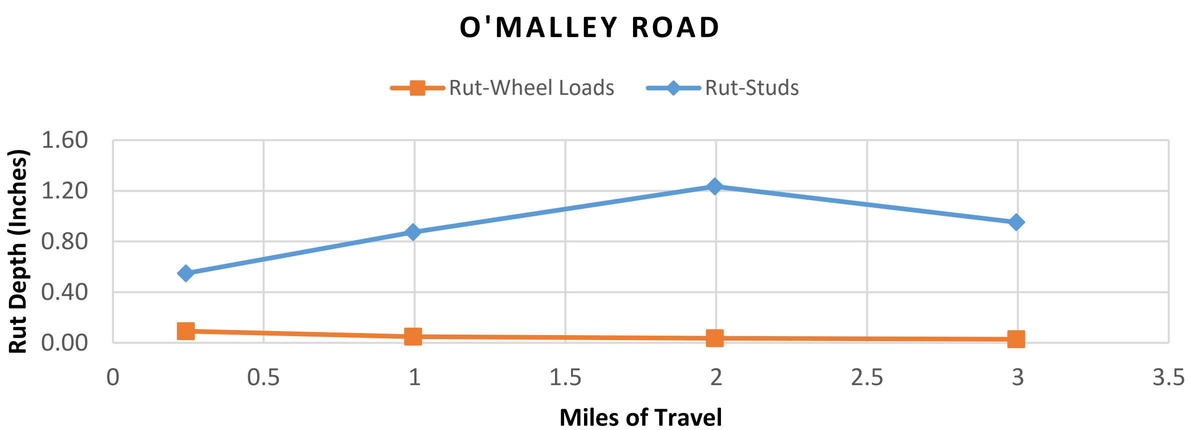


Figure D.8 Distribution of rut rates for O'Malley Road

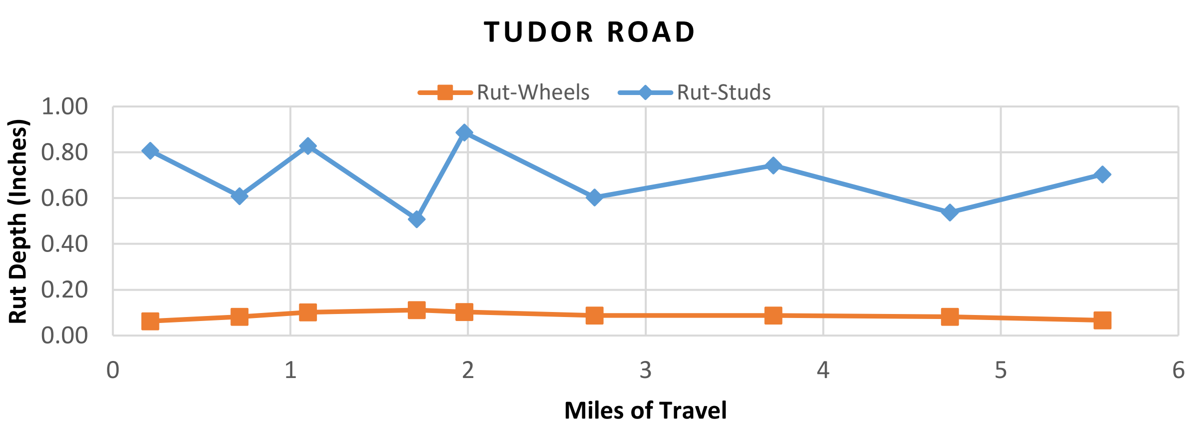


Figure D.9 Distribution of rut rates for Tudor Road

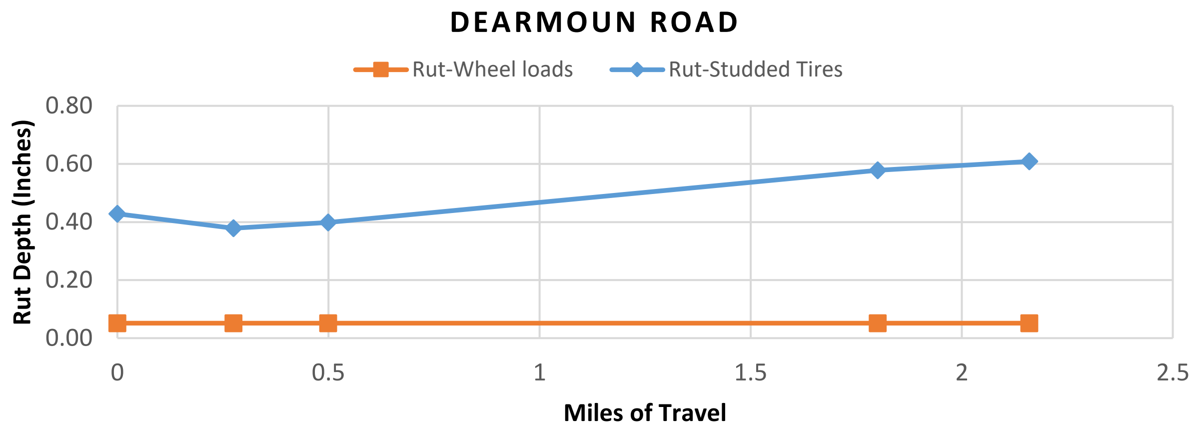


Figure D.10 Distribution of rut rates for DeArmoun Road

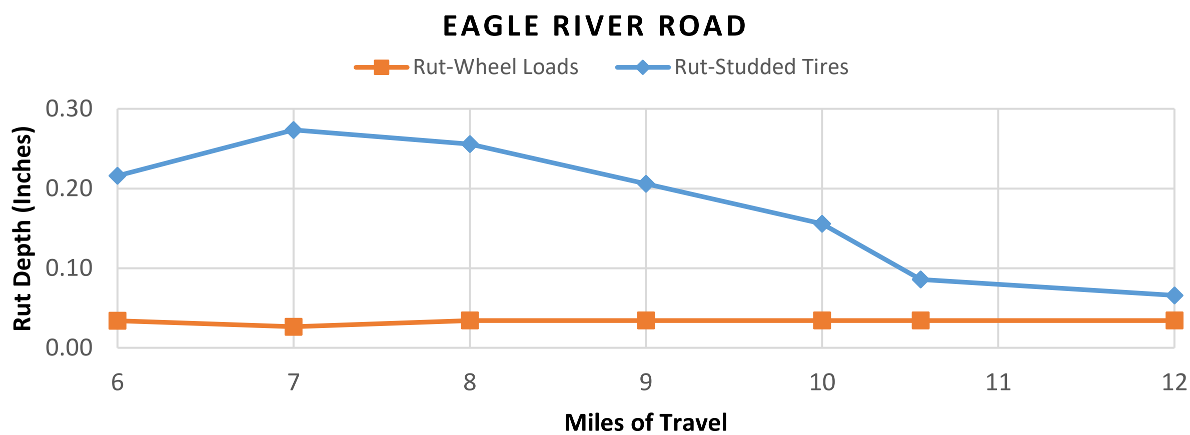


Figure D.11 Distribution of rut rates for Eagle River Road

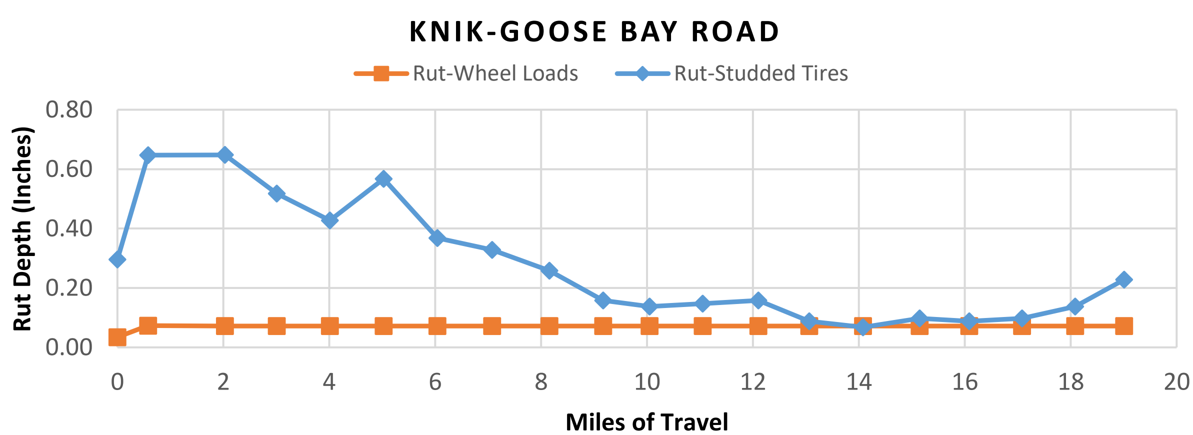


Figure D.12 Distribution of rut rates for Kink-Goose Bay Road

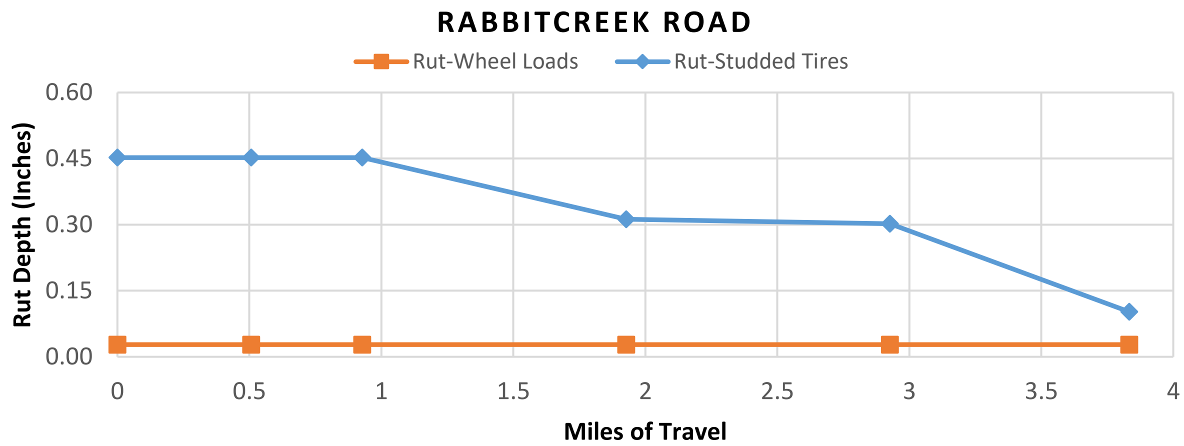


Figure D.13 Distribution of rut rates for Rabbit Creek Road

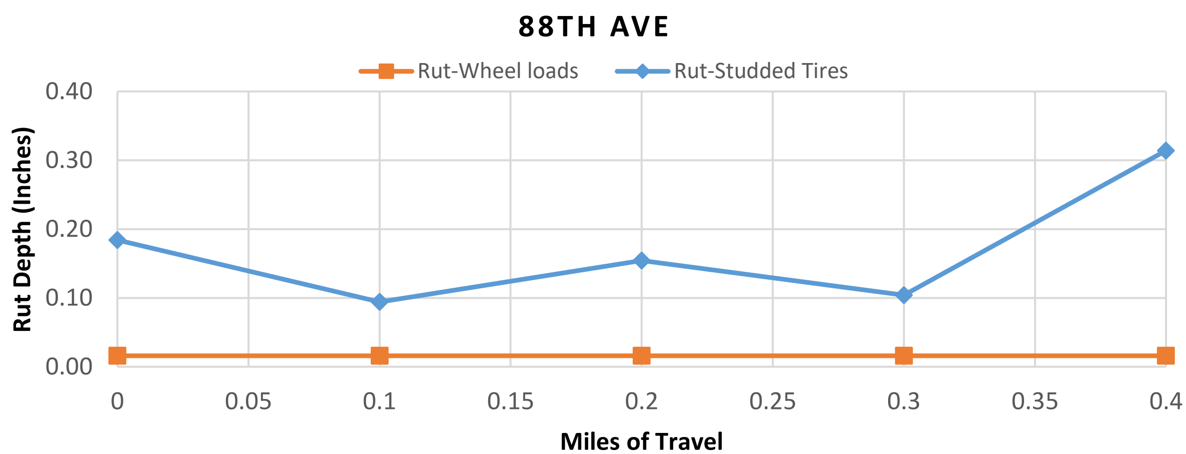


Figure D.14 Distribution of rut rates for 88th Avenue

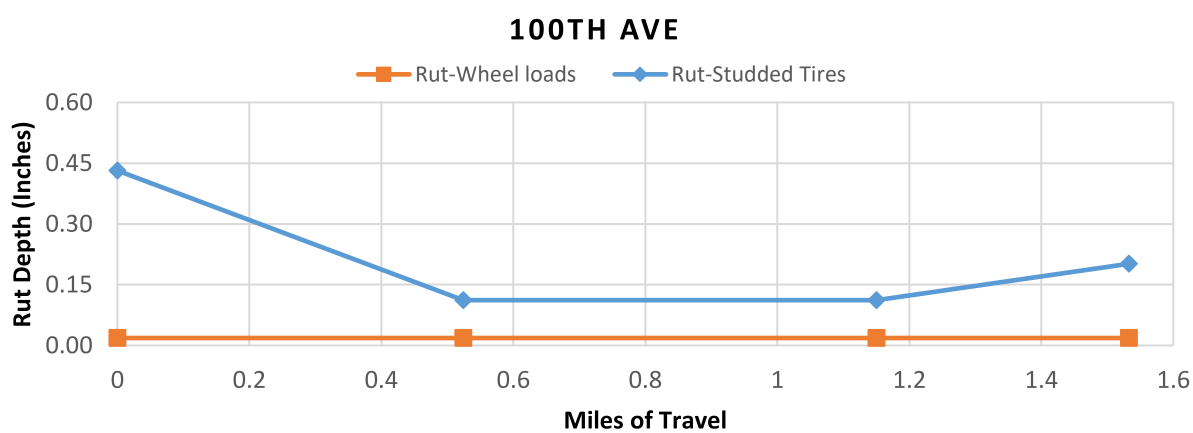


Figure D.15 Distribution of rut rates for 100th Avenue

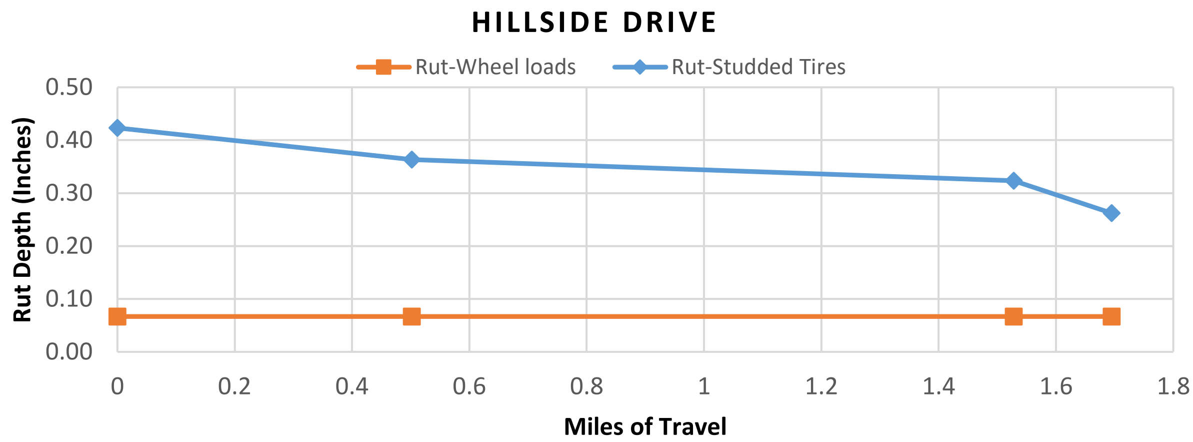


Figure D.16 Distribution of rut rates for Hillside Road

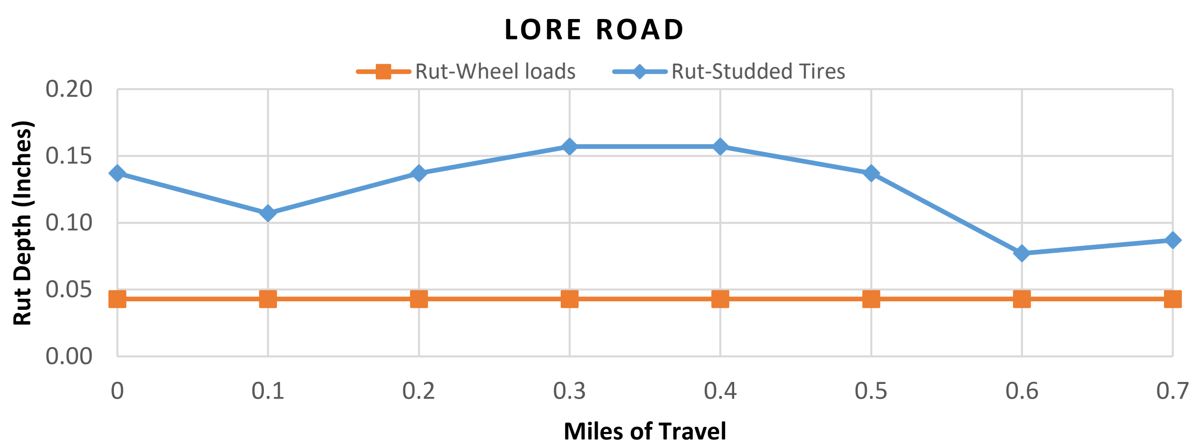


Figure D.17 Distribution of rut rates for Lore Road

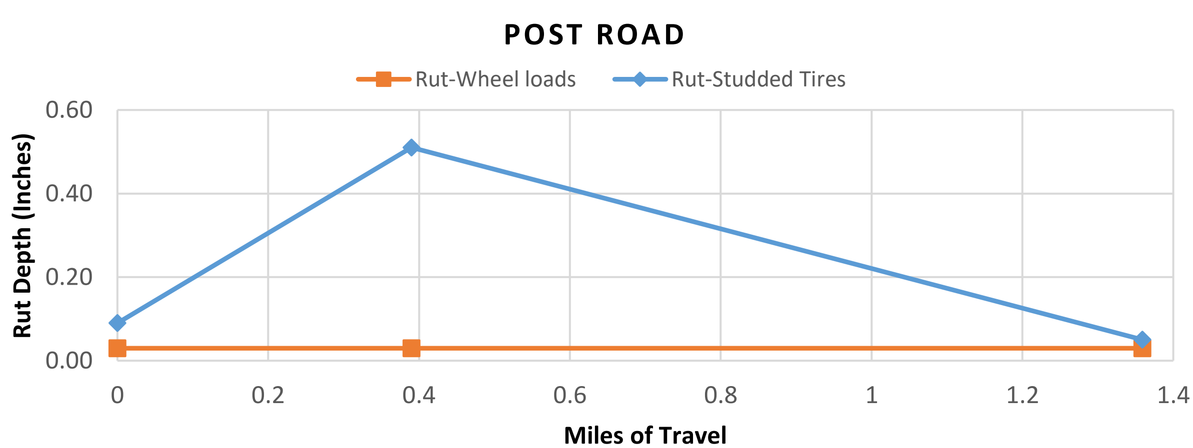


Figure D.18 Distribution of rut rates for Post Road

The average wear rates for studded tires were tabulated for each highway segment including freeways and arterial and collector roads. In addition, actual average lift life for the different roadway classes along with posted speed was addressed. Table D.1 shows the studded tire wear rates for each highway class and the posted speed. In general, it is clear from the wear rate trend that the higher the posted speed, the greater the studded tire damage.

Table D.1 Highway posted speeds versus wear rates

Function Classification	Highway Name	Average No. of Years per Lift		Speed (mph)	Studded Wear Rates (in/100,000 passes)		Percentage of Trucks (%)
		Total	Average		Total	Average	
Freeways	Glenn Highway	8	8	65	0.0122	0.0116	5.74
	Seward Highway	8		65	0.0108		4.05
	Minnesota Drive	8		60	0.0118		3.54
Arterial Roads	Dimond Road	10	10	40 - 45	0.0053	0.0062	3
	Dowling Road	10		40 - 45	0.0046		8
	Intl. Airport Road	10		45	0.0027		4
	Northern Lights Boulevard	10		40	0.0056		3
	O'Malley Road	10		40	0.0134		3
	Tudor Road	10		40 - 45	0.0057		3
Collector Roads	88th Avenue	12	13.45	20	0.0037	0.0045	3
	100th Avenue West	12		35	0.0081		3
	Brayton Drive	12		45	0.0026		3
	DeArmoun Road	12		40	0.0064		3
	Eagle River Road	13		45	0.0039		3
	Hillside Drive	14		45	0.0060		5
	Knik-Goose Bay Road	13		35	0.0028		3
	Lore Road	15		20	0.0020		3
	Post Road	15		35	0.0049		3
	Rabbit Creek Road	15		45	0.0057		3
	Sand Lake Road	15		50	0.0032		3

In order to ascertain the contribution of pavement mix designs in resisting studded tire wear damage, each freeway asphalt structural design was determined from the actual as-built project drawings. For example, stone mastic asphalt (SMA) mixes were used for the Glenn Highway improvements and resurfacing project done in 2003, while HMA Type R and Type V were used for the Seward Highway MP 115–124 resurfacing and the Minnesota Drive resurfacing projects. Wear rate results showed that SMA and HMA Type R mixes have significant resistance compared with mixes used for the other projects.

As shown in Figure D.19, a notable finding from the comparison of the highway classification as it relates to posted speed is that the higher the posted speed, the greater the wear rate.

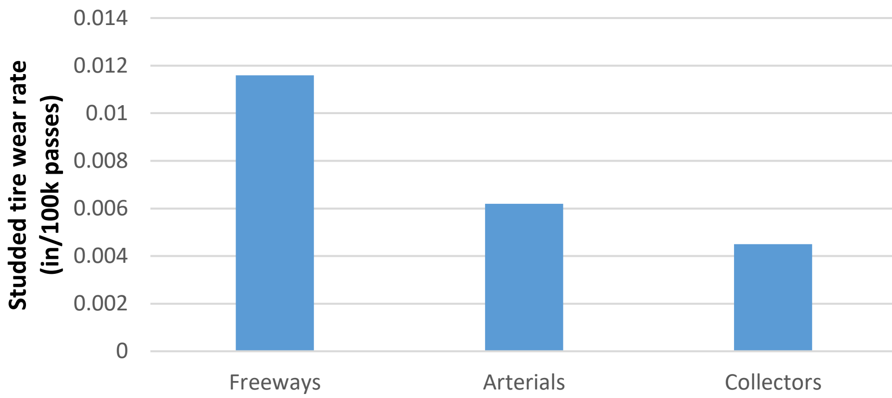


Figure D.19 Relation between highway classification and wear rates

APPENDIX E – COST ESTIMATES

The cost estimate is divided into three sections, one for each type of cost analysis that was employed. These estimates include pavement resurfacing and rehabilitation costs, pavement damage costs due to studded tires, and costs due to reduction of pavement life as a result of studded tires. Cost estimates were generated using wear rates and studded tire traffic data for the freeway segments. All cost estimates were expressed in terms of resurfacing and rehabilitation costs.

Repaving/Resurfacing Cost Estimates

For the given highway samples mentioned in Figure D.20, a list of 20 similar historical projects was developed, as well as the years of resurfacing/rehabilitation of each project. Details of the projects selected are shown in Table E.1. Data from these projects were extracted from the as-built drawings to reflect the actual quantities used during construction.

Several asphalt mix designs with different structural sections were considered to calculate the unit cost per square foot of each project. Data for these structural sections and total price per ton are shown in Table E.2. The repair costs were limited to a rehabilitation strategy of the structural section thickness (mill/fill).

First, a realistic cost estimate was determined per pavement square foot of construction, which includes all direct overall resurfacing costs (milling, striping, traffic maintenance and control) and excludes indirect costs, which are insignificant compared to the main project costs. Then cost of total pavement damage was estimated for the rutting damage on the highways, including rutting damage that reaches the rut threshold limit. Based on feedback from Alaska DOT&PF, a 0.5 in. rut threshold limit was taken into consideration to determine the cost of pavement resurfacing and rehabilitation. However, the exact weighted average for the rut threshold was estimated from the highway samples, including freeways and arterial and collector roads, to capture a range of costs and to provide future prediction cost estimates for Alaska DOT&PF. Table E.3 and E.4 show the rut depth for the selected freeway samples and the collector roads just before the scheduled year of maintenance, which reflects the actual threshold used for rehabilitation.

Table E.1 List of as-built projects

ID #	Title	HMA Type	Year	Length (ft)
51135	Minnesota Dr. Resurfacing, Intl. Airport Rd. to 13th Ave.	2” HMA Type V	2009	18849
51340	Minnesota Dr. Resurfacing, C St. to Intl. Airport Rd.	2” HMA Type V	2009	20250
52491	Seward Highway MP 115–124 Resurfacing	2” HMA Type R	2010	17280
51945	Glenn Hwy., Airport Heights to Highland Resurfacing	1.75”-2” HMA Type R 2” HMA Type IIA	2009	55860
52015	Glenn Hwy. MP 34–42, Parks to Palmer Resurfacing	1.75” HMA Type V	2009	30650
55335	Glenn Highway, Gambell to McCarey Resurfacing	2” Stone Mastic Asphalt	2003	19846
56314	Glenn Highway King River to MP 100 Resurfacing	2” HMA Type IIA	2005	13200
52493	Sterling Highway MP 90–82 Resurfacing	2.5”-3” HMA Type IIA	2010	33800
51046	Sterling Hwy. Resurfacing MP 93.9–89.9	2” HMA Type IIA	2008	21460
53801	Dimond Blvd. Resurf. Jewel Lake Rd. to Seward Hwy.	2” – 3” HMA Type V	2013	18500
55657	Dimond Resurfacing, Jewel Lake to Seward Hwy.	2” Stone Mastic Asphalt	2003	16225
51987	Jewel Lake Rd. Resurf, Dimond Blvd. to West 63rd Ave.	3” HMA Type V	2010	8730
52512	C St. – Intl. Airport Rd. to Tudor Rd.	2” Stone Mastic Asphalt 2” HMA Type II	1998	7720
52881	Resurfacing Glenn Hwy. to Eagle River Rd.	1.75” HMA Type V	2011	13393
53975	Northern Lights and Benson Resurfacing, Lois Dr. to Lake Otis Pkwy.	2” Stone Mastic Asphalt	2001	27000
56333	Anchorage Area Arterial Resurfacing, 2003 (3 Projects)	2” Stone Mastic Asphalt	2003	22440
50810	Muldoon Rd. Resurfacing 36th to Glenn Hwy.	2” HMA Type V	2008	14217

Table E.2 Types of structural sections and unit price

#	Structural Section	Unit price ($/ton)
1	2" Stone Mastic Asphalt	65.00
2	2" & 4" Asphalt Concrete Type IA	135.00
3	2" HMA Type R	120.02
4	2" HMA Type V	95.00
5	1 .75" & 2" HMA Type R	105.54
6	2" HMA Type IIA*	84.45
7	2" HMA Type IIA*	65.85

Department of Transportation. (2017, November 20). Bid Tabulation Summaries. Anchorage, Alaska, USA.

* Unit price per ton for HMA Type IIA were different in some projects

Table E.3 Rut threshold of the freeway samples

Glenn Highway		Weighted Average	Seward Highway		Weighted Average	Minnesota Drive		Weighted Average
Length Miles	Rut 2008		Length Miles	Rut 2008		Length Miles	Rut 2008	
1.44	0.95	1.36	1.01	0.62	0.62	0.97	0.85	0.82
2.55	0.55	1.40	0.80	0.53	0.42	1.19	0.79	0.94
1.62	0.64	1.04	1.02	0.53	0.54	0.76	0.3	0.23
1.00	0.87	0.87	1.06	0.57	0.61	1.07	0.72	0.77
0.51	0.83	0.42	0.98	0.86	0.84	1.03	0.58	0.60
1.78	0.95	1.69	0.81	0.79	0.64	0.72	0.82	0.59
0.51	0.59	0.30	1.14	0.57	0.65	0.68	1.09	0.74
1.15	0.66	0.76	1.00	0.94	0.94	0.57	0.98	0.56
1.40	0.79	1.11	0.45	0.52	0.24	0.76	0.94	0.72
1.22	0.72	0.88	1.33	0.62	0.83	0.73	0.74	0.54
1.00	0.65	0.65	1.06	0.67	0.71	0.60	0.82	0.49
1.09	0.93	1.01	1.00	0.83	0.83	0.48	0.72	0.35
0.45	1.02	0.45	0.61	0.41	0.25	0.57	1.23	0.70
1.01	1.34	1.36	0.28	0.75	0.21	0.66	0.64	0.42
1.01	1.35	1.36	0.28	1.23	0.34	0.71	0.71	0.50
0.45	0.81	0.36				0.35	0.78	0.28
1.54	0.92	1.42				0.42	0.68	0.29
0.81			0.68			0.76		

Table E.4 Rut threshold of the arterial samples

Dimond Boulevard		Weighted Average	Northern Lights & Benson Boulevard		Weighted Average	Tudor Road		Weighted Average	International Airport Road		Weighted Average
Length Miles	Rut 2013		Length Miles	Rut 2001		Length Miles	Rut 2003		Length Miles	Rut 2014	
0.58	0.76	0.44	1.00	0.27	0.27	0.86	0.69	0.59	0.61	0.5	0.31
0.28	0.48	0.13	1.11	0.17	0.19	0.50	0.49	0.25	0.53	1.12	0.60
0.61	0.67	0.41	1.10	0.2	0.22	0.38	0.68	0.26	0.68	0.52	0.35
0.53	0.43	0.23	0.99	0.6	0.60	0.61	1.07	0.66	0.32	0.1	0.03
0.25	0.34	0.09	0.61	0.53	0.33	0.27	0.67	0.18	0.39	0.27	0.10
0.77	0.59	0.45	0.89	0.69	0.61	0.73	1.15	0.84	0.31	0.24	0.07
0.25	0.32	0.08	0.50	0.6	0.30	1.01	0.78	0.79			
0.75	0.21	0.16	0.50	0.53	0.27	1.00	0.92	0.92			
0.06	1.05	0.06	0.92	0.76	0.70	0.39	0.88	0.34			
0.14	0.69	0.10				1.01	0.78	0.79			
0.25	0.34	0.09				0.27	0.67	0.18			
0.77	0.61	0.47				0.84	0.69	0.58			
0.25	0.54	0.14				0.73	1.15	0.84			
0.53	0.48	0.26				1.00	0.92	0.92			
0.75	0.23	0.17				0.61	1.07	0.66			
0.28	0.52	0.14				0.51	0.49	0.25			
0.14	0.5	0.07									
0.51			0.46			0.84			0.52		

Many factors influence the price of an asphalt resurfacing job. Direct and indirect costs should be included in the pavement unit price for small projects, such as repaving a driveway or parking lot. However, for the purpose of this study, large-scale projects that have at least 6 to 10 miles of mill and fill were selected for estimating the cost of pavement resurfacing. Indirect costs were excluded from the analysis, as they are insignificant in the total price. Direct costs included in the unit price per square foot are given below:

- Pavement planning/design
- Milling price, range from (1.92–2.5) $/square yard
- Marking and striping
- Traffic maintenance and control
- Construction signing
- Flagging

The pavement resurfacing cost was calculated from the as-builts of 20 projects to establish a realistic estimated cost of construction/rehabilitation. Table E.5 shows the cost per square foot for each project.

Table E.5 Pavement resurfacing cost per square foot (continued over next page)

Project Name	Total Cost ($)	Cost/SF ($)	Cost/Yr. ($)
Northern Lights & Benson Resurfacing	2,392,208	1.70	341,744
Tudor Road Pavement Rehabilitation	5,928,633	3.08	846,948
Seward Highway MP 115–124 Resurfacing	6,516,993	2.86	930,999
C Street (52512)	1,068,535	15.83	152,648
Minnesota Drive Resurfacing	3,978,760	2.92	568,394
Glenn Highway	10,274,557	2.08	1,467,794
Muldoon Road Resurfacing	3,058,863	3.55	436,980
Sterling Highway Resurfacing	1,645,616	1.27	235,088
Minnesota Drive Resurfacing	3,679,828	4.17	525,690
Jewel Lake Road Resurfacing	1,635,944	3.64	233,706
Glenn Highway MP 34–42	1,617,275	1.93	231,039
Sterling Highway Resurfacing	2,779,942	3.11	397,135
Eagle River Loop Road Resurfacing	2,063,762	2.46	294,823
Dimond Boulevard Resurfacing	5,918,240	3.41	845,463
Glenn Highway Intersection Resurfacing	2,425,790	3.37	346,541

Project Name	Total Cost ($)	Cost/SF ($)	Cost/Yr. ($)
Dimond Resurfacing	3,856,123	2.85	550,875
Glenn Highway Resurfacing	7,728,503	2.04	1,104,072
Anchorage Resurfacing, Boniface Parkway	1,197,920	1.73	171,131
Anchorage Resurfacing, C Street	759,774	2.26	108,539
Anchorage Resurfacing, Lake Otis Parkway	853,825	2.07	121,975

Pavement Damage Cost Estimates Due to Studded Tires

The best method of evaluating pavement damage as a result of studded tire traffic is to define the studded tire damage per vehicle miles traveled (VMT), and future damage predictions can be estimated and applied to any facility with a given VMT. Alaska DOT&PF provides VMT data that are published every year in the annual Traffic Volume Reports. First, the estimated studded tire wear rate was multiplied by total VMT, as shown in Equation E.1; the resulting number is equivalent to total studded tire rut depth. Since pavement resurfacing in Alaska is assumed to take place when rut depth reaches a threshold of 0.5 in., Equation E.2 shows that the resulting rut depth value was divided by 0.5 to get the equivalent number of lane miles at that threshold. Finally, the total lane miles at threshold were multiplied by the average cost of resurfacing for each freeway, as shown in Equation E.3. Table E.6 shows a summary of studded tire damage cost for the freeway samples.

$$\text{Rut}_{\text{Lane-mile}} = VMT_{studded\_tires} * WR_{P.V}$$

Equation E.1

Where:

$VMT_{studded\_tires}$ * = Total Vehicle Miles Travelled * % of studded traffic

$$\text{Rut}_{\text{Lane-mile @ threshold}} = \frac{Rut_{Lane-mile}}{0.5''}$$

Equation E.2

$$\text{Total Cost} = \text{Rut}_{\text{Lane-mile @ threshold}} * \text{Cost}_{\text{Lane-mile}}$$

Equation E.3

The total number of lane miles is equivalent to the total rut depth reaching the threshold of 0.5 in. The resurfacing cost per square foot that was mentioned in Table E.5 was multiplied by 63,360 ft^2 to convert 1 ft^2 to get the total cost per one lane-mile (1 ft * 12 ft).

Table E.6 Pavement damage cost as a result of studded tires

Sample	DVMT	Growth Rate	No. of Years	Sample VMT	Wear Rate	Total Rut (in.)	Total Rut Threshold	Cost $/Lane-Mile
Glenn Highway	657394	1.50%	8	5262968	0.0122	0.6421	1.2840	$169,238
Seward Highway	318842	0.50%	8	2551003	0.0108	0.2755	0.5510	$99,846
Minnesota Drive	265424	0.50%	8	1867258	0.0118	0.2203	0.4406	$81,516

Cost Estimates Due to Reduction in Pavement Life

Using the studded tire wear rates, for any highway segment with a given average studded tire daily traffic per lane, the level of studded tire traffic will equate to a certain value of damage per year. Alaska DOT&PF allows up to 0.5 in. of pavement wear before any scheduled rehabilitation. Dividing the rut threshold by the wear rate, as shown in Equation E.4, a result of studded tires will equate to a number of years of expected pavement life. The difference between pavement design life and the expected life is equal to the total loss or cost due to studded tires.

$$Pavement_{life\_expected} = \frac{Rut_{threshold}}{Annual_{studs\_wear}} \qquad \text{Equation E.4}$$

$$\text{Pavement lifetime Loss} = \text{Pavement life}_{\text{Design}} - \text{Pavement life}_{\text{Expected}} \qquad \text{Equation E.5}$$

For example, for the Glenn Highway, which is a freeway, with an AADT of 10,000 vehicles per lane and 35% of vehicles having studded tires, there are 3,500 vehicles with studded tires using that road per day. From September 15 to May 1, or for 227 days, there are 794,500 vehicles with studded tires per year on that segment of the highway, or 794,500 studded passes per year. Using the wear rate of 0.0116 in. per 100,000 studded tire passes, this level of traffic equates to 0.0922 in. of studded tire wear per year. For a rut threshold of 0.5 in., this roadway segment would need to be rehabilitated after 5.42 years. The normal pavement resurfacing cycle based on different threshold rut value of typical freeways in Anchorage ranges from 7 to 9 years with average of 8 years. Since the pavement design life in Anchorage is 15 years (McHattie, 2004) therefore, the effect of studded tires reduces the asphalt surface life by 6 to 8 years with average of 7 years, which is a 46.67% loss of pavement life. With a given asphalt paving budget for Alaska statewide and with the percentage in reduction of pavement life, the total asphalt cost due to studded tires can be estimated as a monetary value.

Based on Barter's published report (Barter, 1996) and wear rate estimates, the total damage cost for the Alaska roadway system was estimated to be $5 million per year in 1996. According to the Bureau of Labor Statistics Consumer Price Index, the dollar has experienced an average inflation rate of 2.10% per year. Prices in 2018 are 58% higher than prices in 1996. In other words, $1 in the year 1996 is equivalent in purchasing power to $1.58 in 2018, which means Alaska will spend $7.9 million annually to repair stud-related pavement damage in 2018.

Based on the economic analysis of this research, Alaska will spend $13.7 million annually in stud-related pavement damage. Miles of new roadway as well as growth of traffic should be incorporated in the final annual cost of repair as a result of studded tire use.

APPENDIX F – ECONOMIC ANALYSIS

The economic analysis considered 3,025 statewide road segments with resurfacing needs. Various assumptions were made about traffic growth and other parameters (see Table F.1) over the useful life of a road, which was set at 20 years. Results include

(1) an estimate of the total resurfacing cost of mitigating road damage from studded tires equal to the present value of simulated resurfacing projects over the useful life of each road segment, *PV*;

(2) the effective annualized damage cost, equal to the annualized present value in (equation F.1), PV_{annual}; and

(3) simulated annual expenditures to resurface road segments over the next 20 years, C_i.

Note, the latter is not discounted, and all estimates are in real 2019 USD. The use of real dollar amounts and real discount rates allows a comparison of cost and benefits over the life of a road. If the estimates were to include inflation (showing nominal USD), future estimates would be larger by the amount of inflation expected.

In specific, the estimation of (equation F.1) used the following mathematical relationship:

$$PV = \sum_{t=0}^{20} \sum_{i=1}^{3025} \sum_{j=1}^{5} C_i \left(1+d\right)^{-t(j)}, \qquad \text{Equation F.1}$$

Where:

d = the real discount rate accounting for the opportunity cost of capital, and

C_i = the resurfacing cost per road segment calculated as the surface area of road segment, i, times the resurfacing cost per square foot.

The surface area assumes a 12-foot lane width and accounts for the number of lanes and length of each road segment. The analysis accounts for up to three resurfacing projects, j, over an assumed 20 years of useful life. Each resurfacing occurs at a time when the rut depth reaches the rehabilitation threshold. Note, t (j) depends on the projected studded tire use and projected growth in traffic over the next 20 years on each road segment. Additionally, $t(j)$ depends on the studded tire season length, proportion of traffic using studded tires per year, the adoption rate of non-studded tires, proportion of heavy load vehicles, and most importantly, average wear rates due to studded passenger vehicles and rut rates due to heavy wheel loads.

Estimates for (equation F.2), the effective annualized damage cost, are equal to the following amortization formula:

$$PV_{annual} = PV \frac{d}{1-\left(1+d\right)^{-t(j)}} . \qquad \text{Equation F.2}$$

For estimating (equation F.3), the following statement was used:

$$Exp_{t(j)} = \sum_{i=1}^{3025} C_i . \qquad \text{Equation F.3}$$

Data and Assumptions

The analysis of damage from studded tires in Alaska used the data sources described in Table F.1 and the following assumptions.

- No deferred maintenance over the next 20 years.
- Alaska DOT&PF decides to resurface when rut depth reaches 0.5 in. on all 3,025 statewide road segments.
- Damage estimates do not account for impacts on human health caused by studded tire use and any other social costs and benefits associated with studded tire use.
- The sole estimate is of the additional resurfacing costs associated with the use of studded tires within and beyond the allowable studded tire season as stated in Alaska Statute 28.35.155. Since the analysis is based on measured rut depth from studded tire use, the analysis accounts for the proportion of Alaska motorists who continue to use studded tires beyond the studded tire season.
- No estimate is given of damage related to prohibiting studded tire use, should Alaska ban the use of studded tires.

Table F.1 shows the parameter assumptions for a base-case (business as usual) scenario consistent with results from the survey conducted and data on tire fees.

Table F.1 Assumptions for parameters used in the analysis, alternative values and their sources

Parameter Description	Base Case	Alt. Value 1	Alt. Value 2	Alt. Value 3	Source
Start of studded tire season (date)	9/15/2018	10/1/2018			Alaska State Statute: AS 28.35.155
End of studded tire season (date)	5/1/2019	4/15/2019			Alaska State Statute: AS 28.35.155
Length of studded tire season (day/yr)	228	196			
Current studded tire use (% ADT)	35%				Abaza, 2018
Annual change in studded tire use (%)	-2.00%	2%	-11%		Abaza, 2018, Department of Revenue
Reconstruction life of roads (years)	20				Author assumption
Current traffic proportion of heavy load vehicles (%)	5%	9%	5%		Abaza, 2018
Rehabilitation threshold (in.)	0.5	0.75	0.5		Alaska DOT&PF
Lane width (ft)	12				Alaska DOT&PF
Mean resurfacing cost ($/ft^2)	$2.85	$2.85	$2.06	$3.24	Abaza, 2018
Real interest rate (%)	3%	2%			T-bill rate, Melvin et al., 2016, use 3%
Annual traffic growth (%)	0.4%	0.4%	-1.0%	2.0%	Alaska DOT&PF
Average wear rate – studded passenger vehicles (in./100,000 ADT)	Varies by road classification. See sheet: “data” Table 2.				Abaza, 2018, mean of studied highways
Average wear rate – heavy wheel loads (in./100,000 ADT)	0.003052				Abaza, 2018, mean of studied highways

Since no data on current rut depth on all 3,025 Alaska road segments were available, the analysis assumed that all roads in Year 1 of the 20-year analysis have no rut damage and accumulate rut damage at the rates measured in this study. While the assumption of no rut depth in Year 1 of the analysis may seem artificial, it allows for the estimation of damage over the useful life of roads equal to 20 years. Consequently, this assumption may underestimate statewide expenditures in the first few years of analysis (Years 1–4), but on a statewide basis the assumption averages out over the life of roads in the state.

The survey of Alaska motorists conducted as a part of this study was used to estimate how quickly Alaskans might adopt new non-studded snow tire technology. The survey was representative of passenger vehicle ownership, particularly in the Fairbanks and Juneau areas. Survey response was higher than the proportional passenger vehicle ownership in the Mat-Su

Valley, in Kenai, and in other regions, and relatively lower in Anchorage (Table F.2). The most important survey finding was that 11% of studded tire users (64% of all motorists) plan to buy non-studded tires within the next 2 years, and 63% of studded tire users will consider buying non-studded tires in the future.

Table F.2 Adoption rates for non-studded winter tires based on results from a survey of Alaska motorists by region

Item	Anchorage	Fairbanks	Juneau	Kenai	Other	Mat-Su	Statewide
% 2017 passenger vehicle registrations	66%	13%	4%	1%	7%	9%	
% survey respondents	44%	14%	5%	8%	16%	13%	
Consider buying non-studded tires	63%	70%	46%	33%	59%	68%	63%
Will buy non-studded tires in 2 years	11%	10%	15%	0%	11%	16%	11%

Alaska Department of Revenue tire fees for the past 6 years were analyzed (ADOR, 2018). Published annual fees from studded tire sales and stud installations were divided by the tire fee of $5 to calculate the number of studded tires and stud installations sold each year. Figure F.1 illustrates studded tire and stud installations sold over the past 6 years and associated state revenue from the tire fee. The survey results led to the conclusion that the use of studded tires will decline overall in the future as more Alaska motorists adopt new non-studded tire technology and learn more about the safety of non-studded tires. Even though the stated adoption rates range from 0% to 16% across regions and 11% statewide, a 2% annual rate of decline in studded tire and stud installation sales was used for the base case analysis. Since the survey of motorists did not measure potential self-selection bias, bias was not accounted for in the analysis, but the survey was certainly subject to self-selection bias. As a result, the stated adoption rate in the survey is likely higher than what would be expected had bias been accounted for. It is thought that an arbitrary adjustment in the adoption rate from 11% to 2% is adequate and consistent with the recent decline in studded tire sales of 2% when the number of registered passenger vehicles remained unchanged. The projected studded tire and stud-installation sales and associated revenue predictions are shown in Figure F.1.

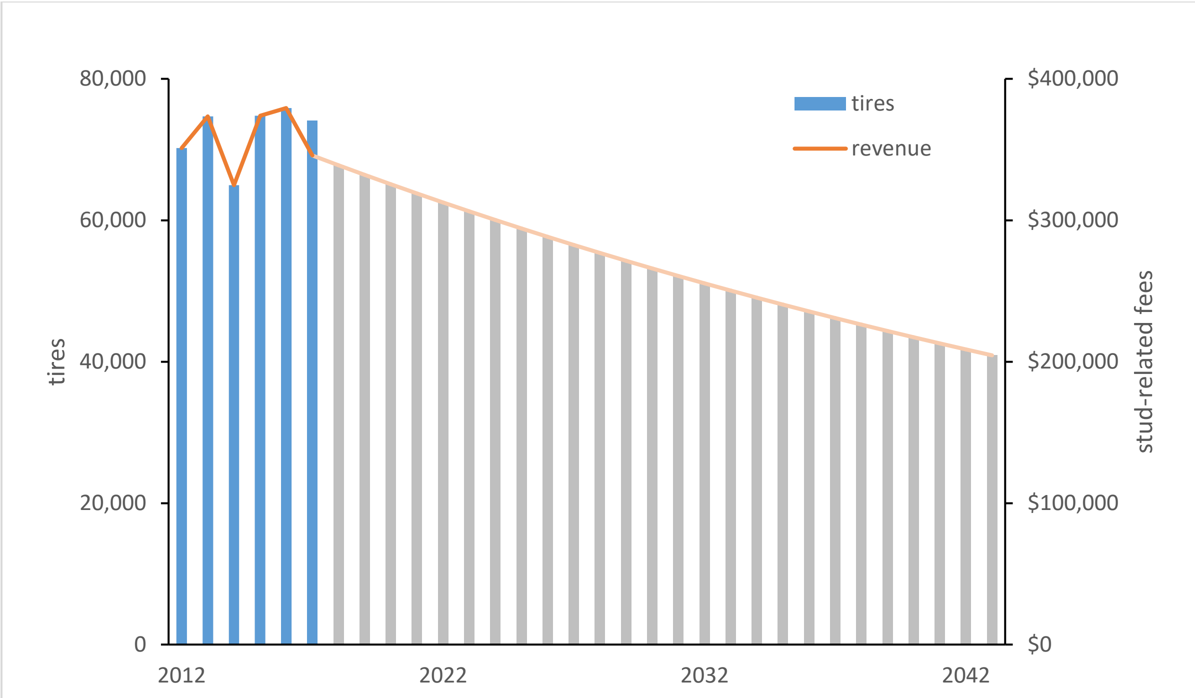


Figure F.1 Studded tire and stud-installation sales (blue bars) and fees (orange line) from 2012 to 2017 and projections for 20 years from now, shown as gray bars (tires) and Orange line (fees)

Results

Using the base-case assumptions, the estimated total cost of mitigating road damage from studded tires in Alaska over the next 20 years will amount to $203.2 million in 2019 USD, discounting any future damage by 3%.

Even though the projected decline in the sale and subsequent use of studded winter tires would result in less wear to Alaska roads, the effective annualized damage cost associated with studded tires still amounts to $13.7 million annually. This effective annualized damage cost compares with the annualized studded tire fees of $318,000. Consequently, the resurfacing cost associated with road damage from studded tire use is more than 42 times larger than the state's fees from the sale of studded tires and stud installations.

Assuming base-case assumptions, the annual non-discounted expenditures in 2019 USD projected over the next 20 years range from $1.3 million to $25.3 million, with a mean of $17.3 million (Figure F.2).

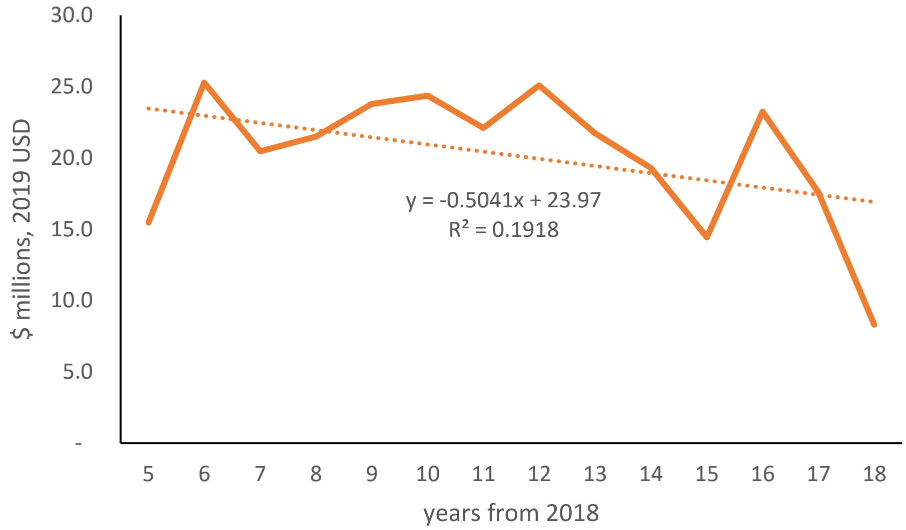


Figure F.2 Estimated total annual expenditures for statewide resurfacing projects over the next 20 years

Due to lack of data on current rut depth for all 3,025 Alaska road segments, the analysis assumes all roads are brand new, an assumption that underestimates expenditures in earlier years of the analysis. For more realistic illustrative purposes, only expenditures starting in Year 5, after the first rehabilitation life has passed, are shown. Since the simulated total annual expenditures vary from year to year, the added trend line shows slightly decreasing expenditures over time resulting from continuing adoption of non-studded winter tire technology. Note that since the annual expenditures shown here are not discounted, the annualized damage estimate of $13.7 million (which is discounted) is below the average annual expenditure of $17.3 million.

For an analysis of resurfacing expenditures by road, the road segments were combined to arrive at the total expenditures by road and resurfacing project over 20 years of useful road life. The top ten most expensive roads are also the roads where most of Alaska's traffic occurs: the Glenn Highway is the most expensive followed by the Seward Highway (Figure F.3).

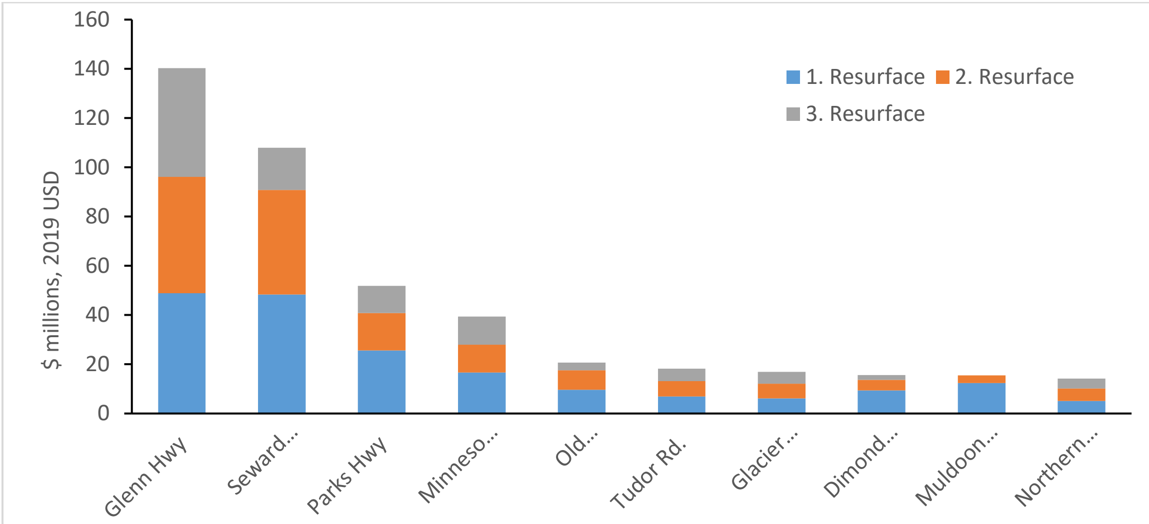


Figure F.3 Estimated resurfacing expenditures for Alaska's 10 most expensive roads over the next 20 years by resurfacing project. Due to predicted continuation of drivers switching to non-studded winter tires, subsequent resurfacing expenditures decline for each road.

Sensitivity Analysis

The sensitivity of how annualized effective damage estimates vary depends on parameter assumptions. Table F.3 shows the implications of assuming a positive rate of studded tire use, in contrast to the main finding of the household survey, which was a decline in studded tire use. If motorists do not adopt non-studded snow tires and studded tire use increases annually by 2%, the annualized damages will increase by 14% to $15.5 million.

An adoption rate of 11%, consistent with the survey results, would lower annualized damage by 33% to $9.2 million. This result underlines that an ad campaign to increase the use of non-studded winter tires could decrease damages, but not substantially.

Table F.3 illustrates the sensitivity of assumptions regarding the cost of resurfacing. The median cost ($2.85/ft^2), as observed across 19 recent resurfacing projects, was used for the base case of $13.7 million in annualized damages. The cost associated with the 25th percentile of this group of projects ($2.06/ft^2) results in 28% lower damage estimates of $9.9 million, whereas a more expensive cost ($3.24/ft^2), the 75th percentile cost, results in an increase of 14% or $15.5 million in annualized damages.

Table F.3 shows that estimated damages are most sensitive to the assumed rehabilitation threshold, determining at what rut depth the Alaska DOT&PF decides to resurface a damaged road. Increasing the rehabilitation threshold from 0.5 in. to 0.75 in. reduces damage estimates by

50% to $13.7 million. Note that this analysis does not account for costs related to reduced safety associated with increasing the rehabilitation threshold, which results in increased rut depth. Estimated damages could be reduced by shortening the allowable season for studded tire use by 2 weeks on each end (196 days instead of 228 days), consistent with recent warming trends Alaska has experienced (Markon et al., 2012). Such a policy could reduce damage by 23%, or $10.5 million in annualized damages (Table F.3).

Table F.5 shows that the estimated damages are subject to assumptions related to traffic growth as well. Traffic data for the Glenn Highway and the Seward Highway as well as for Minnesota Drive are inconclusive as to whether these roads experienced an increase in traffic between 2010 and 2015. In the future, traffic growth primarily in wintertime will depend on economic conditions in the state and will be driven by population growth. Most recent population projections estimate the annual percentage of change to range between 0% and 2% (Robinson et al., 2014). An annual traffic increase of 2% would result in 35% higher damages, amounting to $18.4 million in annualized present value terms (Table F.3).

Increased damages due to a higher assumed heavy load proportion of traffic are insignificant. Table F.3 shows that a 0.9% versus a 0.3% proportion of heavy load traffic would only increase annualized damages by $3.9 million (29% increase from base case). This result indicates the much smaller impact of heavy loads versus studded tires on rut depth.

Table F.3 Sensitivity analysis showing how various parameter assumptions influence the estimated annualized damages from studded tire use.

Annual change in studded tire use				
		-2%	2%	-11%
Resurfacing	$ 2.06	$ 9.9	$ 11.6	$ 6.6
cost ($/ft^2)	$ 2.85	$ 13.7	$ 16.1	$ 9.2
	$ 3.24	$ 15.5	$ 18.3	$ 10.4
Studded tire season in days				
		196	228	
Rehabilitation	0.5	$ 10.5	$ 13.7	
threshold (in)	0.75	$ 4.5	$ 6.8	
Traffic growth				
		-1.00%	0.40%	2.00%
Real discount rate	2%	$ 11.3	$ 14.0	$ 18.4
%	3%	$ 10.9	$ 13.7	$ 18.0
Studded tire proportion				
		0%	35.00%	
Heavy loads	5%	$ -	$ 13.7	
proportion (% ADT)	9%	$ 0.1	$ 17.6	

APPENDIX G – POLICY OPTIONS

This section is a summary of the policy options that Alaska has to reduce the resurfacing costs associated with road damage caused by studded tires.

- **Option A: Phase out the allowed use of studded tires.**
  Option A would result in the elimination of current statewide annualized damages of $13.7 million and eliminate damages of almost $203 million over the next 20 years without additional cost to the state and consumers, as non-studded tire options are similar in cost and safety to studded tires.

- **Option B: Ban the use of heavy metal studs and switch to lightweight studs.**
  Option B would result in a net cost savings of 50% in total pavement damage. Based on the research results, the total pavement rehabilitation life of the Alaska roadway system would increase by 7% to 10%. Net cost savings could reach $6.9 million annually in total annual expenditures for pavement resurfacing due to studded tire damage. A ban on using heavy metal studs is encouraged especially; lightweight studs are tax free by Alaska law.

- **Option C. Subsidize the sale of non-studded winter tire technology.**
  Option C considers potential adoption rates of non-studded winter tires as high as 11% without a subsidy and, as stated in the survey results, is associated with an annualized damage reduction of $4.5 million. Given the potential for even higher adoption rates under a tire subsidy, it raises the question of whether providing non-studded winter tires for free or at a substantially reduced price could offset associated damages caused by studded tire use. Unfortunately, under this study, limited information was gained about how consumers would respond to a tire subsidy. Nevertheless, the analysis shows that Alaska could save by promoting higher adoption rates through a subsidy or other incentive program. A $6 million investment by the state incentivizing the use of non-studded tires would equal a subsidy of $80 per non-studded snow tire for the 75,000 studded tires bought by Alaskans annually. Under an incentive program, the likely adoption rate would be much larger than 11%, which is the percentage of survey respondents who stated they would switch given no incentive. Perhaps such a $6 million investment could entirely eliminate annualized studded tire damage of $13.7 million, resulting in a benefit cost ratio of almost 3/1. For example, an adoption rate of 25%

would reduce annualized damages to $6 million and eliminate studded tire use by 2034. The subsidy program could be tied to the useful life of the tire to avoid arbitrage, which means limiting the issuance of the subsidy to when the old tire needs replacement.

- **Option D: Shorten the studded tire season by 2 weeks on either end, consistent with recently observed climatic changes.**
  Option D would allow studded tire use between October 1 and April 15, which would shorten the current season under AS 28.35.155 by 4 weeks and reduce annualized studded tire damage by $3.2 million, leaving $10.5 million in annualized damages.

- **Option E: Educate motorists about the safety of non-studded winter tires.**
  Under Option E, the state would promote switching to non-studded tires. If 11% instead of 2% of motorists were to switch to non-studded winter tires every year, annualized damage would decrease by $4.5 million, still leaving $9.2 million in annualized damages. An education campaign should particularly target the Kenai region, where resistance to new winter tire technology is higher than average, with only 33% of studded tire users considering the use of non-studded winter tires and none planning to buy non-studded winter tires in the next 2 years.