SOCIO-ECONOMIC EFFECTS OF STUDDED TIRE USE IN ALASKA

FINAL REPORT

by

Hannele Zubeck, Ph.D., P.E.,
Lynn Aleshire,
Susan Harvey, and
Stan Porhola
University of Alaska Anchorage
School of Engineering
3211 Providence Drive
Anchorage, AK 99508

and

Eric Larson
University of Alaska Anchorage
Institute of Socio-Economic Research
3211 Providence Drive
Anchorage, AK 99508

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Abstract

The University of Alaska Anchorage conducted a study on the socio-economic effects of studded tire use on Alaska. The Alaska Legislature funded the study in Spring 2002. This final report explains and compares technologies to provide winter traction, gives a regulatory overview of studded tire usage in the U.S. and abroad, investigates the effect of studded tire usage on human health due to air pollution impact and reduced number of traffic accidents, and describes the affect of studded tire usage on pavement wear. The stud usage in Anchorage was surveyed and an economic analysis was conducted. In total, the use of studded tires seems to have a positive impact on the overall Alaskan economy. The savings from avoided crashes are the most substantial impacts and benefit the broadest range of groups including the state government, vehicle owners, passengers, and insurance companies (and their policy holders).

Executive Summary

The University of Alaska Anchorage conducted a study on the socio-economic effects of studded tire use on Alaska. The Alaska Legislature funded the study in Spring 2002. The objective was to investigate usage of studded tires, different tire and stud technologies, effects of stud use on traffic safety, air quality, and pavement wear. The economic impact of these factors on Alaska was evaluated.

Technology to Provide Winter Traction: The winter tire technology improves continuously as the manufacturers release their newest tire models. Several tire manufacturers supply both factory-installed studded tires and non-studded winter tires in Northern Europe. A limited number of these are on the market in Alaska. According to the test results studded tires provide on average better traction on ice than non-studded friction tires. On snow or wet pavement there are no significant differences. Alternatives to winter tires, chains and special equipment, are currently not practical for Alaska, where snowy and icy roads occur regularly.

Regulatory Overview: Six states (Colorado, Kentucky, New Hampshire, New Mexico, Vermont, and Wyoming) allow virtually unrestricted use of studded tires on state roads and highways. Thirty-six states (including the District of Columbia) allow studded tires but restrict their use seasonally, geographically, or through equipment specifications. Seven states (Alabama, Florida, Hawaii, Illinois, Louisiana, Mississippi, and Texas) currently prohibit the use of studded tires under any circumstances; however, out of these states only Illinois has significant amount of ice and snow. Several states, including Minnesota and Wisconsin, prohibit studded tires with exceptions. Recent studies in Finland and Japan found that prohibiting studs produces a net increase in total costs. Pavement repair costs are greatly reduced, but costs of accidents plus the increased requirement of surface applications to improve surface traction (e.g. sand, salt) result in an overall increased financial burden at the state level. These studies have lead to legislation that continues the use of studded tires during winter months, but limits that use to lightweight studs to minimize adverse effects.

Air Pollution Impact: There does not appear to be any human health benefit associated with banning studded tires in urban areas of Alaska. A reduction in roadway particulate levels due to the ban would be offset by increased dust levels due to increases in the volume of winter traction sand.

Traffic Safety: All but one of the studies reviewed concluded that studded tires reduce accident risk. Banning stud usage increases the overall cost despite the savings in road maintenance. The relationship between rutted pavement and summer hydroplaning accidents needs to be researched in Alaska, where the ruts sometimes exceed 25 mm.

Pavement Wear: Studded tires wear pavement surface and cause rutting. Rutting is also caused by plastic deformation due to heavy vehicles. The major part of rutting, however, is due to studded tires in regions where studded tires are used. Finland, Sweden and Norway have conducted a tremendous amount of research on studded tire issues. Each country reports that the significant problem of studded tire related pavement wear has been greatly reduced. They

attribute their success mainly to wear resistant pavements, less aggressive studs and strictly enforced seasonal studded tire usage.

Stud Usage: The visual inspection and vehicle counting method was used to determine the stud usage rate in this study. Parked vehicles were visually inspected and counted in parking garages and in parking lots across Anchorage. In all, 2174 vehicles were surveyed, 214 in December, 550 in January, 950 in February, 240 in March and 220 in April. Several conclusions were made from the gathered data: Stud usage rates in Anchorage have remained about the same from February 1990 to February 2003. Usage rates for passenger cars, SUV's, trucks and vans are 59, 43, 40 and 60%, respectively. Based on the data from December 2002 to April 2003, the highest rate for studded tire usage was for January. Lightweight studs have been available for Anchorage since 1995. Twenty-night percent (29%) of studded tires have lightweight studs. Almost every vehicle with studs has them on all four tires.

Economic Impact of Studded Tires on Alaska: An effort was made to analyze the economic impact of studded tires on Alaska. With the information available and the assumptions stated in the report, it seems that the use of studded tires has an overall positive impact on Alaska's economy. Tire tax money moves from the hands of vehicle owners to the state government. The state government spends the money in another part of the Alaska economy. Therefore, the money moves from one part of the economy to another and the overall net economic impact on Alaska from the tire tax is small. The savings from avoided crashes are the most substantial impacts and benefit the broadest range of groups including the state government, vehicle owners, passengers, and insurance companies (and their policy holders). The quality of life benefits of avoided crashes benefit mostly passengers and drivers of vehicles.

Recommendations: On the basis of this study, the following recommendations for Alaska are given for implementation:

- continue to study, test and apply wear-resistant asphalt mixtures, which have been proven to reduce the amount of rutting by studded tires.
- consider mandating the use of lightweight studs in the studded tires, which have been proven to reduce the amount of rutting by studded tires.
- develop a comprehensive winter road maintenance policy that would consider traffic safety, pavement wear and the health and environmental effect of winter traction sand and anti-icing agents.
- continue the enforcement of the seasonal restrictions on studded tire usage.
- consider reducing the winter speed limits on high trafficked urban highways.
- consider the pavement wear by studded tires in the geometric design of its roads and streets.

Further research is needed to

- determine the extent to which rutting contributes to summertime accidents.
- determine how much improved pavement materials and mix designs would reduce pavement wear in Alaska.
- determine how much would reduced winter speeds in urban areas reduce accidents and pavement wear.
- enforce criteria for acceptable rut depth triggering maintenance operations taking into considerations reduced accident rate.

- determine how much road wear is actually attributed “solely” to studded tire use, and how much road wear is attributed to heavy vehicle loads and non-studded tires.
- determine the winter traction of studded tires, friction tires and all-season tires with tire life (e.g. km/tire).
- directly compare site-specifically in Alaska’s urban area the human health trade-off of increased respiratory risk of studded tire dust, versus the human health risk associated with a studded tire ban or decreased studded tire use. Additional research is necessary to speciate roadway dust samples and evaluate chemicals of concern to human health.
- determine actual economic costs of owning and using studded tires more accurately using data from collected tire tax revenue.

Acknowledgements

The authors would like to thank Senator John Cowdery for introducing Senate Bill 216 to the Legislature of the State of Alaska on April 30, 2001 for the funding of this study. Although the bill did not pass, the Senate Finance Committee added the proposed funding in the FY03 for the University of Alaska for the purposes of this study. Warm thanks go to Dean Robert Lang for his invaluable help with the literature search. The authors would also like to thank the reviewers of this report, Bruce Brunette, Billy Connor, Dave Esch, Scott Gartin, Chuck McGee, and Dennis Nottingham. Their questions, comments and insight were invaluable.

1. Introduction

1.1 Background

Studded tires have been used since the 1960s to provide enhanced vehicle traction under winter driving conditions in cold regions with snowy and icy roads. The leading countries using the studded tires are the Nordic Countries, especially Finland and Sweden. In Finland the studded tire usage is 95% (Leppänen 1997), and Sweden mandates the tire use for winter months. The studded tire usage in Alaska has been historically 73% in 1970 and 49% in 1990 (AKDOT 1973; Hicks et al. 1990).

The use of studded tires needs to be considered at the State level, as it affects the winter maintenance policy for roads. The main goal of winter maintenance is to guarantee that winter traffic conditions are sufficiently good, safe and consistent enough to allow society to function efficiently. The State of Alaska Legislature funded this study in Spring 2002 to determine the current studded tire usage in Alaska and what are its socio-economic effects on Alaska. This information will be used to possibly legislate stud usage and guide winter maintenance of Alaskan roads.

1.2 Problem Statement

Studded tires wear the pavement surface, which causes rutting of the road (Figure 1.1). As the ruts are a traffic safety hazard, a rutted pavement needs to be rehabilitated. The Nordic Countries and US states that allow stud usage report spending annually millions of dollars on repairing the pavement damage due to the studded tires. In addition to rehabilitation and maintenance costs, the wear by studded tires may cause health risks. Due to the pavement wear, particles of dust are produced, some of which are small enough to be inhaled into the human respiratory tract. Elevated particulate levels can aggravate respiratory systems of sensitive populations, such as people with asthma, children, and the elderly. (Asano et al. 2002).

1.3 Goals and Objectives

The goal of this research is to determine the current studded tire usage in Alaska and what are its socio-economic effects on Alaska. The objectives are to identify the effect of studded tires on Alaskan air quality, health, traffic safety, pavement wear and overall economy.

1.4 Scope of Work

The study was conducted as a field survey and literature study. The studded tire usage rate was determined by conducting surveys on parking lots and recording the percentage of vehicles using tires without studs, tires with conventional heavyweight studs and lightweight studs. The effect of studded tires on air quality, health, traffic safety and pavement wear was conducted as a literature review. This final report details the results of the studded tire usage for winter months of 2002-2003 and the results of the literature review.

Figure 1.1. Pavement Rutting on Lake Otis Parkway in Anchorage, Alaska

2. Technology to Provide Winter Traction

The technology to provide winter traction includes winter tires, chains and special equipment. Winter tires can be divided in studded tires and friction tires. Both studded and friction tire technologies improve quickly. Traction, durability and driving comfort are among the factors constantly improved. These factors depend on kind of studs, stud-tire systems, treads, tire structure and materials. The winter tire developers need to consider driving performance on bare dry and wet pavement, ice, slush and snow. Depending on the location and target customers of a company, the tire manufacturers develop their winter tires for different conditions. For example, tire manufacturers in Germany may develop a winter tire that is good in driving on a wet high speed freeway, at the same time compromising driving on ice, whereas the manufacturers in the Nordic Countries have to consider traction also on ice and snow. The following sections describe different kind of winter tires and alternative technologies.

2.1 Studded Winter Tires

Studded winter tires are equipped with studs that protrude out of the tire to provide traction on ice and snow. Original studs used in the 1960s and early 1970s were steel, soon followed by designs that had a steel jacket with a tungsten carbide pin similar to today's conventional studs. Figures 2.1 and 2.2 illustrate the construction of a typical stud. Stud protrusion increased when the tire wore out, which subsequently increased the pavement wear. Average protrusion was 2.2 mm. Studs that are in market today are controlled protrusion studs that are designed to allow the tungsten carbide pin to maintain a fixed protrusion length. The average protrusion today is 1.1 mm. One of the latest developments in the stud technology is a square stud that was introduced to European market in winter 2003 in Nokian Hakkapeliitta 4. Figure 2.3 shows several conventional and lightweight studs.

In Anchorage, there are two categories of studs available:

1. Conventional – steel jacket with tungsten carbide pin. The mass of these studs is typically 1.9 g for passenger cars, 2.4 g for vans and 2.8 – 9.3 g for trucks. Conventional studs have typically one flange.
2. Lightweight – light metal composite or polymer jacket with tungsten carbide pin. The mass of these studs is smaller than 1.1 g for passenger cars, 2.3 g for vans and 3.0 g for trucks. The lightweight studs come with single and double flanges.

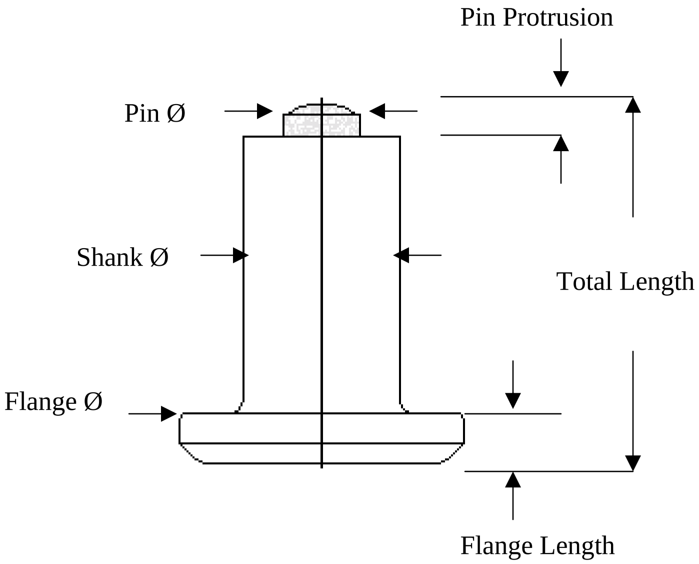

Figure 2.1. Stud Construction, Single Flange (Simon Company Group 2003)

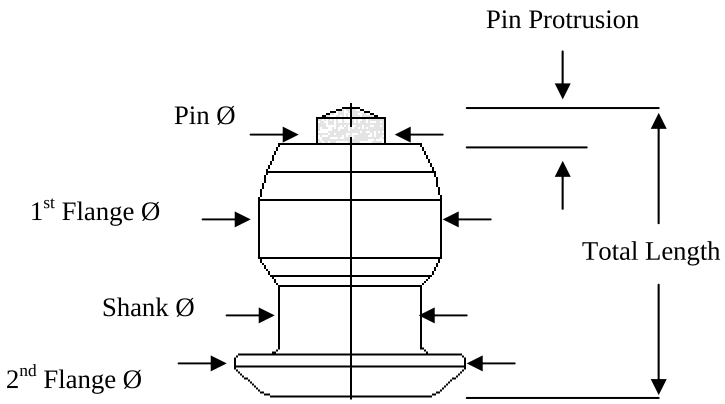

Figure 2.2. Stud Construction, Multi-flange (Simon Company Group 2003).

Figure 2.3. Lightweight and Conventional Studs

2.2 Non-studded Friction Winter Tires

Friction winter tires are designed with special winter tread patterns and sipes to increase traction on wet pavement, ice and snow.

The friction winter tire technology also improves rapidly. With a warming trend in the climate, these tires have become more and more popular. Sipes and rubber compounds are among the factors continually improved. Some examples are Bridgestone Blizzak tires which include micro bubbles. Green Diamond Tyres include silicium carbide and aluminum oxide and Nokian Hakkapeliitta Q tires include safflower and low aromatic oils in the surface rubber compound to improve the traction on the slick road surface.

2.3 Comparison of Studded and Non-studded Winter Tires

Traction is the main factor when tires are compared with each other. Traction is evaluated with tests that show stopping distance and lateral maneuverability on different pavement conditions. Driving comfort and noise are also factors that are compared. As tire technology develops quickly, only recent comparison studies can be considered.

Anttila and Mäkelä (2002 and 2003) tested 14 winter tires in 2002 and 17 in 2003.The tests included studded tires and non-studded friction tires on the market in the Northern Europe. Each test was run twice with several repetitions by several drivers in each test set. The 2003 tire selection included a set of studded tires and a set of friction tires that were seven years old. These tires were broken in, but were not used otherwise. This was done to see, if the tire technology has improved significantly in seven years. As few of the tire sets were tested on both years, the tests included 13 different kinds of studded tires and 11 different kinds of friction tires. Anttila and Mäkelä (2003) state that all the studded tires tested produce significantly reduced pavement wear when compared to the conventional studs. The tests included objective tests with a quantitative test result and subjective tests with a qualitative grade given by the drivers. The test results with a quantitative test results are shown in Tables 2.1 – 2.2 and in Figures 2.4 - 2.6.

Table 2.1. Comparison between different winter tires (assembled from Anttila's and Mäkelä's test results, 2002)

	Icy Conditions			Snowy Conditions; undulating packed snow graded with a blade			Slush	Wet Asphalt Pavement
Test Car: Saab 9-5 Tire size: 195/65 R 15	ABS- braking distance on smooth ice from 50km/h, m	Acceleration time[1] on smooth ice from 5 to 30 km/h, s	Track laptime[2] on rough ice, s	ABS- braking distance from 80km/h, m	Acceleration time[1] on snow from 5 to 30 km/h, s	Lap time on track, s	Speed at which drivers started losing control[3], km/h	ABS- braking distance from 60km/h, m
Studded Tires								
Agi Sarek 2	55.0	12.1	79.1	58.0	4.5	70.4	48	20.0
Aurora W403	45.5	9.1	77.2	57.0	4.4	68.1	46	22.5
Continental Winter Viking I	38.5	8.4	74.9	55.5	4.2	66.8	46	21.5
Gislaved Nord Frost 3	42.0	8.8	75.4	55.5	4.2	66.2	49	22.0
Goodyear Ultra Grip 500	43.0	9.8	74.5	52.5	4.1	66.3	46	23v
Kumho KW-11	56.0	12.7	80.4	58.0	4.2	69.6	42	21.5
Michelin Ivalo	40.5	8.2	73.4	55.5	4.2	67.1	42	22.0
Nokian Hakkapeliitta 2	42.0	7.1	74.5	55.0	4.2	66.3	49	23.0
Average	**45.3**	**9.5**	**76.2**	**55.9**	**4.3**	**67.6**	**46**	**21.9**
Friction Tires								
Agi Soft Sarek	63.0	15.9	88.3	54.0	4.2	66.9	45	22.0
Bridgestone Blizzak WS-50	53.5	14.2	80.1	53.5	4.1	66.9	45	22.5
Continental ContiVikingContact 2	60.0	14.3	81.0	52.0	4.1	66.3	43	20.5
Goodyear Ultra Grip 6	67.0	18.6	87.2	59.5	4.5	71.2	46	18.0
Michelin Maxi-Ice	59.5	15.7	81.5	55.0	4.3	67.9	42	21.0
Nokian Hakkapeliitta Q	52.5	13.6	78.7	52.0	4.1	66.4	44	24.0
Average	**59.3**	**15.4**	**82.8**	**54.3**	**4.2**	**67.6**	**44.2**	**21.3**

1) Maximum acceleration using vehicle's anti-skidding system

2) Driving with maximum speed using vehicle's anti-skidding system. The value is the average of all successful laps driven by several drivers.

3) Drivers drove to a curve with slush faster and faster until the vehicle started skidding.

Table 2.2. Comparison between different winter tires (assembled from Anttila's and Mäkelä's test results, 2003)

	Icy Conditions			Snowy Conditions; undulating packed snow graded with serrated blade			Slush	Wet Asphalt Pavement
Test Car: Fiat Stilo Tire size: 195/65 R 15	ABS- braking distance on smooth ice from 50km/h, m	Acceleration time[1] on smooth ice from 5 to 30 km/h, s	Track laptime[2] on rough ice, s	ABS- braking distance on from 80km/h, m	Acceleration time[1] on snow from 5 to 30 km/h, s	Laptime[2] on track, s	Speed at which drivers started losing control[3], km/h	ABS- braking distance from 60km/h, m
Studded Tires								
Agi Sarek 2	48.0	10.8	83.8	55.0	4.4	88.0	48	24.0
Bridgestone Noranza	44.5	10.4	83.7	57.0	4.4	87.6	49	22.0
Continental Winter Viking I	45.5	9.9	81.9	55.5	4.2	86.2	48	23.0
Gislaved Nord Frost 3	45.0	9.8	81.9	56.0	4.4	86.1	50	22.5
Goodyear Ultra Grip 500	38.5	9.0	81.6	52.0	4.2	86.7	48	24.0
Michelin Ivalo	42.0	9.6	82.5	52.5	4.3	87.8	48	23.0
Nokian Hakkapeliitta 4	40.0	8.9	80.1	56.0	4.3	85.6	50	23.0
Pirelli Winter Carving	41.5	9.0	82.5	49.5	4.1	86.9	49	22.5
Uniroyal MS Plus Nordic	43.0	9.6	81.0	55.5	4.3	85.8	48	23.0
Michelin XM+SM260 (7a)	55.0	13.3	94.3	61.5	4.6	93.2	50	21.5
Average	**44.3**	**10.0**	**83.3**	**55.1**	**4.3**	**87.4**	**48.8**	**22.9**
Friction Tires								
Bridgestone Blizzak WS-50	61.0	13.5	91.5	53.5	4.4	86.2	48	23.5
Continental ContiVikingContact 3	59.0	13.6	89.5	53.0	4.4	84.6	48	22.5
Gislaved Soft Frost 2	57.5	13.3	89.5	52.5	4.3	84.5	46	23.0
Michelin Maxi-Ice	61.5	13.3	94.6	54.5	4.4	85.7	46	22.0
Nokian Hakkapeliitta Q	52.0	12.5	92.5	54.0	4.4	85.2	47	26.5
Pirelli Icesport	60.5	13.3	95.7	53.5	4.5	88.1	46	23.5
Bridgestone Blizzak MZ-01 (7a)	66.5	15.5	97.9	56.5	4.5	89.7	48	24.0
Average	**59.7**	**13.6**	**93.0**	**53.9**	**4.41**	**86.3**	**47.0**	**23.6**

1) Maximum acceleration using vehicle's anti-skidding system

2) Driving with maximum speed using vehicle's anti-skidding system. The value is the average of all successful laps driven by several drivers.

3) Drivers drove to a curve with slush faster and faster until the vehicle started skidding.

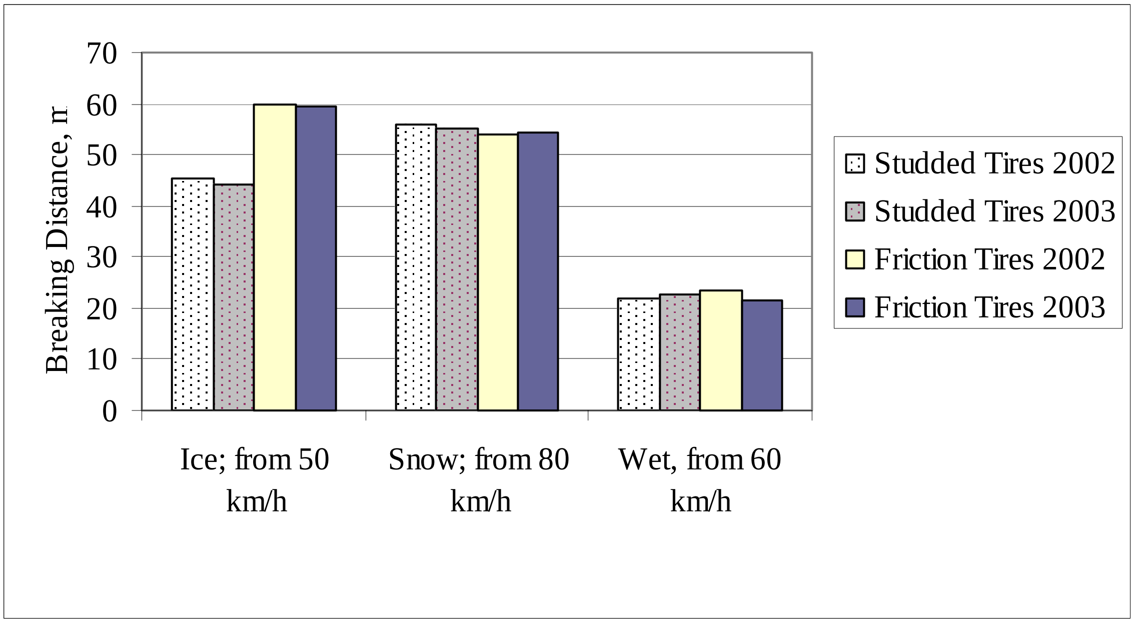

Figure 2.4. Average ABS-braking distances on test track (created from Anttila's and Mäkelä's test results, 2002 and 2003)

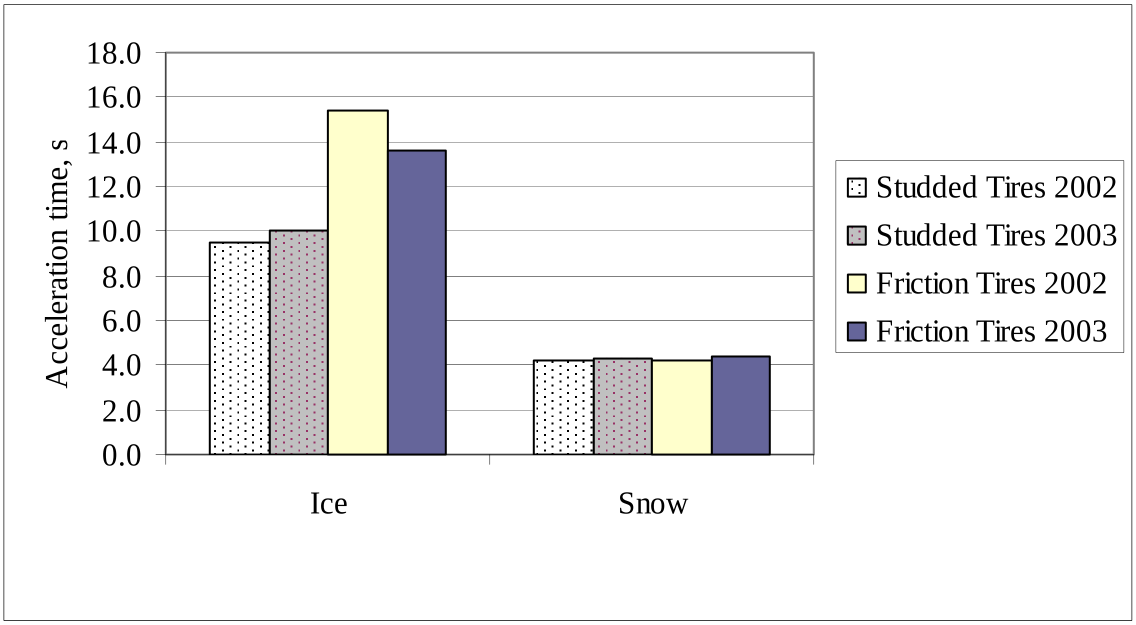

Figure 2.5. Average acceleration time from 3 to 50 km/h (created from Anttila's and Mäkelä's test results, 2002 and 2003)

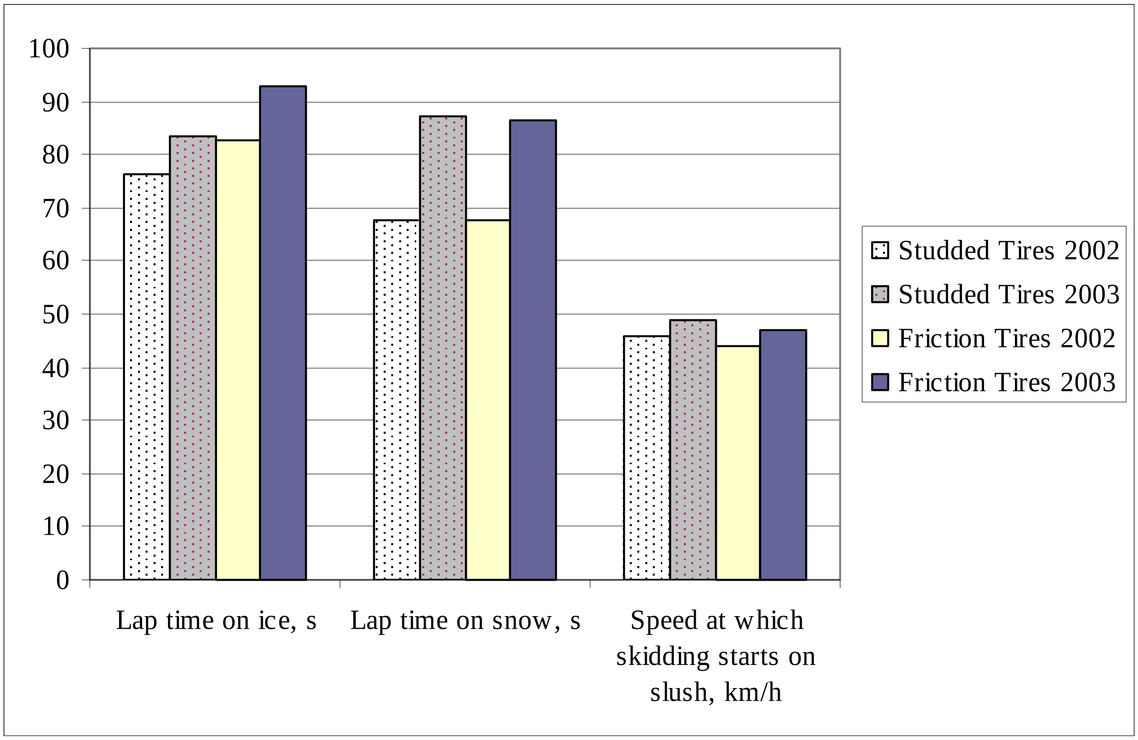

Figure 2.6. Averages of lateral maneuverability tests (created from Anttila's and Mäkelä's test results, 2002 and 2003)

The traction of the tires was tested in braking distance (Figure 2.4) and acceleration test (Figure 2.5). In these tests, the average braking distance on ice is about 15 m shorter for studded tires than for friction tires. There is no significant difference in the braking distance between the averages of the two tire groups on packed graded snow or on wet pavement. The same trend repeated itself in the acceleration test. The acceleration time was 3 to 6 s faster on ice for vehicles with studded tires than friction tires, but on snow there was no significant difference. The tests were conducted using maximum acceleration and the vehicle's anti-skidding system.

The lateral maneuverability was tested on ice, packed graded snow and slush (Figure 2.6). The vehicles with studded tires had about 10% greater speeds on ice track than the vehicles with friction tires. On snowy track, there were no differences. The tests were conducted by driving with maximum speed using the vehicle's anti-skidding system. The reported values are the averages of all successful laps driven by several drivers.

The other factor that describes the lateral maneuverability is the speed at which vehicles started to skid on slush. Drivers approached a curve covered with slush faster and faster until the vehicle started skidding, and this speed was recorded. There was no significant difference between the speed of the vehicles with studded and friction tires (Figure 2.6).

In most of the tests, the seven years old tires did not perform as well as the new tires, which indicated that the winter tire technology has improved in seven years. However, the old tires may have performed better if they were fresh from the production line, as the rubber compounds age in storage (Anttila and Mäkelä 2003).

The subjective test results indicated that the friction tires produced less noise than the studded tires on bare and dry pavement. The noise test was a blind test, where the drivers gave a grade from scale 4 to 10 to each tire set. (Anttila and Mäkelä, 2002 and 2003).

Older test results include Lu's tests on Bridgestone Blizzak tires in Fairbanks, Alaska in 1995 (Lu 1995). He compared the performance of the non-studded Blizzak tires to studded tires. He concluded that the Blizzak tires produce significantly less road wear, and have shown better traction than studs on bare pavement while still having comparable traction on packed snow. However, Blizzak tires have a significant disadvantage for braking distance on ice when compared to studded tires. (Lu 1995)

2.4 Alternatives to Winter Tires

Colorado Department of Transportation (2003) approves alternative traction devices. These include:

- Wheel sanders that provide traction by distributing sand beneath the wheels of the vehicle.
- Pneumatically driven chains that spin beneath the driving wheel automatically as traction is lost. Chains cause high pavement wear rate if used on bare pavement.
- Conventional chains that are wrapped around each tire. They cause high wear rates if used on bare pavement and are not practical for everyday driving needs.

These devices must be installed seasonally or as road conditions change. They are usually for trucks and not practical for passenger cars.

Inuzuka (1997) patented a retractable anti-skidding device that is installed on the underside of the vehicle. It deploys rubber fins beneath the wheels of the vehicle at the touch of a button. It does not cause pavement rutting and can be used when necessary. The device must be professionally installed on the vehicle each winter. The device is not currently commercially produced, and there is not sufficient performance information about its use.

2.5 Research Needs

Friction tires show promise as a good alternative to studded tires. Proponents of friction tires contend that after one season of use the traction of a studded tire is significantly reduced. That is, the studs are worn to the point that they offer little or no advantage over a friction tire. No published research could be found that addresses this issue. Research should be conducted to compare the traction characteristics of friction and studded tires as a function of driven distance.

3. National and International Regulation of Studded Tire Use

3.1 Regulatory Overview

The use of studded tires on motor vehicles is limited or restricted by many jurisdictions worldwide. Most studded tire regulations reflect a policy decision that weighs the potential safety benefits afforded by enhanced traction under winter driving conditions against the road maintenance costs and human health effects caused by studded tires (Elvik 1999). On the basis of these considerations, jurisdictions that regulate studded tire use have adopted a variety of approaches to prohibiting or limiting their use.

Countries such as Japan, Germany, Holland, and Belgium prohibit the use of studded tires outright ("Studded Tires" 2001). Other countries, like the United States and Canada, regulate the use of studded tires at the state or provincial level, so that studded tire use may be banned, limited seasonally, and permitted with no restrictions in certain states or provinces. Studded tire use has not been banned in the Nordic countries, although Denmark, Finland, Sweden, and Norway all restrict studded tire use to the winter months ("Nordic Regulations" 2003). A handful of US states and Canadian provinces still allow unrestricted use of studded tires (Scheibe 2002).

3.2 National Regulations

United States studded tire regulations, which are implemented at the state level, began to emerge shortly after the initial introduction of studded tires in the 1960s. As studded tires became more common, states began to acknowledge their utility by legalizing their use under certain conditions. In 1963, only 13 states permitted studded tire use. By 1965, an estimated 28 states allowed their use, and by 1967, approximately 34 states had legalized studded tires (Angerinos et al. 1999). At present, forty-two states, plus the District of Columbia, allow studded tire use on state roads for at least part of the year, with a variety of additional restrictions in place.

Seven states (Alabama, Florida, Hawaii, Illinois, Louisiana, Mississippi, and Texas) currently prohibit the use of studded tires under any circumstances. In Minnesota, only nonresidents may operate vehicles with studded tires. Most of the US states that have banned studded tires are in the southern latitudes and experience relatively mild winters, with the exception of Illinois, Minnesota, where studded tires have been banned to minimize pavement impacts. Minnesota's studded tire ban, which has been in effect since 1972, was implemented on the basis of a Minnesota Department of Highways (MDH) report that cited the high rate of pavement damage caused by studded tires. The report also indicated that the pavement wear caused by studded tires was exacerbated by de-icing sand and road salt; however, the road salt and sand were observed to cause far less pavement damage in the presence of non-studded tires (MDH 1971).

Thirty-six states, including the District of Columbia, allow studded tires but restrict their use seasonally, geographically, or through equipment specifications. Only six states (Colorado, Kentucky, New Hampshire, New Mexico, Vermont, and Wyoming) allow virtually unrestricted use of studded tires on state roads and highways.

Of the states that regulate studded tires, nearly all (thirty-three, including D.C.) have set seasonal restrictions on studded tire use. The period of time during which studded tire use is permissible varies, generally beginning in the fall (September - November), and ending in the spring (March - May). Some states that use such seasonal restrictions (e.g. California, Massachusetts, Washington) allow discretion to the regulating state agency (generally, the transportation or public safety department) to extend the period of allowable studded tire use under certain conditions, such as extended winter weather conditions or other extenuating circumstances.

A number of state regulations specify the standards for permissible tire studs, such as the type of metals that may be used (most commonly tungsten carbide), the maximum stud diameter, or the maximum distance that a stud may protrude from the tire surface. Only three states specify the maximum diameter for a metal tire stud (1/4 inch in D.C., 5/16 inch in Nebraska, and 3/8 inch in New York). A larger number of states regulate the distance that a stud may protrude from the tire tread. These stud protrusion requirements recognize that increased stud length corresponds to increased pavement wear. In Arkansas, Iowa, North Carolina, North Dakota, Rhode Island, South Carolina, and Virginia, studs may protrude no more than 1/16 an inch from the tire surface. Other states limit this protrusion to lengths ranging from 1/8 of an inch (D.C.) to 3/32 of an inch (Oklahoma, New York, and Indiana), to 7/64 of an inch (Nebraska and Minnesota non-residents). Oregon is the only state that sets both an upper and a lower limit for stud protrusion (.06 inches and .04 inches, respectively). Utah’s protrusion standard is .05 inches.

In addition to the length of stud protrusion, several states also regulate the maximum amount of metal that is allowed to be in contact with the roadway, measured either by the number of studs allowed per tire, or as a percentage of the total tire surface. Arizona, California, Nevada, Oklahoma, and Virginia require that the percentage of metal in contact with the roadway may not exceed 3% of the total tire area. In Maryland, this number is 3.25% of the total tread area, or a maximum of 150 studs per tire. New York allows only 0.75% of the total tire surface to be metal studs, while the limit for non-resident vehicles operating in Minnesota is 2%.

Oregon’s studded tire laws, passed in 1996 and revised in 1997, include a provision limiting the legal sale of tire studs to “lightweight” studs. The definition of lightweight studs is based upon the Tire Stud Manufacturing Institute’s (TSMI) designations which clarify for installers the allowable weight for a given size stud. Stud size is in effect dictated by the tire manufactures since they create the holes in the tire rubber to receive the installed studs. Lightweight stud regulations recognize that the weight of the stud also has an impact on pavement wear. The sliding scale recognizes that different stud weights are required depending upon tire size (Angerinos et al. 1999). A 2000 report commissioned by the state of Oregon estimates that the lightweight stud requirement will “spare Oregon highways somewhere between 43% and 29% of the costs of repairing studded tire damage” (Malik 2000). A 1996 study estimated the annual cost to repair studded tire damage to Oregon state highways, prior to the lightweight stud regulations, at $37million (1994 dollars), with similar damage costs to municipal and county roads (Brunette and Lundy 1996). In 1999, the neighboring state of Washington followed Oregon’s example, adding a similar “lightweight stud” provision to their motor vehicle laws. Table 3.1 briefly describes the TSMI designations.

Table 3.1. Tire Stud Manufacturing Institute (TSMI) per stud weight designations used in Oregon and Washington statute.

TSMI Designation*	Allowable Weight, g
TSMI11	1.5
TSMI12	1.5
TSMI13	1.5
TSMI14	1.5
TSMI 15	2.3
TSMI16	2.3
TSMI17	3.0
*The number following the TSMI initials indicates the tire size in inches	

A few states limit the use of studded tires on vehicles over a certain weight class. In Tennessee and Utah, vehicles with a gross weight over 9,000 lbs. may not use studded tires, with the exception of school buses, emergency equipment, and certain farm machinery. In Virginia and Washington State, the gross weight limit for studded tires use is 10,000 lbs. Virginia allows exceptions for certain farm machinery, while Washington waives their weight requirement for school buses and fire department equipment.

Nearly all US states with studded tire restrictions allow for exceptions in the case of emergency vehicles, school buses, rural mail carriers, certain types of farm or road construction equipment, or in pre-defined geographic areas. Likewise, most state laws restricting studded tire use do not apply to tire chains or rubber studs. Table 3.2 summarizes the provisions of US state laws addressing studded tire use.

Table 3.2. Summary of United States Studded Tire Regulations by State

State	General Provisions	Seasonal Restrictions	Exceptions	Cite
Alabama	Studs prohibited.	Not permitted at any time.	Farm machinery with studs that will not injure the highway or "when required for safety."	Code of Alabama § 32-5-210
Alaska	Permitted to use "pneumatic tires having studs designed to improve traction without substantially injuring the surface of the highway."	Studs permitted Sep 15 - May 1; South of 60 degrees - Sep 30 - Apr 15.	None specified.	13 AAC 04.230

State	General Provisions	Seasonal Restrictions	Exceptions	Cite
Arizona	Permitted to use pneumatic tires containing metal studs of tungsten carbide or other suitable material. The number of studs or the percentage of metal in contact with the roadway may not exceed 3% of the total tire area in contact with the roadway.	Studs permitted October 1 to May 3.	None specified.	Arizona revised statutes § 28-958
Arkansas	Stud cannot protrude more than 1/16 inch from the surface of the tire.	Studs permitted November through April.	To be superceded by federal law banning studs, if enacted.	Arkansas Statute § 75-733.1
California	Permitted to use pneumatic tires containing metal studs of tungsten carbide or other suitable material. The number of studs or the percentage of metal in contact with the roadway may not exceed 3% of the total tire area in contact with the roadway.	Studs permitted November 1 Through April 30 - may be extended by the state DOT Commissioner.	Certain construction vehicles; permitted traction engines or tractors; authorized emergency vehicles.	California Vehicle code § 27454
Colorado	No restrictions. There may be periods of time when studs or tire chains are required by Colorado Transportation Commission.	None.	None.	§ 2-CCR 601-14
Connecticut	Seasonal restrictions only.	Studs allowed Nov 15 to April 30.	Emergency vehicles.	CT Statutes § 14-98
Delaware	Seasonal restrictions only.	Studs permitted October 15 to April 15.	None.	Title 21 § 4302 Delaware Code
District of Columbia	Permitted to use pneumatic tires containing metal studs, with tips protruding no more than 1/8-inch and a cross-sectional diameter of no more than 1/4-inch.	Studs permitted October 15 through April 15.	None.	CDCR § 18-732
Florida	Studs prohibited.	Not permitted at any time.	Studs that do not harm roads; some farm equip. and DOT construction equipment.	Florida statutes, Title 23, § 316.299
Georgia	Studs permitted only when required for safety because of snow, ice, or other conditions.	None.	Certain farm machinery.	Georgia code § 40-8-74.
Hawaii	Studs prohibited.	Not permitted at any time.	Certain roads in the Mauna Kea Science Reserve and some types of tractors.	Hawaii code § 291-33

State	General Provisions	Seasonal Restrictions	Exceptions	Cite
Idaho	Seasonal restrictions only.	Studs permitted from Oct. 1 through April 30 (date extended from Apr. 15, pending state approval).	Ladder trucks; other exemptions may be granted by the Idaho Transportation Board.	IDAPA § 39.03.46.100; § 39.03.46.101; and § 39.03.46.102
Illinois	Studs prohibited on the state toll highway or on any part of its Right-of-Way.	Not permitted at any time.	None.	92 Ill. Adm. Code § 2520.201
Indiana	Stud projections must not exceed 3/32 of an inch beyond the tread of the traction surface of the tire, and must be constructed to "prevent any appreciable damage to the road surface."	Studs permitted October 1 to May 3.	Farm machinery.	IC § 9-19-18
Iowa	Studs permitted for "pneumatic tires with inserted ice grips or tire studs projecting not more than 1/16 inch beyond the tread of the traction surface of the tire."	Studs permitted November 1 to April 3.	Farm machinery, school buses, fire dept. emergency apparatus.	Iowa Code § 323.442
Kansas	Seasonal restrictions only.	Studs permitted November 1 to April 15.	Farm equipment.	Kansas statutes § 8-1742
Kentucky	No restrictions.	None.	Specifications for lugs used on tractors and other such vehicles.	KRS Chapter 189 § 190
Louisiana	Studs prohibited.	Not permitted at any time.	None.	LAC Title 55, § 835
Maine	Seasonal restrictions only.	Studs permitted Oct. 1 through April 30.	Front-wheel drive vehicles with studded front tires must have studs on rear tires as well.	29-A MRSA § 1769
Maryland	Studs prohibited in most counties of the state, except Allegany, Carroll, Frederick, Garrett, and Washington counties during prescribed time period. The maximum number of tire studs may not exceed 1 1/4 percent (0.0125) of the total area of the tread surface, and the number of tire studs installed may not exceed 150 per tire.	Studs permitted from November 1 through March 31 in Allegany, Carroll, Frederick, Garrett, and Washington counties.	None.	COMAR § 13.13.02.10
Massachusetts	Seasonal restrictions only.	Studs permitted Nov. 2 through April 30.	As approved by the Registrar of Motor Vehicles.	540 CMR § 23.03

State	General Provisions	Seasonal Restrictions	Exceptions	Cite
Michigan	Studs allowed in Upper Peninsula only. Studs not permitted "unless they wear either concrete or asphalt pavements, typical of those in this state, at a rate not to exceed 25% of the reference standard studded tire." Reference studded tire defined as size E 78-14, 4-ply, bias construction tubeless snow tire containing 90 studs (kennametal class III (16-3-585)) fixed in 6 rows around the tire with 15 studs in each row.	None.	Farm machinery, law enforcement, rural postal carriers, and emergency vehicles.	MICH. ADMIN. CODE R. § 247.171, 247.174
Minnesota	Stud prohibited except for nonresidents, who are subject to restrictions on length of projection beyond tread (no more than 7/64 inch) and percentage of total tread in contact with the road (no more than 2%).	None.	Rural mail carriers, farm or husbandry vehicles, tractors, permits issued by state/local authorities, certain nonresidents.	MN Statutes § 169.72
Mississippi	Studs prohibited.	Not permitted at any time.	Certain farm and tractor equipment.	MS code § 63-7-67
Missouri	Seasonal restrictions only.	Studs permitted Nov. 2 through March 31.	None.	MRS § 307.171
Montana	Seasonal restrictions only.	Studs permitted Oct. 1 through May 31.	None.	MCA § 61-9-406.
Nebraska	Studs permitted for pneumatic tires with metal or metal-type studs not exceeding 5/16 of an inch in diameter inclusive of the stud-casing with an average protrusion beyond the tread surface of not more than 7/64 of an inch.	Studs permitted Nov. 1 through April 3.	School buses, mail carriers, emergency vehicles, farm machinery, permits issued by state or local authorities.	Nebraska statutes § 60-6,250
Nevada	Studs permitted for pneumatic tires containing metal-type studs of tungsten carbide or other suitable material. Studs can be no more than 3% of the total tire area in contact with the roadway.	Studs permitted between October 1 and April 30.	Certain highway repair vehicles, permitted tractors.	NRS **§** 484.6425
New Hampshire	No restrictions.	None.	None.	N/A
New Jersey	Seasonal restrictions only.	Studs permitted between Nov. 15 and April 3.	None.	N.J.A.C. § 13:20-32.19

State	General Provisions	Seasonal Restrictions	Exceptions	Cite
New Mexico	No restrictions. Studs permitted on snow tires when "designed to increase traction on ice or snow upon any vehicle when required for safety because of snow, ice or other conditions tending to cause a vehicle to skid."	None.	Farm equipment, tractors, others by state/local permit.	NM Statutes § 66-3-847
New York	Studs permitted on pneumatic tires containing metal type studs with a diameter not exceeding 3/8 inch and which do not protrude beyond the tread surface more than 3/32 inch. The contact area may not exceed ¾ of one per cent of the total nominal contact area.	Studs permitted from Oct. 16 to April 30.	School buses and state or municipally-owned vehicles.	§ 9-375 NY Consolidated Laws
North Carolina	Studs permitted on any vehicle for increased safety. Studs may project not more than 1/16 inch when compressed.	None.	Farm vehicles, tractors, others by state/local permit.	NC Statutes § 20-122
North Dakota	Studs permitted for pneumatic tires, providing metal studs do not project more than 1/16 inch [3.59 millimeters] beyond the tread of the traction surface of the tire.	Studs permitted from Oct. 15 to April 15.	Farm machinery, school buses.	ND Century Code § 39-21-40
Ohio	Seasonal restrictions only.	Studs permitted from Nov. 1 through April 15.	Public safety vehicles, school buses.	Ohio Statutes § 5589.081
Oklahoma	Studs permitted for pneumatic tires equipped with studs of metal, porcelain or other material, if constructed to provide resiliency upon contact with the road surface, so that not more than 3% of the traction surface be composed of such studs and so that such studs do not project more than 3/32 of an inch beyond the tread of the traction surface and have a rate of wear which will so limit such projection.	Studs permitted Nov. 1 through April 3.	Farm machinery.	OK statutes § 47-12-405
Oregon	Permits studs of metal or other material extending beyond the tread surface of the tire not less than .04 inch nor more than .06 inch and made of such material that the studs will wear, through use, at the same rate as the tread surface of the tire. State law prohibits selling studs other than "lightweight studs" as defined by law.	Studs permitted Nov. 1 through April 3. Can be extended by DOT for safety reasons.	Vehicles on private roads, school buses, emergency vehicles, certain farm & highway construction vehicles, others by permit.	Oregon statutes § 815.160, 815.165, 815.167
Pennsylvania	Seasonal restrictions only.	Studs permitted Nov. 1 to April 15.	None.	67 Pa. Code § 175.130
Rhode Island	Studs permitted only if they have a flat head and project 1/16 inch or less beyond the tread of the traction surface.	Studs permitted Nov. 15 to April 3.	None.	CRIR § 01-100-021

State	General Provisions	Seasonal Restrictions	Exceptions	Cite
South Carolina	Studs permitted “upon any vehicle for increased safety.” Studs must project beyond the tread of the traction surface of the tire not more than 1/16 of an inch when compressed.	None.	Farm machinery.	SC Code §. 56-5-5040
South Dakota	Seasonal restrictions only.	Studs permitted Oct. 1 to April 30.	School bus, firefighting vehicle > 5K lbs.	SD Code § 32-19-3
Tennessee	Tires with metal studs or wires permitted if the percentage of wire or other material in contact with the roadway does not exceed, after the first 1,000 miles of operation, 5% of the total tire area in contact with the roadway. During the first 1,000 miles of use or operation, the wire or other material in contact with the roadway shall not exceed twenty percent 20% of the total tire area in contact with the roadway. Studded tires prohibited on vehicles with a maximum gross weight of more than 9,000 lbs., except as noted.	Studs permitted Oct 1 through April 15.	Farm machinery, school buses, and emergency vehicles.	TN Code § 55-9-106
Texas	Studs prohibited.	Not permitted at any time.	Studs “that do not injure the highway.”	TX statutes § 547.612
Utah	Tungsten carbide studs permitted. Studs shall not project beyond the tread of the traction surface of the tire more than .050 inches. Studs shall not be used at any time on a vehicle with a maximum gross weight in excess of 9,000 lbs., except as noted.	Studs permitted from Oct. 15 through March 33.	School buses, emergency vehicles, farm machinery.	UT statutes § 41-6-150
Vermont	No restrictions	None	None	N/A
Virginia	Studs permitted on any vehicle whose gross weight does not exceed 10,000 pounds. Studs may project no more than 1/16 of an inch beyond the tread of the traction surface of the tire when compressed and cover no more than 3% of the traction surface of the tire.	Studs permitted Oct. 15 through April 15.	Farm machinery.	VA statutes § 46.2-1044

State	General Provisions	Seasonal Restrictions	Exceptions	Cite
Washington	Studs permitted but must be metal, tipped with tungsten carbide, and inserted only in a new tire or a newly-recapped tire which has molded in the tread the "pin-holes" into which metal studs are to be inserted. Metal studs may be installed only by the tire manufacturer, or by a tire dealer in conformance with the manufacturer's specifications. All studded tires sold should have a minimum of seventy metal studs evenly spaced around the tread of the tire. A tire shall contain a minimum of fifty-six metal studs at all times in order to qualify as a "studded tire." Studded tires prohibited on vehicles weighing 10,000 lbs. or over.	Studs permitted Nov. 2 through March 33.	School buses, and fire department equipment.	WAC § 204-24-030 and § 204-24-060
West Virginia	Studs permitted, however no vehicle may use studded tires which are operational with a recommended air pressure greater than forty pounds per square inch.	Studs permitted from Nov. 1 through April 15.	Farm machinery, school buses, certain tractors, others by permit.	W. Virginia statutes §17C-15-37
Wisconsin	Studs prohibited.		emergency vehicles, school buses, vehicles used for mail delivery and automobiles with out-of-state registration.	Wisconsin Statute 347.45
Wyoming	Studs permitted for pneumatic tires when "designed to improve traction without materially injuring the surface of the highway."	None	Certain husbandry equipment, tractors, and others by permit.	Wyoming statutes § 31-5-956

3.3 International Regulations

3.3.1 Canada

In Canada, studded tire regulations are promulgated on a provincial level. Of the twelve provinces, Ontario is the only one with a studded tire ban in effect. Studded tire use is permitted with no restrictions in Alberta, the Northwest Territories, Saskatchewan, and the Yukon Territory, although Alberta laws include a provision requiring that "a studded tire shall not have less than one half the number of studs that are on the corresponding tire on the same axle" (Consolidated Regulations of Alberta, 2002).

Seven provinces impose seasonal restrictions on studded tire use. The period of permissible use is October 1 through April 30 in British Columbia and Manitoba. New Brunswick and Nova Scotia permit studded tires from October 15 through April 30. The period of allowable use is

November 1 through April 30 in Newfoundland, October 1 through May 31 in Prince Edward Island, and October 1 through May 1 in Quebec.

Quebec regulations include a weight limit of 3,000 kg on commercial vehicles with studded tires. Similar to the requirements in the US state of Maine, Quebec mandates that any vehicle with studded tires on the front axle must also have them on the rear axle (R.R.Q. 1981). British Columbia has a similar front and rear axle requirement, with the exception of snowplow trucks over 9,100 kg gross weight. British Columbia also specifies that tire studs may not protrude more than 3.5 mm from the tire tread, and there may be no more than 130 studs per tire for vehicles weighing less than 4,600 kg and no more than 175 studs per tire for vehicles or a greater gross weight (Consolidated Regulations of British Columbia, 2002).

3.3.2 Nordic Countries

Denmark, Finland, Norway, and Sweden all allow studded tire use during the winter months; however, the studded tire usage patterns and federal policies vary slightly among these nations. All four nations have seasonal restrictions, and the time periods for permissible studded tire use are identical in Denmark and Sweden (first of October through the end of April) and in Norway and Finland (first of November through the first Monday after Easter, except in Northern Norway where the time period is slightly extended). Finland, Norway, and Sweden all have regulations in effect governing the number of studs per tire, stud protrusion, and stud weight. The three nations have identical stud weight provisions, and the stud number and protrusion policies are identical in Finland and Sweden and only slightly more permissive in Norway. Table 3.3 summarizes the studded tire provisions in the Nordic Countries ("Nordic Regulations" 2003).

Table 3.3. Summary of Studded Tire Regulations in Nordic Countries

Country	Seasonal Restrictions	Number of Studs per Tire	Stud Protrusion	Stud Force/Weight
Denmark	Studs permitted Oct. 1 through April 30.	No limit.	No regulation.	No regulation.
Finland	Studs permitted Nov. 1 through first Monday after Easter.	Limits vary by tire size: 13" tire – max. 90 studs. 14-15" tire – max. 110 studs. 16" or larger tire – max. 130 studs.	PC – 3.2 mm CV – 3.5 mm	PC 120N/3.1g C/LT 180N/2.3g CV 340N/3.0g
Norway	Studs permitted Nov. 1 through first Monday after Easter (in N. Norway, permitted Oct. 16 through April 30).	Limits vary by tire size: 13" tire – max. 90 studs. 14-15" tire – max. 110 studs. 16" or larger tire – max. 150 studs.	PC – 3.2 mm CV – 3.7 mm	PC 120N/3.1g C/LT 180N/2.3g CV 340N/3.0g
Sweden	Studs permitted Oct. 1 through April 30.	Limits vary by tire size: 13" tire – max. 90 studs. 14-15" tire – max. 110 studs. 16" or larger tire – max. 130 studs.	PC – 3.2 mm CV – 3.5 mm	PC 120N/3.1g C/LT 180N/2.3g CV 340N/3.0g
Iceland	Studs permitted Nov. 1 through April 15.			

In Finland, where studded tires have been in use since the 1960s, approximately 95% of passenger cars use studded tires during winter months. Road salt is used for de-icing, and the simultaneous use of salt and tire studs has caused problems including degradation of drinking water supplies, negative impacts to nearby vegetation, and the production of irritating dust particles. During the early 1990s, the Finnish government conducted a series of experiments to determine whether degrees of reduction in studded tire use, road salting, or both (in various combinations) would yield sufficient benefits to outweigh the potential losses in terms of traffic safety and driver confidence. The study confirmed that the use of studded tires and road salt at their present levels was the most favorable option due to the high socio-economic costs associated with higher accident risks when salt and studded tire usages were reduced (Finnish Road Administration 1996).

While studded tire usage remains high in Finland, neighboring Norway has seen a reduction in studded tire use over recent years. Since the mid-1990s, the Norwegian Roads Authority has actively promoted a reduction in studded tire use, especially in urban areas where the main roadways remain clear of snow throughout most of the winter. Studded tires have been identified as a major source of airborne particulate matter, contributing an estimated 17% of the annual suspended dust pollution (Krokeborg 1998). In 1999, the city of Oslo enacted a tax of approximately $160 USD on studded tires as part of an effort to reduce studded tire use in the city to a level of 20%. The Norwegian Roads Authority has actively campaigned to encourage drivers to use non-studded winter tires or tire chains in place of studded tires (Fridstrom 2000, "Winter Tires and Chains – Norway," 1998).

While some researchers have reported a similar decline in studded tire use in Sweden ("Studded Tires" 2001), a proposed tire ban in that country was unsuccessful, and studded tire use has actually increased slightly in recent years (CBC 2003b). The Swedish National Road and Transportation Research Institute reports that a 1999 governmental decree, which requires that vehicles weighing less than 3,500 tonnes be fitted with winter tires (not necessarily studded) from December through March, has actually led to a slight increase in studded tire use in the region of Östergötland. According to the Swedish researchers, the law has led to an increase in studded tire use from 75% to 80%, with a similar increase in non-studded winter tire use, from 15% to 20% (Oberg et al. 2002). A researcher with the Swedish Road and Traffic Research Institute notes that newer, lightweight traffic studs impart less wear to pavement while affording a significant safety risk, stating that "in spite of the ongoing improvement of non-studded tires, still the studded tire is quite superior under [icy and snowy] conditions" (CBC 2003b).

Studded tires are legal in Greenland for approximately six months out of the year; however no additional information was located regarded specific limitations on their use ("Development of Infrastructure in Nuuk" 2000).

3.3.3 Japan

In 1990, Japan enacted the Law to Prevent the Generation of Particulates from Studded Tires, which banned the use of studded tires on "non-snowy or non-frozen road surfaces" beginning in the 1991-1992 winter. Japan's studded tire ban reflects a policy decision aimed primarily at reducing dust pollution levels, and the statutory language confirms this intent, stating, “All people must make an effort not to generate dust caused by studded tires” (Konagi et al. 1993).

During the 1970s, studded tires were used extensively in Japan’s cold, northern regions, with usage levels nearing 100% by the end of that decade. By the early 1980s, a number of local governments, including the City of Sapporo and the prefectures of Miyagi, Niigata, Nagano, Akita, Ishikawa, Toyama, Hokkaido, Aomori, Fukui, Tottori, Fukushima, Yamagata, Iwate, and Gifu, had begun to issue voluntary guidelines restricting the use of studded tires. However, despite these voluntary measures, studded tire sales in Japan were at record high levels by 1985. Responding to public concerns regarding the environmental and human health impacts of studded tires, the Japanese government initiated a series of tests to examine the biological impacts of the asphalt dust generated by studded tires, using rats as a test species. The outcome of these studies led to a decision to halt the production and sale of studded tires in Japan, followed by the passage of the 1990 law banning their use (“History of measures to address issues related to studded tires” 2003).

An economic evaluation of Japan’s studded tire ban, completed ten years after the ban went into effect, found that the regulation was indeed successful in reducing road dust and in limiting noise pollution. However, in a recent economic valuation analysis that assigned monetary values to the operational costs and direct and indirect benefits associated with the studded tire ban, researchers found that the reduction in studded tire use actually led to an increased annual cost of approximately $137 million (Asano et al. 2002). Part of this increased cost was attributed to an increase in traffic accidents due to icy, slippery road conditions; however, road users incurred the vast majority of these costs. Road user cost increases included increases in travel time caused by decreased vehicle speed, and increased tire purchase costs due to the fact that non-studded tires wear out and need to be replaced more often than studded tires. The economic evaluation study did not take into account the costs and benefits relevant to human health, because of difficulties in establishing a relationship between dust pollution and negative health effects (Asano et al. 2002).

While the Japanese researchers found that the studded tire ban had in fact led to total cost increases among road users and the government, according to their evaluation methods, they did not recommend that the ban be removed. Rather, they concluded that their findings highlighted the need to “improve road surface maintenance and transportation policies” (Asano et al. 2002).

3.3.4 Other Countries

The studded tire policies in the Canada, Japan, and the Nordic Countries have been the subject of numerous published studies that have considered the safety, cost, environmental, and human health implications of a number of regulatory approaches. Other nations have also promulgated various studded tire policies, however a literature search of published literature yielded few English-language reports regarding the impacts of studded tire regulations in other cold-weather nations.

While Belgium, Holland, the United Kingdom, and Germany have all implemented studded tire bans (“Studded Tires” 2001), no additional information could be located to describe the rationale behind or impacts of these restrictions. In the United Kingdom, studded tires have been banned "because of the horrendous damage they would cause to our roads" ("Global Warming" 2001).

An Internet search reveals that the use of studded tires is on the increase in Russia ("Automotive Market" 2001), however no additional information was located regarding the regulation of studded tires in Russia or the former Soviet Republics. Similarly, no information was located regarding studded tire use or regulation in China.

3.4 Studded Tires Policy Decisions

A number of jurisdictions have commissioned studies to quantify the safety benefits provided by studded tire use, in order to better understand the potential implications of studded tire regulations. These studies consistently document both the safety benefits of studded tires on snow- and ice-covered roads and the economic and human health costs associated with studded tire use on paved surfaces. However, the manner in which these studies have been utilized as a basis for policy decisions varies greatly.

In a study of studded tire pavement effects in the US state of Oregon, researchers measured the impacts of studded tires to paved roadways and used the estimated costs associated with studded tire damage to weigh the potential costs and benefits associated with different approaches to studded tire regulations. The study considered a number of regulatory alternatives to reduce the pavement impacts of studded tires, including a complete ban on studded tires, shortening the length of permitted studded tire use, requiring lightweight studs, establishing a user fee for studded tires, installing more resistant pavement, educating the public about the situations in which studded tires are effective, and using any combination of these approaches. The authors concluded that a combined approach of lightweight studs, a reduction in the time permitted for stud use, and a user fee structure to recoup pavement damage costs would provide a balanced, effective studded tire policy. However, the authors noted, "past studded tire legislation efforts have been on the basis of politics instead of rationality" (Brunette and Lundy 1996). Consistent with this study's recommendations, Oregon law specifies that metal tire studs must be lightweight.

In the Canadian province of Ontario, that nation's only studded tire ban has been in effect since 1973. In the face of criticism from motor vehicle safety analysts, questioning the nearly 30-year old policy, (CBC 2003a), the Ministry of Transportation reconsidered the studded tire ban during 1999-2000, conducting an extensive review of studded tire policies in other national and regional jurisdictions. Their findings supported the continuation of the studded tire ban "because, despite advances in technology, the disadvantages of studded tires continue to outweigh their advantages." The specific disadvantages cited included the "considerable health and road safety problems" caused by studded tires, the "limited potential [safety] benefits" compared to the negative impacts" ("Studded Tires" 2001).

In interpreting accident rate data for different types of tires, it is important to account for the role that human behavior plays in motor vehicle safety. In a meta-analysis of studded tire evaluation studies conducted in Norway, Sweden, Finland, Germany, France, Japan, Canada, and the United States, a researcher at the Institute for Transport Economics in Oslo, Norway found that studded tires decrease the winter accident rate by approximately 5% for snow- or ice-covered roads, 2% for bare roads, and 4% for all road surfaces combined. The author noted that these reductions in accident rates are disproportionate to the increase in traction provided by tire studs (15 to 20%), suggesting that drivers are likely to alter their driving behaviors based on their perceptions regarding tire traction. Drivers with non-studded tires tend to drive slower, on average, than drivers using studded tires, due to a heightened perception of accident risks (Elvik 1999).

For jurisdictions that have either banned or limited the use of studded tires, the key to their policy decisions involves weighing the documented safety improvements of studded tires against their economic and human health impacts, which are often more difficult to measure. In the US, studded tire bans and regulations limiting studded tire use evolved in response to research completed in the 1970s, which focused on the pavement degradation caused by the early generation of metal-studded tires. Recent investigations, which take into account technological advances in metal stud composition, have yielded revised regulatory approaches such as the lightweight stud specifications in Oregon and Washington laws. However, US studded tire regulations still appear to be focused primarily on an analysis of pavement wear costs compared to safety benefits. By comparison, studded tire policies in Japan and Norway, where a number of published studies have linked studded tire use to increased dust pollution, reflect a more targeted consideration of the resulting human health effects.

The meta-analysis study (Elvik 1999) concludes that studded tires “slightly” improve automobile safety during winter, and that laws banning studded tire use are likely to increase the number of wintertime automobile accidents on the order of 1% to 10%. However, the authors do not offer any specific policy recommendations, noting that “whether the small improvement in safety obtained by studded tires is sufficient to warrant permitting their use, in view of the disadvantages in terms of environmental degradation and road wear, is left for others to decide.”

4. Air Pollution and Human Health Impact of Studded Tire Use

4.1 Introduction

Studded tires have been widely used as an additional safety measure during winter months. When road surfaces are covered with ice or snow, studded tires provide additional traction and have been documented to reduce vehicle accident rates. When paved roads are bare, however, studded tires may cause extensive wear and damage to the pavement. Proponents of studded tires have historically argued that the increased safety benefits associated with their use outweigh the economic damage caused to paved roads. However, the Japanese observed another human health effect of studded tires that might offset their safety benefits, in the form of increased respiratory aggravation caused by studded tire generated dust.

As studded tires wear away paved road surfaces, they produce particles of dust, some of which are small enough to be inhaled into the human respiratory tract. Elevated particulate levels can aggravate respiratory systems of sensitive populations, such as people with asthma, children, and the elderly. The Japanese were the first to recognize that high volumes of vehicles equipped with studded tires, when traveling on paved roads, contributed to high urban dust levels that posed a health risk to sensitive populations. Based on this human health risk, the Japanese government banned studded tire use in urban areas. According to published studies, the 1990 Japanese studded tire ban has had some measurable impact in lowering road dust, however the ban also had adverse human health impacts due to increased accident rates (Asano et al. 2002).

Studded tire literature from around the globe consistently finds that studded tire use on paved roads produces road damage and increased levels of road dust. However, because the severity of the dust level is site-specific, the decision whether to permit studded tire use depends upon a number of socioeconomic factors. Before making a decision to ban studded tires in Alaska, based solely on the human health impact of increased particulate levels, the State must complete site-specific technical evaluation and research, as national and international study results for air quality impacts from studded tires may not be applicable to various parts of Alaska. Banning studded tire use in Alaska may also produce the undesired human health effects of increasing vehicle accident rates.

While studded tire dust certainly contributes to local air pollution levels in urban areas, the large number of unpaved roads throughout Alaska causes the state's most significant problem with road dust (Koziel 1993; MOA 1999a). Studded tire pavement dust is an urban phenomenon, and generally only applicable to Alaska's major cities, where significant stretches of pavement exist, along with a higher density of sensitive human receptors along the paved roadway. Even in urban areas, where pavement is more predominant, studded tire dust is only one piece of the Alaskan urban dust puzzle, as other anthropogenic and natural sources of road dust also play a key role. In urban and rural Alaska alike, the most significant respiratory distress episodes are natural in origin (e.g. volcanic eruptions, wild land fires).

Key variables such as pavement type, population density along the roadway, traffic speed and volume, roadway maintenance practices, precipitation trends, and meteorological conditions all weigh into the severity of studded tire's contribution to roadway dust, and the ultimate human health impact of that dust on the receptor population. While scientific evidence is overwhelming that studded tires do generate increased levels of road dust, a number of site-specific factors warrant consideration in determining whether the use of studded tires poses unacceptable health risks in the urban areas of Alaska, such as:

- The relative contribution of road dust to the overall volume of particulate matter (road and non-road sources) in an area;
- The relative contribution of studded tire generated road dust to the overall volume of road dust in an area;
- The relative contribution of road dust, and studded tire generated road dust to the toxicity of road dust;
- The number and type of sensitive human receptors effected by road dust as compared to other sources of particulate matter in an area;
- The human health benefits associated with increased safety afforded by use of studded tires; and,
- The human health impacts associated with alternatives to studded tire use (e.g. increased use of traction sand).

For Alaska, due consideration of these factors is very important in developing studded tire use policy on the basis of human health considerations. This section provides a general background on the human health effects of particulate matter, evidence that studded tires do contribute to road dust levels, an understanding of the relative contribution of road dust and studded tires to the overall particulate matter problem in Alaska, a brief discussion on the human health trade-offs, and other alternatives to studded tire use. The paper provides a list of key conclusions and recommended actions for Alaska.

4.2 Human Health Effects of Particulate Matter

Due to the adverse human health impacts associated with inhalation of airborne particulate matter (PM), many countries throughout the world have adopted particulate matter standards that limit the overall levels. Particulate matter regulations are established to protect the most sensitive human receptors such as children, the elderly, persons with preexisting respiratory or cardiovascular illness, and athletes and others who engage in frequent exercise. Structures that house these persons or places where they gather to exercise are defined as sensitive receptor sites.

Particulates are usually categorized by size. “Fine” particulates measure less than 2.5 micrometers in diameter ($PM_{2.5}$) and “coarse” particulates less than 10 micrometers in diameter (PM_{10}). Inhalable matter includes both fine and course particulates. Regulatory standards for particulate matter usually focus on limiting the availability of small particulates in the air, because small particles tend to remain suspended in the air for long periods and eventually collect in the human respiratory tract. Inhalable particulates can have a damaging effect on human health by interfering with the body’s mechanism for clearing the respiratory tract or by acting as a carrier of an absorbed toxic substance.

Most medical researchers agree that smaller particles are more hazardous to human health; however, particle size is not the only contributing factor. The composition of those particles is also of great importance, since some fine particulates contain a high proportion of metals and carcinogens (Dockery, Schwartz and Spengler 1992; Katsumi et al. 1988). While particulate matter volume and composition are both important to their human health effects, to date most air quality standards throughout the world have focused on reducing the total volume of particulate matter rather than a combination of volume and composition. The future trend for particulate matter regulation is to establish source-specific air toxin regulations to minimize the presence of toxic particulates, even in small quantities.

4.2.1 National Standards for Particulate Matter

In the United States, the Environmental Protection Agency (EPA) establishes air quality standards to protect public health, including the health of sensitive populations. EPA also sets limits to protect public welfare, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings (USEPA 1990). National Ambient Air Quality Standards (NAAQS) for particulate matter were established to limit the volume of fine particulate matter in the air. Based on human health criteria, EPA initially set a PM_{10} standard in 1987, and then added a $PM_{2.5}$ standard in 1997 (USEPA 1997). Both regulations were established to reduce the total volume of airborne particulate matter available for inhalation. EPA's health standard for PM_{10} is 150 $\mu g/m^3$ (24-hour period) and 50 $\mu g/m^3$ (annual average), and the health standard for $PM_{2.5}$ is 65 $\mu g/m^3$ and 15 $\mu g/m^3$, respectively.

4.2.2 Human Health Impacts of PM_{10} and $PM_{2.5}$

Medical researchers generally agree that episodes of fine particulate matter can be linked to respiratory disease, including asthma morbidity (Choudhury, Gordian and Morris 1997; Dockery, Schwartz and Spengler 1992; Schwartz and Dockery 1992; Pope, Schwartz and Ransom 1992; Gordian et al. 1996). A strong correlation has been observed between air pollution episodes and increased aggravation of respiratory diseases, especially asthma (Pope, Schwartz and Ransom 1992; Abbey, Hwang and Burchette 1995; Euler et al. 1987). Increased particulate levels have also been attributed to cases of airway obstructive disease and chronic bronchitis (Abbey et al. 1993). Increased risks of incident lung cancer have been associated with elevated long-term ambient concentrations of PM_{10}, and increased severity of asthma seems to be strongly correlated with $PM_{2.5}$ episodes (Greer, Abbey and Burchette 1993). These correlations prompted the EPA to regulate both $PM_{2.5}$ and PM_{10} levels.

In addition to the obvious human health risks, higher levels of particulate matter, especially $PM_{2.5}$, also cause adverse socioeconomic impacts. These may include: increased cost of medical care associated with episodes of respiratory infections and other illnesses; increased use of medications to relieve eye and throat irritation, headache, nausea, and aggravated asthma; increased number of days of discomfort and missed days from work and school; and shortened life spans (Evans et al. 1987; Krokeberg 1998). Fine particulates are most closely associated with increased hospital admissions for heart and lung disease, decreased lung function, and even premature death (USEPA 1997).

4.3 Contribution of Studded Tires to Roadway Dust

Field studies on the impact of studded tires on pavement began in the 1960s, when studded tire usage increased in popularity. Substantial research conducted during the 1960s and 1970s concluded that studded tires caused a majority of the pavement wear in regions where they were used (Transportation Research Board 1975; Minnesota DOT 1971). Quantitative values were assigned to studded tire wear in terms of inches of wear per million studded tire passes, providing clear evidence that studded tires generate dust on paved roads. Dust produced by studded tires "grinding" the asphalt and by the studded tires themselves contributes to the level of roadside particulate matter (Lindgren 1996; Swedish VTI 1995). However, the dust volumes measured by various scientists range considerably, due to variability in site-specific conditions such as tire selection, pavement types, precipitation levels, snow removal, and road maintenance practices. These studies generally agree that studded tire wear causes greater damage on bituminous pavements than on concrete pavements, and in areas where studs were banned pavement damage was significantly reduced. Over 95% of asphalt pavement mixes are composed of stone aggregate fractions, with approximately 5% bituminous binder, which are more readily degraded by studded tires than concrete (Lindgren 1996).

Numerous studies have been conducted to quantify the amount of road wear caused by studded tires, in order to attach a price tag to those repairs. Norwegian authorities estimate asphalt wear at 20-50 g/km/vehicle (Lygren, Gjessing and Berglind 1984). Overall, they estimate that annually 250,000 tonnes of asphalt is worn away from Norwegian roads, resulting in repairs of approximately 250 million Norwegian kroner ($28 million US) on an annual basis (Dragland 1998). The Ontario Ministry of Transportation estimates that it spends approximately $39 million Canadian per year on increased road maintenance due to pavement damage associated with studded tires (Ontario 2001). The Alaska Department of Transportation estimates highway damage from studded tire use in Alaska to be $5 million annually (Esch 1994). The Oregon Department of Transportation estimates that highway damage from studded tire use in Oregon is $42 million annually (Brunette and Lundy 1996). The magnitude of road repairs required annually provides further evidence that studded tires cause significant wear by converting a portion of the pavement into asphalt dust.

While there is clear evidence that studded tires cause road wear, considerable road damage also results from heavy vehicle traffic. Careful research is required to distinguish between load-related rutting from heavy trucks and large equipment and surface wear attributed with studded tire use on passenger vehicles. The two types of road damage result in different patterns of wear that can be used to distinguish between them. Studded tire ruts are well defined and sharp shouldered, while heavy wheel loads are broader and less severe in the cross section. In some studies of studded tire impacts (Brunette and Lundy 1996), all of the road wear was attributed to studded tires, unless the wheel track spacing indicated rutting caused by heavy vehicles. Other studies recognize that approximately 20-30% of road wear is attributed to non-studded tires and heavy vehicle traffic (Finnish Road Administration 1996). Further site-specific work is necessary in Alaska to determine how much of the wear is actually attributed "solely" to studded tire use.

4.3.1 Studded Tire Generated Dust vs. Other Sources of Road Dust

The overall contribution of road dust to the total particulate loading in an air shed is site-specific, and is only a sub-set of the total airborne particulate matter problem in any community. Several steps are involved in measuring contribution of road dust to total airborne particulates. First, the total particulate loading must be determined for an area. Second, the portion of the total particulate load associated with road dust must be determined. Third, the portion of road dust associated with studded tire pavement wear must be apportioned. Fourth, the relative toxicity of studded tire generated dust as compared to other sources of road dust must be examined. In Japan's large cities, where both traffic levels and population density are high, studded tire dust was found to be a significant contributor to the overall urban dust problem. In Alaska, however, dust associated with studded tires is only a portion of the road dust equation.

A number of studies have been completed to determine the proportion of roadway particles attributable to studded tire wear compared to other sources. The results of these studies are site-specific, but do reveal some general trends. A significant source of road dust is the dust that is formed when icy or snowy roads are sanded to improve traction. When the road surfaces dry out, the road dust created by road sand is re-entrained into the air, resulting in high particulate levels and adverse respiratory effects. This is particularly relevant in Alaska, where use of traction sand for snow and ice control has been found to make as significant a contribution to road dust as studded tire wear (MOA 1999a). Other significant sources of road dust typically include corrosion of vehicle components such as brakes, use of traction sand for snow and ice control, spillage of material from construction sites, track out from unpaved streets, automobile exhaust soot, biological debris, litter (e.g. uncovered loads), and dust fall (USEPA 2000a; Fukuzaki, Yunaka and Urushiyama 1985). The literature also reveals that, while studded tires generate larger volumes of coarse particulate matter, they are not the major contributor to the more toxic $PM_{2.5}$ particulates.

4.3.2 Studded Tire Contribution to Road Dust Suspension and Re-entrainment

In cold climate regions, roadside particulate levels have been observed to be at their highest in the spring season, when road surfaces begin to dry and traffic disturbs the particles that have collected over the winter (Swedish EPA 2001). Scientists and regulators agree that quantifying the available reservoir of roadway dust is useful; however, researchers must take the next step and examine the parameters that are likely to influence the total amount of road dust that is actually suspended and available in the air shed for human inhalation. These parameters include mechanical disturbance and activity levels, particle-size distributions, surface conditions, wind speed, surface moisture, and humidity (Stantec 2002). One of the greatest uncertainties is the large reservoir of particles available for re-entrainment and further pulverization into smaller particles. The amount of dust that is left in the road system for further pulverization, re-entrainment, and inhalation is a function of the road maintenance practices in an area (Baekken 1993; Bates 1994; Euler et al. 1987). Use of dust palliatives and removal of roadway dust by street cleaning is critical to reducing this available dust load[1].

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[1] Morris, S., Municipality of Anchorage, Air Pollution Control Authority, personal communication, 2003.

There seems to be general agreement on the need to apportion and understand the various source contributions to particulate emissions and the mechanisms that disturb them, re-entrain them, and ultimately deposit them, to make them available for human inhalation (Watson and Chow 2000). For example, recent work conducted in the Nevada desert reveals that the availability of dust for human inhalation is highly dependant on the speed of the vehicles traveling on the road (Etymezian et al. 2002). Studies in Alaska have also concluded that un-swept winter traction sand is the main source of road dust in the spring season (Cooper, Valdovinos and Sherman 1988).

4.3.3 Toxicity of Studded Tire Generated Road Dust vs. Other Sources of Dust

Historically, the trend in particulate matter regulation was to regulate increasingly smaller sizes of particulates in order to reduce the total volume of these small particulates. More recently, regulators and researchers have identified the need to better understand particulate matter toxicity and to increase regulation of toxic sources of fine particulates. While published studies have concluded that studded tires do contribute to road dust toxicity, the literature indicates that the toxic contribution of studded tire dust is far less than that of exhaust gas particles and other combustion sources (Dragland 1998; USEPA 2000b; NIES 2003; British Columbia 1995).

The EPA considers combustion processes to be the largest contributor to toxic $PM_{2.5}$ levels in the United States (USEPA 2002). While industrial sources of emissions generate toxic $PM_{2.5}$ particles, which become airborne and settle on roadways, emissions from vehicles and other road traffic are by far the largest source of toxic $PM_{2.5}$ levels in the roadway. Exhaust gas particles in the roadways have been the focus of most of the air toxic research (Gustafsson 2002). Road dust contains metals, carcinogens such as benzopyrene, sulfates, nitrates, carbonaceous organics, ammonium, and lead, which are mostly attributed to traffic exhaust (Koziel 1993; Miguel et al. 1999; GeoViro 2001).

Although combustion sources are the primary contributor to toxic $PM_{2.5}$ levels, studded tires also contribute to the overall road dust toxicity. Road dust source apportionment studies have identified that wear of metal tire studs can contribute to the presence of heavy metals and Polycyclic Aromatic Hydrocarbons (PAH) in the airborne dust (Swedish VTI 1995). Dust produced by studded tires “grinding” the asphalt contributes to the heavy metal content of the dust, since the stone material used in the asphalt mix contains metals (Yoshinori and Naohiro 1988). Ground asphalt particles also act as carriers for traffic-generated pollutants from vehicles. It is important to note that studded tires and non-studded tires alike both contribute tire wear particles to the road; however, studded tires contribute a higher metal content due to the wearing of the metal studs. Overall, tire wear is the largest transportation-related contribution of zinc to the dust content (Lindgren 1996).

While studded tires do contribute to road dust toxicity, studded tire dust tends to be a small contributor to the toxic $PM_{2.5}$ problem, which is the biggest respiratory risk. Findings from Japanese studies indicate that pavement fragments worn out by studded tires were mainly released into the atmosphere as relatively large particles (Fukuzaki, Yunaka and Urushiyama 1986; Takishima et al. 1992). These studies confirm that while some studded tire road dust is retained in the lungs, it is not as severely toxic as other sources of road dust and usually clears during a period of days to months (Takishima et al. 1992; Yoshinori and Naohiro 1988). Roadway dust does appear to be a significant contributor to larger PM_{10} levels. Yet, similar to $PM_{2.5}$, the health effects associated with roadway pollution are significantly less harmful than PM_{10} generated from combustion processes (British Columbia Ministry 1995).

Dust associated with studded tire pavement wear may play a more important role in some communities relative to others based on site-specific circumstances. For example, if high particulate episodes in an area are more commonly associated with wood smoke and unpaved roads, there would be little health benefit associated with a studded tire ban. In large urban areas with major industrial combustion sources and paved roads, road dust associated with studded tire wear would be a much smaller fraction of the overall total particulate loading problem; regulators would be more concerned with control of toxic industrial combustion sources of particulates. In larger urban areas with paved roads and no significant industrial combustion sources of PM, like Anchorage and Fairbanks, road dust associated with studded tire wear becomes a more significant contributor to the overall particulate matter level. In rural areas where paved roads are predominant, road dust associated with studded tire wear is negligible.

Researchers generally agree that additional research is necessary to speciate roadway dust samples and evaluate the chemicals of concern to human health. This type of research will aide in differentiating natural sources from anthropogenic sources and may identify control strategies that will be focused on reducing harmful dust, as opposed to simply reducing dust volumes.

4.4 Studded Tire Contribution to Particulate Matter Monitoring Trends

Prior to examining the contribution of studded tires as a sub-set of the roadway particulate matter level, it is important to obtain an overall understanding of Alaska's PM_{10} and $PM_{2.5}$ trends to determine whether road dust is a significant contributor to elevated particulate matter levels and human health in Alaska. It is also important to review the air quality trends in other countries that have reported severe air quality problems associated with studded tire use, to determine if their findings are relevant to Alaska.

4.4.1 Particulate Matter Monitoring in Alaska

Alaska's current monitoring network has three monitoring sites for PM_{10} (Anchorage, Juneau and Matanuska-Susitna Valley), and seven monitoring sites for $PM_{2.5}$ (Anchorage, Fairbanks, Juneau, Matanuska-Susitna Valley and Denali National Park). Of these monitoring locations, the only site that recorded elevated $PM_{2.5}$ levels over the last three years was Fairbanks, and the elevated levels were attributed to coal burning (ADEC 2002).

Overall, Alaska's data indicates that road sources are a contributor to the overall levels of PM_{10} and $PM_{2.5}$ but violations of the PM_{10} NAAQS are most commonly triggered by natural particulate matter episodes such as volcanic activity and wild land fires, rather than road sources of particulate matter. Correspondingly, violations of the $PM_{2.5}$ NAAQS are most commonly associated with either combustion sources or natural sources and not road sources of particulate matter. Alaska, like many other cold weather regions, tends to have higher particulate matter episodes in spring and fall. These episodes are typically preceded by extended periods of cool, dry, windy weather and low precipitation (Gordian et al. 1996).

Across Alaska, the most significant anthropogenic source of road dust has historically been unpaved roads. While the number of paved road miles in Alaska has increased over the last decade, a large percentage of roads (68%) are still either listed as unpaved or pavement status is indeterminate (AKDOT 2002). Controlling dust levels on unpaved roads in rural Alaska is key to controlling road sources of PM_{10} in these areas. Road paving efforts have substantially reduced anthropogenic source of road dust, but have introduced a secondary dust impact by necessitating the use of studded tires and/or traction sand to increase traction on paved roads in the winter (MOA 1999a). Both the Municipality of Anchorage and Alaska Department of Transportation have been active in further examining dust control options for paved and unpaved roads.

Approximately 40% of Alaska's residents (260,000 people) reside in smaller rural communities throughout Alaska and are affected by unpaved road dust. The remaining 60% of Alaskans reside in three major cities: Anchorage, Fairbanks, and Juneau. A portion of this urban population is also affected by unpaved road dust, since not all of Alaska's urban road systems are paved. In total, over half of Alaska's population is still adversely impacted by elevated particulate matter due to unpaved roads.

Since unpaved roads are the largest contributor to road dust levels in Alaska, evaluation of dust levels on paved roads is a second tier refinement for Alaska and is only applicable in urban areas of Alaska where paved roads are predominant. For the portion of Alaska's roads that are actually paved (32%), the total road particulate matter load must then be apportioned between dust attributed to studded tires use and dust attributed to other paved road sources, such as automobile exhaust soot, traction sand, litter, soil particles, fragments of tire rubber, and other sources (Fukuzaki, Yunaka and Urushiyama 1985; Stantec 2002).

4.4.1.1 Rural Alaska

As rural communities have increased their understanding of the human health effects associated with airborne dust, their desire to monitor and address high levels of airborne dust has increased. The first step in this process is to secure the quantitative data necessary to institute source-specific mitigation measures.

Road dust associated with unpaved roads is believed to be the most significant anthropogenic contributor to $PM_{2.5}$ and PM_{10} levels in rural Alaska. Natural sources of dust are also a problem in Western Alaska and in communities near wide river valleys with exposed gravel bars and high winds (ADEC 2002). Dust levels associated with these high wind events can increase dust levels to 3-5 times the ambient air quality standard. A quantitative assessment of the rural Alaska PM problem severity is not provided in the current literature. It appears that little actual PM monitoring data has been secured in rural Alaska, and that most concerns are attributed to visual observations and traditional knowledge. However, the Alaska Department of Environmental Conservation (ADEC) recently developed joint monitoring projects with Northwest Arctic

Borough (via the Maniilaq Association, a non-profit health organization), the Alaska Department of Transportation in Kotzebue, and the Bethel and Ekultuna native councils (ADEC 2002).

Although Alaska has only recently begun monitoring rural PM, this issue has been well studied and documented internationally and nationally. Internationally, there is general agreement that unpaved roads are the largest contributor to road dust, and that paving these roads results in a significant human health benefit associated with reducing the amount airborne particulate matter (Pritchett and Cooper 1985; Etymezian et al. 2002). In the United States, the EPA provides an emission estimating reference tool called AP-42 for use in estimating total paved and unpaved road emissions for particulate matter, among other pollutants (USEPA 2000b). AP-42 clearly shows unpaved road emissions to be a much more substantial source of particulate matter than paved roads. Unpaved roads provide an infinite supply of particulate matter available for re-entrainment and for further pulverization into fine particulate matter, unless counteracted by dust palliatives or precipitation cover (water, snow, ice). Conversely, paved roads can become supply limited in the absence of continual inputs of particulates to the road surface.

The published literature provides no indication that leaving a road unpaved is a better option, from a respiratory health point of view, than paving a road, even when studded tires are allowed. Since unpaved roads provide an infinite supply of particulate matter, speed reduction and traffic volume are the main determinates of road dust levels for unpaved roads. There is no indication in the literature that the type of tire plays a significant role in the dust levels produced on unpaved roads. As a result, there is consensus that paving roads, whenever economically viable, results in respiratory human health benefits.

Overall, the optimum socioeconomic trend is to pave roads in high traffic speed and high traffic volume areas to reduce road dust (Etymezian et al. 2002; GeoViro 2001; HDR and Parsons1997; Lygren, Gjessing and Berglind 1984). This is particularly beneficial to human health in areas were there are also higher numbers of human receptors along the roadway. There also seems to be general acceptance that traffic speed reduction, along with the use of dust palliatives when precipitation is low, is the best socioeconomic alternative to dust mitigation on unpaved roads.

From a human respiratory health point of view, there is no benefit to banning studded tires on unpaved roads. Banning studded tires on unpaved roads may actually be detrimental to overall human health, due to the accident reduction safety benefits associated with use of studded tires (Elvik 1999; Asano et al. 2002).

4.4.1.2 Urban Alaska

Anchorage

Major sources of particulate pollution in Anchorage, Alaska, include road dust, combustion engine exhaust, volcanic ash, and minor sources of industrial particulate pollution (Pritchett and Cooper 1985). Because natural gas is the primary heating source in Anchorage, wood burning is generally recreational and not a significant contributor to PM in the area.

The 24-hour NAAQS for PM_{10} (150 $\mu g/m^3$) was exceeded in Anchorage thirty-one times during the ten-year period from 1987 to 1997 (MOA 1999a). Approximately one-half of those exceedances were attributed to natural events, such as volcanic eruptions, wildfire smoke, or storm-induced wind blown dust. The annual average PM$_{10}$ (50 µg/m^3) has never been exceeded (USEPA 2002).

A 1997 study examined the correlation between medical records in Anchorage and particulate matter episodes (Choudhury, Gordian and Morris 1997) and concluded that PM$_{10}$ elevations are closely related to visits to medical providers for the diagnosis of asthma. Studies also show a very high incidence of asthma-related medical visits following the volcanic eruption in August 1992, which covered Anchorage with volcanic ash and caused PM$_{10}$ in excess of 100 µg/m^3 (Gordian et al. 1996).

In 1995, the Environmental Protection Agency, the State of Alaska, and the Municipality of Anchorage signed a memorandum of understanding to expedite the resolution of the PM$_{10}$ problem and achieve compliance with the NAAQS, at least for the controllable sources of PM$_{10}$, such as road dust. The largest source of road dust was associated with unpaved roads, which prompted an aggressive road pavement campaign. Significant reductions in roadway dust levels were achieved through refinements in the composition of winter traction sand, which limited the amount of fine particulate material, increased use of salt for winter to improve winter traction, and improved spring road cleaning practices[1].

The Anchorage Air Pollution Control Authority has found that surface silt loading on paved roadways is a good predictor of PM$_{10}$ emissions. Anchorage paved roadways tend to be heavily laden with silt, especially during late March and early April. The median spring silt load in Anchorage on high volume paved roads (13.5 g/m^2) tends to be 4-5 times higher than Denver, Colorado or Butte, Montana (MOA 1999a). To better understand the sources of road dust in the Anchorage area, a research effort was conducted by the Anchorage Air Pollution Control Agency to collect and speciate the road dust during the period of 1989 to 1994, to determine its composition and origin (Crutcher 1994). Samples during this period were heavily influenced by the presence of volcanic ash from the volcanic eruption of Mt. Redoubt in 1989, followed by Mt. Spurr in 1992. During the period of 1989 to 1994, volcanic ash made the highest contribution to particulate episodes, followed by contributions of dust due to winter road traction sand, dust from unpaved roads, wind blown dust and traffic debris.

Thus far, road pavement efforts and winter maintenance practice refinements have been successful in reducing airborne particulates in Anchorage. During the period of 1999-2001, there were no violations of either the PM$_{10}$ or PM$_{2.5}$ NAAQS in the Anchorage area (ADEC 2002), and studded tires were in use during this time. PM$_{10}$ ranged between 33-53% of the NAAQS annual average, and between 41-74% of the 24-hour average. PM$_{2.5}$ averaged 41% of the NAAQS annual average and 34% of the 24-hour average.

Eagle River

During the period of 1985-1987, PM$_{10}$ monitoring data collected in Eagle River, Alaska, resulted in 13 exceedances of NAAQS (USEPA 2002). Source apportionment studies attributed over 90% of the PM$_{10}$ exceedances observed to road dust, originating from a combination of crustal dust (Cooper, Valdovinos and Sherman 1988). The remaining 10% was attributed to wood smoke emissions (1-3%), river dust (up to 4%), and other natural sources. Crustal source categories in the Eagle River area include mostly dust associated with paved and unpaved roads, such as paved freeway road dust, paved local streets, unpaved roads, paved parking lots, unpaved parking lots, river sediment, gravel, and exposed unvegetated soils (Koziel 1993).

A 1998 study attempted to distinguish between and quantify the major crustal categories, however, the chemical mass balance methods used in this study were only able to isolate river sediment as a separate measurable category. However, the apportionment study was useful in isolating the root cause of the high PM_{10} levels, and provided insight into a major control strategy, which was to increase the number of paved road miles to control dust. In 1991, a PM_{10} control plan was adopted by Alaska, to reduce the predominant source of PM_{10} in Eagle River by surfacing unpaved roads (MOA 1991). Extensive road paving commenced in 1987 and has continued since that time, as the community of Eagle River continues to expand. Overall, surfacing unpaved roads was successful in eliminating the NAAQS violations for PM_{10} in the Eagle River area. Since 1987, the only NAAQS exceedances in Eagle River have been due to uncontrollable, natural sources of particulates, such as volcanic eruptions (ADEC 2002). Studded tires have been in used during this entire time.

Fairbanks

Of Alaska's current PM monitoring locations, the only site with elevated $PM_{2.5}$ levels over the last three years was Fairbanks (ADEC 2002). Fairbanks is at 77% of the annual average $PM_{2.5}$ level of 15 $\mu g/m^3$, and is at 63% of the annual $PM_{2.5}$ level of 65 $\mu g/m^3$. While the NAAQS has not been exceeded, the levels are relatively high and closely monitored. ADEC attributes the elevated $PM_{2.5}$ levels in Fairbanks to wintertime inversions and the use of coal for local power needs (ADEC 2002). Fairbanks is also heavily influenced by summertime particulate episodes resulting from wild land fires. Unpaved roads in Fairbanks also contribute to the "controllable" anthropogenic sources of particulate matter, and efforts have been underway to increase the number of paved road miles and optimize road maintenance practices to reduce total particulate loading due to winter traction sand.

Juneau

Juneau has historically struggled with NAAQS violations for particulate matter (USEPA 2002). Source apportionment studies completed during the 1980s attributed approximately 70% of the PM_{10} exceedances to road dust, originating from a combination of crustal dust (Cooper, Valdovinos and Sherman 1988). The remaining 14% was attributed to wood smoke emissions, 7% to combustion sources, and 9% unexplained. However, a combination of efforts has led to overall reductions in PM_{10} levels in Juneau. These include an effective wood smoke control program, an effective cruise ship emission control program, an increase in the number of paved road miles, limiting use of traction sand, and spring cleaning of roads (ADEC 2003). There were no PM_{10} or $PM_{2.5}$ exceedances during the last three years of available data, from 1999 to 2001, and studded tires were in use during this time. For this same period, PM_{10} averaged only 15% of the NAAQ annual average, and 20% of the 24-hour average. $PM_{2.5}$ averaged 37% of the NAAQ annual average, and 34% of the 24-hour average (ADEC 2002). The higher $PM_{2.5}$ level is indicative of a more significant particulate matter contribution from combustion sources.

4.4.2 Particulate Matter Monitoring in Other Cold Weather Locations

Elevated particulate matter levels observed in Japan in the early 1980s caused great concern. PM levels were reported to exceed 400 µg/m^3 in the cities of Sendai and Sapporo, Japan, well above the Japanese standard of 100µg/m^3 (Ikeda et al.1986). Severe visual opacity reductions were also reported in the major urban cities during the winter months and early spring. One group of researchers characterized the high level of particulate matter in the air as "black clouds covering cities," causing people to have trouble breathing deeply (Asano, Hirasawa, and Oikawa 2001). Japanese authorities assigned the blame for these high particulate levels to dust generated by studded tires and instituted a studded tire ban.

Japan's studded tire ban reflects a policy decision aimed primarily at reducing dust pollution levels. The statutory language confirms this intent, stating, "All people must make an effort not to generate dust caused by studded tires" (Konagi, Asano and Horita 1993). However, another research team in Niigata, Japan, obtained much lower measurements, recording particulate matter levels of 40-130 µg/m^3 even in the presence of studded tires (Fukuzaki, Yunaka and Urushiyama 1985). The difference between the study results was attributed to high precipitation in Niigata, Japan. However, even in Niigata, 50% of the winter and early spring road dust was attributed to studded tire use. In urban areas, the amount of asphalt dust was found to be approximately 30% in autumn, before studded tires were installed, while jumping to over 90% in the winter and early spring after studded tires were installed (Noguchi et al. 1995).

While studded tires were allocated much of the blame for high particulate levels in Japan during the 1980s, particulate matter generated by combustion, emitted from stationary smoke and dust facilities such as boilers and incinerators, and emitted by automobiles, was also a significant source of suspended particulate matter, especially in highly industrialized urban areas. Many scientific papers document the dramatic reduction in urban PM and attribute the reduction solely to the studded tire ban, without much consideration of the other environmental regulations that were instituted in Japan to control industrial sources of particulate matter during that same period (Nobuaki et al. 1987; Amemiya et al. 1984). It is much more likely that the PM reduction seen in Japan's urban areas is a combination of the PM reductions from the studded tire ban, and PM control measures implemented on combustion sources, including vehicle emission control.

Although Japanese scientists correlated studded tire use with elevated PM_{10} levels, they consistently agree that studded tires are not a significant source of $PM_{2.5}$. Rather, they attribute combustion sources as the most significant $PM_{2.5}$ contributors (NIES 2003; Fukuzaki, Yunaka and Urushiyama 1985; Takishima et al. 1992). Combustion sources of $PM_{2.5}$ are particularly troubling due to their toxicity (Yoshinori and Naohiro 1988). Fine particles are typically composed of heavy metals, semi-volatile compounds such as ammonium nitrate, and certain organic substances including carcinogens emitted directly from combustion sources or secondary particles (Otoshi 2002). An increasing focus continues today on control of the more "toxic" $PM_{2.5}$ dust generated by combustion sources in Japan's major cities (Shirahase et al. 2002).

Vancouver, British Columbia, has extensively studied urban particulate emissions and concluded that paved road dust is a large source of total particulate emissions (Stantec 2002). Approximately 34% of the PM_{10} and 17% of the $PM_{2.5}$ was attributed to paved road dust.

Researchers attribute Vancouver's road dust to vehicle emissions (tailpipe, tire wear, brake, and clutch wear), pavement wear, vehicle trackout and carry out, fugitive deposition, load spillage, wind and water erosion, biological sources, and anti-skid controls (sand, salt, studded tires, and chains). Unpaved roads were not examined, since the majority of Vancouver traffic occurs on paved roads. Over 81% of the paved road dust was composed of particles larger than 10µm. Although these larger particles do not immediately contribute to inhalable PM_{10} emissions, they may be available for further pulverization into smaller particle sizes over time, unless mechanically removed from the roadway by street cleaning or by natural processes such as wind or run-off. The Vancouver study (Stantec 2002) also concluded that the contribution of road dust to the total small particles, under $PM_{2.5}$, was small. Mobile, area, and point sources were estimated to be the largest contributors of $PM_{2.5}$ emissions, at 30%, 29% and 24% respectively, compared to 17% $PM_{2.5}$ from paved road sources.

The Nordic Countries tend to have high PM_{10} in the late fall and early spring. These particles are attributed to resuspended dust from street sanding and dust generated by studded tire use (Pekkanen et al. 2002; European Commission 1997). In fact, Finnish researchers have found that roadway sand used for anti-skid protection is largely responsible for producing total suspended particulate (TSP) concentrations that exceed design guidelines (Valtonen, Mustonen and Paavilainen 2002). Other fine particles are attributed to traffic exhaust emissions and particles deposited from long-range transport. Overall, the Nordic Countries have reported that studded tire generated dust can be mitigated by a combination of tougher asphalt mixtures and use of lightweight studded tires (Krenchel and Maage 1982; Lampinen 1983; McQuillen and Hicks 1987; Johnson 1996; Finnish Road Administration 1996; Neimi 1985; Brunette and Lundy 1996).

4.4.3 Application of International Studies to Alaska

While Japanese studies are useful in demonstrating a correlation between elevated particulate levels and studded tire use on pavement, the severity of the particulate matter problem observed in Japan cannot be superimposed on Alaska's situation. Elevated particulate levels were observed in Japanese cities such as Sapporo, which have dramatically higher population, traffic, and industrial density than even the largest city in Alaska. Human health concerns associated with road dust caused by studded tires have been elevated in urban areas with high traffic volumes, high paved road density, and high population density, such as the cities of Sapporo and Hakido, Japan and large cities in Norway and Finland. In these situations, high traffic density produces larger volumes of road dust associated with studded tire wear, and there is a much higher concentration of sensitive receptors for inhalation of that road dust.

In comparison to these international cities, Alaska has a much smaller proportion of paved road miles, and a much lower overall number of sensitive human receptors along the major high traffic roadways, such as the Parks Highway, Seward Highway and Glenn Highways. Respiratory impacts from studded tire use in Alaska would be limited to urban areas with higher population densities and more extensive paved roads, such as Anchorage and Fairbanks. In rural areas of Alaska, where unpaved roads are the norm, unpaved roads and winter traction sand are the predominant causes of road dust, and therefore the respiratory impacts of studded tire use in these areas is relatively insignificant.

While international research does indicate that reductions in studded tire use can reduce levels of airborne particulate matter, a road dust reduction policy focused primarily on studded tires would not address the full problem in Alaska. Instead, comprehensive road dust control practices, relative to population density and types of sensitive human receptors, such as children, the elderly, persons with preexisting respiratory or cardiovascular illness, and athletes and others who engage in frequent exercise, may be more effective. Increasing road dust control practices near structures that house these sensitive receptors or places where they gather to exercise will go a long way to reducing the human health impacts associated with road dust. For example, increasing dust palliatives on unpaved roads proximate to elementary schools reduces the amount of road dust inhaled by children.

While there are clearly health benefits associated with control of particulate matter, most of Alaska's most severe historical high particulate events were due to natural events such as ash fall associated with volcanic eruptions and wildfires. Since control of natural sources is not possible, reduction in the human health impact of these events corresponds with any actions taken to clean up and remove natural ash fall from the environment to prevent further re-entrainment of the ash and to limit the amount of ash available to human receptors.

4.5 Health Trade-Offs

While the scientific evidence clearly demonstrates that studded tires damage paved roads, they also provide a clear benefit to vehicle safety by abrading the road surface and increasing the coefficient of friction on snow and ice covered roads (Tomoyuki, Hieki and Hidetsugu 1994; Masaru, Keishi and Norikazu 1996; Akinori and Hideki 1997). Studded tires also provide a safety benefit to other vehicles that are not using studded tires by eliminating the surface "polishing effect" caused by regular tires (Asano, Hirasawa and Oikawa 2001).

In a recent literature review and economic analysis of the safety benefits associated with studded tire use, the author concluded that studded tires reduce accident rates by approximately 5% on snow or ice covered roads, and approximately 2% for bare roads (Elvik 1999). The study's source data, based on numerous previous studies by other researchers, indicated that automobile accident rates on snow or ice covered roads ranged from a 72% to a 4% reduction and 70% to 10% on dry roads. The author dismissed much of the research supporting the higher estimates, citing errors in study design or quality. The study also posited that the "true safety" benefits of studded tires may have declined over time, as technical innovations with respect to rubber compounds and tire tread patterns have improved the friction of non-studded winter tires.

Use of studded tires on paved roads poses a health trade-off that needs to be evaluated on a case-specific basis. In urban areas with high population density and high volumes of traffic on paved roads, the heath risk from respiratory aliments associated with studded tire pavement wear may outweigh the safety benefits of studded tire use. Based on such analyses, jurisdictions such as Japan and Vancouver, Canada, have banned studded tire use. In other countries, such as Finland, it was determined that although studded tires do result in some adverse respiratory effects, a studded tire ban could not be supported due to the adverse human health impacts associated with increased accident rates (Leppänen 1995).

To date, no published studies have directly compared the human health trade-off of increased respiratory risk versus the risk of increased accident rates associated with a studded tire ban in Alaska. Additional study in this area may be warranted. Such a study should focus on urban areas with high concentrations of paved roads and high traffic densities, and then compare the human health impact of increased particulate matter associated with studded tire pavement wear to the overall the human health impact of decreased studded tire use. This study would require a quantification of human health effects in terms of the number of lives saved and injuries prevented by the use of studded tires, as well as the number of cases of respiratory illness directly attributed to increased particulate matter. A comparison of the human health impacts associated with alternatives to studded tires, such as increased use of traction sand, also need to be evaluated, as increased use of traction sand contributes to particulate level loading on the road system.

4.6 Alternatives to Traditional Studded Tires

The literature clearly shows that banning studded tires will result in an increase in vehicle accidents unless other winter maintenance strategies are adopted to increase roadway traction. The main alternatives to studded tires are the use of winter traction sand and the use of road salt, both of which contribute to environmental and human health impacts.

4.6.1 Traction Sand

The primary alternative to studded tire use is to increase the amount of sand applied to the roads to improve winter traction. However, increased use of traction sand also contributes to the dust load on the roadway. Therefore, in terms of respiratory health, studies have shown that the increased use of traction sand provides no improvement over the use of studded tires (Reckard 1996). Studies in Alaska have confirmed that un-swept winter traction sand, used for snow and ice control, is the main source of road dust in the spring season and is as significant a contributor to road dust as studded tire wear (Cooper, Valdovinos and Sherman 1988; MOA 1999a). Thus, the use of traction sand doesn’t improve the dust levels and has an associated cost for application and removal.

Finnish authorities have had some success in reducing the total suspended particulate level of traction sand by establishing quality classifications for sanding materials and wet-sieving the sanding materials (Valtonen 2002; Utah SIP 1999). Some researchers have also found that it is possible to reduce the harmfulness of dust by selecting dark rock materials low in quartz that resist further fragmentation in the roadway (Räisänen, Kupiainen and Tervahattu 2002).

Further study by Tervahuttu (2004) indicates that the use of traction sand produces significant asphalt particles. The conclusion from this finding is that traction sand contributes to pavement wear, a phenomena called the sandpaper effect. Potential wear rates may be quite significant and are the subject of further research in Finland.

4.6.2 Road Salt

Another alternative is to increase the use of road salting, or use a combination of salt and sanding. In Finland, the main substance used for chemical de-icing is sodium chloride (NaCl). Finnish authorities have found that reduced salting increased accidents by 5-20% on high traffic roads; sanding is used as an alternative to salt on roads with little traffic to minimize the dust load (Leppänen 1995; Finnish Road Administration 1996). In the United States, two types of road salt are common: sodium chloride (NaCl) or calcium chloride (CaCl) (Wisconsin Transportation Center 1996).

However, salting comes with another set of environmental problems. Road salt can contaminate wells or drinking water reservoirs near salt-treated highways or salt storage facilities (Transportation Research Board 2003; NYSDH 1977). High salt levels contribute to a host of other adverse human health impacts. Road salt can also damage or kill vegetation along roads and can adversely effect the fish and other organisms in waterways along the road system (Hanes, Zelazny and Blaser 1970). Direct runoff of high amounts of salt into small marshes and creeks can create a toxic environment for fish (Buist 2002). Road salt is also responsible for increased vehicle corrosion and accelerated deterioration of roadway concrete and steel structures, such as bridges. Even small amounts of chloride will significantly accelerate any existing corrosion (Wisconsin Transportation Center 1996). One study assessed the damage cost of road salt at 15 times the cost for purchase and application of road salt, and about six times the cost for snow and ice removal; this study recommended that the level of salting be reduced and that a greater emphasis should be placed on snow removal and sanding (Murray and Ernst 1976).

4.7 Alternatives for Minimizing Studded Tire Generated Dust

Rather than outright studded tire bans, the current international trend is to develop site-specific, socioeconomic optimized preventive and mitigative measures that use a combination of studded tire technology, salting, traction sand, dust palliatives, road maintenance techniques, and asphalt designs to minimize the amount the road dust load. Preventative measures reduce particulate matter source material from being created on the road surface. Mitigative measures includes measures by which material is removed from the road surface to limit or eliminate the reservoir of dust available for re-entrainment or further crushing into finer particulate matter. Common preventative and mitigative measures that may be useful to Alaska include wear-resistant asphalt, improved studded tire design, speed reduction, and improved road maintenance.

4.7.1 Wear-resistant Asphalt

There is general agreement in the literature that the installation of wear-resistant pavement substantially reduces the amount of road dust and road damage caused by studded tires. (Kazuyuki et al. 1991; Krenchel and Maage 1982; Lampinen 1983; McQuillen 1987). Swedish researchers have found a direct correlation with the quality of the road surface and the amount of dust generated by studded tires; poorer quality asphalt designs generate more dust per road mile. Swedish road authorities have had success in reducing dust levels using rubber-modified asphalt pavement (Takallou and Hicks 1990). Norwegian researchers have found that the proper selection and use of hard aggregate in the asphalt mix is one of the most important factors in achieving high wear-resistant asphalt surfacing (Dragland 1998). Norwegian authorities have also increased use of high-strength concrete in pavements, which resist wear by a factor of two to three times that of bituminous pavements (Transport Research Laboratory 1994). In Europe, stone matrix asphalt (SMA) has been successfully used for over 20 years and has increased in popularity in the United States since the early 1990s (Brown et al. 1997). SMA provides better rutting resistance and also resists studded tire wear.

4.7.2 Improved Studded Tires Design

There is general agreement that lightweight studded tires reduce pavement wear by approximately one-half that of regular studded tires, thus reducing the studded tire contribution to road dust (Neimi 1985; Brunette and Lundy et al. 1996; Finnish Road Administration 1996; Folkeson 1992). Furthermore, changing the number, protrusion, and configuration of studs can reduce the wear caused by studded tires and the dust generated by studded tires (Kazuyuki et al. 1991).

4.7.3 Speed Reduction

Since the availability of dust for human inhalation is highly dependant on the speed of the vehicles traveling on the road (Etymezian et al. 2002), consideration may be warranted for variable speed limits during certain times of the year that present high roadway sediment loading. Reducing traffic speed, especially in and around high population areas, will reduce re-entrainment of roadway dust. Slower speeds also reduce vehicle accident rates and reduce the need for studded tires. In Finland, winter speed limits are used; normal speed limits are typically reduced by 20 km/hr (Robinson et al. 2002). On several major roadways, the Finnish National Road Administration has installed electronic speed limit sign systems that automatically change the speed limit in response to road conditions. The electronic sign systems were introduced to influence driving behavior and improve road safety, without decreasing driver motivation to obey posted speed limits, as a “one-size-fits-all” lower winter speed limits were often not obeyed when the road conditions were good. Electronic signs provide a system to instruct drivers to slow down in response to poor road conditions.

In the United States, variable speed limit systems have been installed in Arizona, Colorado, Michigan, Minnesota, Nevada, New Jersey, New Mexico, Oregon, and Washington State (Robinson 2000). Several states specifically use their systems to require traffic speed reduction during periods of ice, snow, and fog (Zarean et al.1999). Internationally, Finland, France, Germany, and the Netherlands also use their system to slow traffic in foul weather (Robinson 2000).

4.7.4 Improved Road Maintenance

There is general agreement in the literature that with or without studded tire use, optimizing road maintenance for snow and ice traction control and subsequent dust suppression is the key to minimizing the available roadway dust load. As discussed in Section 2.6, optimizing the use of traction sand is critical to minimizing the amount of dust available in the roadway for re-entrainment and suspension. Once elevated levels of particulate matter exist on the roadway, either from natural or anthropogenic sources, roadway maintenance techniques play a key role in minimizing the amount of dust available for inhalation by either removing that dust from the roadway or by minimizing the amount of dust that is re-entrained.

Prompt removal of roadside snow and accumulated dust can minimize roadway dust. During the winter, pollutants such as road dust are accumulated in snow and are released in mass quantities in the spring as the snow melts (Baekken 1993). Prompt removal of roadway snow reduces the amount of air borne particulate matter loading in the spring season. Quicker and more efficient methods of road cleaning include vacuum sweeping, PM_{10} efficient sweepers, broom sweeping, and water flushing to open up slush drains (Leppänen 1995). Installing curbs and gutters also helps to channel run-off and to eliminate mud and dirt track-out onto paved roads (Maricopa 2003; South Coast 1994).

Roadway dust can be suppressed by using dust palliatives to stabilize dust on paved and unpaved roads and parking lots. Calcium magnesium acetate (CMA) is increasing in popularity as a dust palliative and de-icing agent (MOA 1999b). CMA has much lower environmental and corrosion impacts than traditional road salts, such as sodium chloride or calcium chloride, however CMA is also more expensive than traditional road salts (Wisconsin Transportation Center 1996).

4.8 Conclusions

- While scientific evidence is overwhelming that studded tires do generate increased levels of road dust by “grinding” the pavement into smaller particles, the use of studded tires in Alaska does not appear to present an unacceptable respiratory health risk.

- In urban and rural areas of Alaska alike, the most severe particulate level episodes are attributed to natural sources of particulate matter, not to dust associated with studded tire use. Road dust associated with studded tire pavement wear is only a fraction of Alaska’s total particulate matter issue.

- Alaska’s data indicates that while road sources are a contributor to the overall levels of dust, violations of the PM_{10} National Ambient Air Quality Standards (NAAQS) are most commonly triggered by natural particulate matter episodes such as volcanic activity and wild land fires rather than road sources of particulate matter. Correspondingly, violations of the $PM_{2.5}$ NAAQS are most commonly associated with either combustion sources or natural sources of particulate and not with studded tire generated dust.

- Alaska’s biggest problem with road dust is the large number of unpaved roads. Elevated particulate matter due to unpaved roads still adversely impacts roughly half of Alaska’s population. Banning studded tires in areas that predominately contain unpaved roads will have no appreciable human health respiratory benefit, compared to the obvious human health respiratory benefit of road paving. Socioeconomic analysis will be necessary to determine the optimal number of paved roads versus unpaved roads in rural Alaska.

- Road dust generated by studded tires is an urban phenomenon, and generally only applicable to Alaska's major cities, where significant stretches of pavement exist, along with a higher density of sensitive human receptors along the paved roadway. Even in urban areas of Alaska, where pavement is more predominant, studded tire dust is only one piece of the Alaskan urban dust puzzle, as other anthropogenic and natural sources of road dust also play a key role.

- Key variables such as pavement type, population density along the roadway, traffic speed and volume, roadway maintenance practices, precipitation trends, and meteorological conditions all weigh into the severity of studded tire's contribution to roadway dust, and the ultimate human health impact of that dust on the receptor population. These variables must be evaluated on a site-specific basis.

- Dust generated by studded tires is only a sub-set of the overall paved road dust level, and is not currently causing violations in the NAAQS for particulates. There does not appear to be a significant human health benefit associated with banning studded tires in urban areas of Alaska, as a reduction in roadway particulate levels due to the ban would likely be offset by increased dust levels due to increases in the volume of winter traction sand.

4.9 Recommendations

- Alaska should continue to study, test and apply wear-resistant asphalt mixtures, which have been proven to reduce the amount of paved road dust generated by studded tires.

- Alaska should evaluate the use of lighter weight studded tires, which have been proven to reduce the amount of paved road dust generated by studded tires.

- Site-specific road maintenance practices should be developed to remove large particulate matter loads in the roadway that accumulate in the spring. Road maintenance practices should be refined to include efficient removal of contaminated snow, use of PM_{10} efficient street sweepers, and use of dust palliatives.

- Alaska should continue to study and develop economical and environmentally friendly alternatives for improving the coefficient of friction on winter roads.

- Site-specific road maintenance practices should be developed to reduce particulate loading due to winter traction sand. Additional study, refinement, and implementation of winter traction sand mixtures should be continued to limit the amount of fine material introduced into the road system.

- Consideration should be given to paving unpaved roads and improving the frequency of road maintenance and road maintenance strategies on existing paved roads to limit the amount of dust available for re-entrainment near sensitive receptors (e.g. schools, homes for the elderly, outdoor sports fields, walking/biking paths and centralized gathering locations "downtown," etc.).

- Further site-specific work is necessary in Alaska to determine how much road wear is actually attributed "solely" to studded tire use, and how much road wear is attributed to heavy vehicle loads and non-studded tires.

- Site-specific studies in Alaska's urban area are needed to directly compare the human health trade-off of increased respiratory risk of studded tire dust, versus the human health risk associated with a studded tire ban or decreased studded tire use.

- Additional research is necessary to speciate roadway dust samples and evaluate chemicals of concern to human health. This type of research will aid in differentiating natural sources from anthropogenic sources and may identify control strategies that will be focused on reducing harmful dust, as opposed to simply reducing dust volumes.

- Site-specific studies are necessary to understand the human health impact and contribution of studded tire dust in areas of Alaska that predominately include paved roads, such as urban areas. Anchorage and Juneau have completed quite a bit of scientific study in this area, and these studies could be updated, and expanded to other urban areas of Alaska. Site-specific studies in urban areas should examine the following issues:
    a. The relative contribution of road dust to the overall volume of particulate matter (road and non-road sources) in an area;
    b. The relative contribution of studded tire generated road dust to the overall volume of road dust in an area;
    c. The relative contribution of road dust, and studded tire generated road dust to the toxicity of road dust;
    d. The number and type of sensitive human receptors effected by road dust as compared to other sources of particulate matter in an area;
    e. The human health benefits associated with increased safety afforded by use of studded tires; and,
    f. The human health impacts associated with alternatives to studded tire use (e.g. increased use of traction sand).

- Elevated particulate matter levels from unpaved roads still adversely impact half of Alaska's population. The socioeconomic impact of road paving should be examined as a measure to reduce airborne particulate matter levels. To complete this examination, site-specific studies are needed to:
    - Measure PM_{10} and $PM_{2.5}$ levels and quantitatively assess the magnitude of the PM problem;
    - Differentiate between "controllable" anthropogenic sources of PM (such as unpaved roads) and "uncontrollable" natural sources of PM,
    - Examine the human health impacts of elevated PM levels (correlate medical records to air quality episodes); and,
    - Evaluate the economics and health benefits of additional paved roads or alternative dust control strategies such as speed reductions, the use of dust palliatives, etc.

5. Effect of Studded Tires on Traffic Safety

Studded tire usage is common in Alaska. Drivers use studded tires to increase traction and control in winter driving conditions. Studded tire usage significantly affects pavement surface conditions both positively and negatively. Studs coarsen a pavement surface allowing for greater traction for any type of tire. But pavement rutting is a costly negative result of studded tire usage. Pavement ruts are generally assumed to increase the likelihood of hydroplaning in summer conditions. Determining the policies that allow for maximum traffic safety with the least expense is the goal for the State of Alaska.

5.1 Goals and Objectives

The purpose of this work is to provide a review and summary of published literature on studded tire usage and how it relates to tort liability, traffic safety, and economic effects. Included are studies of accident statistics and the effects of policies and regulations enacted by government agencies in North America, Europe, and Japan.

5.2 Highway Tort Liability

Tort liability and risk management are very broad and complex subjects. Since this review addresses studded tire usage and effects, some publications that address the tort liability of pavement conditions and design are reviewed.

Lewis (1994) summarized present practice for highway risk management. The goal of risk management is to allocate resources to achieve effective and efficient transportation while minimizing human loss. The human factor takes priority. Regarding design and maintenance liabilities he summarized the situations in the U.S.:

- Design: Immunity varies greatly. Usually, design is a discretionary function and afforded immunity. Some states protect design by statute while in other states such immunity has been eroded, waived or lost. As for any project design, decisions must be carefully thought out and properly documented.
- Maintenance: Maintenance activities are generally held to be ministerial and immune. However, if total immunity is not legislated an agency is fully exposed when injury results from work performed negligently. Maintenance is the primary source of tort claims for many highway agencies. Snow and ice control is another potential risk in some states in the event of failure to remove it in a timely manner.

To gain some perspective on the risk exposure of different activities and features Blost (1993) published an evaluation of risk management for the state of Michigan. Table 5.1 ranks these activities by total payout. Pertinent to the subject of studded tires would be pavement surface conditions since a problematic effect of studded tire usage is pavement rutting and the possible resulting increase in the risk of hydroplaning accidents in warmer weather. Pavement surface conditions are ranked number 5 for Michigan which allows restricted use of snow tires similar to the state of Alaska. What portion rutting accounts for in the payout is unknown.

Table 5.1. Sources of major risk exposure in Michigan (Blost 1993).

Rank	Activity or Feature	Total Payout* (Millions of Dollars)
1	Traffic controls	46
2	Shoulder	20
3	Physical obstruction	18
4	Geometrics	17
5	Pavement surface	15
6	Guardrails	14
7	Winter maintenance	8
8	Sight distance	7

*Summary based on alleged defect for 540 cases.

5.3 Pavement Rutting and Hydroplaning Accidents

Glennon (1996) states that a roadway section that causes hydroplaning has a combination of one or more of the following factors:

- Inadequate pavement cross slope—the tilt of pavement to the side, usually down to the right. If less than 1.5% can contribute to hydroplaning.
- Sag vertical curve—a low spot in the roadway. When combined with steep grades and deficient cross slopes is a potential hydroplaning section.
- Build-up of turf shoulders—produce thatch and collect dirt and debris which cause ponding against the raised shoulder especially when combined with deficient cross slope
- Sheet-flow conditions—roadway sections which cause water to flow in sheets across the pavement during rainy weather. Most commonly caused by poor drainage.
- Rutted pavements—wheel-path ruts allow ponding during rainy weather when cross-slope is deficient, grades are flat, and/or at the bottom of sag vertical curves. When ruts hold 0.10 inch or more of water hydroplaning can occur. There is no standard maximum wheel rut depth criterion. Some states have adopted various values, usually around one-half inch.

The Wisconsin Department of Transportation (WisDOT) proposed to quantify how pavement rutting affects accident rates and to evaluate possible safety-based guidelines for the treatment of pavement rutting (Start et al. 1998). They found that as a practical matter it is very difficult to establish hydroplaning as the cause of an accident because of the numerous influencing factors, some of which are listed above, plus vehicle type and condition and a driver’s physiological and psychological state. Consequently, WisDOT sought to correlate accident frequency with rut depth. Randomly selected road segments averaged 1.79km (1.1mi). Accident data was reviewed eliminating accidents that could not be rut-related. WisDOT found that possible rut-related accident rates begin to increase significantly as rut depths exceed 7.6mm (0.3in).

The most recent study available, Ihs et al. (2002), looked at traffic safety and road surface conditions in terms of rut depth and unevenness on Swedish roads. International Roughness Index (IRI) is an international standard for measuring road roughness. It is used to analyze economics involving road quality vs. user cost (University of Michigan 2003). The index measures roughness in terms of the millimeters per kilometer that a laser, mounted in a specialized van, jumps as it is driven across a road. A lower IRI number indicates a smoother ride than a higher IRI number (Pennsylvania Department of Transportation 2003). An IRI of 0.0 means the profile of a road is perfectly flat. IRI values above 8m/km are nearly impassable except at reduced speeds.

Ninety-five percent of Swedish state roads were found to have rut depths less than 15.4mm and an IRI Number under 5.1mm/m. Consequently the results represent good road surface conditions. Accident data from roads with the same speed limit, pavement, width and traffic flow were used to determine an accident ratio (accidents/100 million axle pair km). The accident ratio was plotted against IRI and rut depth. The following linear relationships were found using linear regression calculations:

- With only ruts as an independent variable—Ruts have an overall negligible effect on accident ratio. The accident ratio increases with rut depth in the winter and decreases with increasing rut depth in the summer.
- With only IRI as an independent variable—The accident ratio increases with increasing unevenness. The increase is a little greater in the winter than in the summer.
- With both ruts and IRI as independent variables—The accident ratio decreases with increasing rut depth and increases with increasing unevenness regardless of the season.

Variance analysis was also used in the Swedish study to detect whether abnormally large rut depths or IRI values have a special effect on accident risk. This analysis found that the roads with the deepest ruts, 18mm on 2% of the roads, do not have dramatically different accident rates. It did show that a higher IRI value correlates with a greater accident risk.

5.4 Accident Statistics and Economics

Government agencies in North America, Northern Europe and Japan have commissioned studies of studded tires and their socio-economic effects. Europe and Japan have done the most recent, most detailed work on this subject. The Nordic countries in particular have similar problems and climate to Alaska and have done a great deal of research in the past ten years.

Research is primarily focused on wintertime driving safety with little or no mention of the effects that pavement wear, usually rutting, have on safety when the roads are not covered with ice or snow.

The two primary motivating factors for all the studies are pavement wear and dust pollution. What follows is a summary, by country, of the findings, both qualitative and quantitative, of the available studies of socio-economic effects with respect to traffic safety.

5.4.1 North America

In the 1960's and 1970's many studies were done regarding studded tires. The states of Michigan, Minnesota, Illinois and the province of Ontario prohibited studded tires as a result of this research. At that time usage rates were around 40% and driver behavior was not considered.

Since then there have been substantial advancements in tire design and pavement mix designs as well as more in-depth studies of driver behavior. The findings of the 1970's studies are probably not applicable to today's situations but are reviewed here since much of the thinking that carries through to today is based upon those studies.

5.4.1.1 Alaska

There have been no studies in Alaska to determine the effect studded tires have on driving safety. Alaska Department of Transportation and Public Facilities (2000) reported the types and causes of accidents within the state. Their presentation of data does not take into consideration factors such as studded tire usage or pavement ruts. But there have been several studies documenting pavement wear and its costs (Lu 1994; and Barter and Johnson 1996). Alaska allows restricted use of studded tires.

5.4.1.2 Michigan

Perchonok (1978) collected winter accident and driver exposure data in both Michigan and Minnesota and used the data to predict the effect of banning studded tires. Table 5.2 shows the Michigan findings when the relationship between vehicles with studded tires and vehicles with snow tires is compared. These figures do not account for the proportion of vehicles with studded tires or the proportion of accidents that occur on slippery surfaces. Those aspects are taken into account in Table 5.3, which contains results from both Michigan and Minnesota. Michigan's lower effect is probably because fewer cars were equipped with studs.

The findings of Perchonok's Michigan study include:

- Highest injury rates were in rural areas regardless of tire type.
- Likelihood of injury was least on snowy roads.
- Drivers using studded tires were less likely to be injured than those using snow tires.
- Studded tires were least likely to be involved in sliding accidents.
- Snow tires were less likely to be involved in sliding accidents than standard tires.

Perchonok's study is discussed further in the meta-analysis by Elvik (1999).

Table 5.2. Studded tire versus snow tire comparisons in Michigan showing change in risk if studded tires were banned (Perchonok 1978).

	Tire Group			
Risk Measure	Studs	Snow	Change in Risk	Statistical Significance
Proportion of accidents due to sliding on icy or snowy roads	.27	.30	+11%	Yes
Accident rate due to sliding relative to accident rate due to sliding on clear roads	.42	.45	+7%	Yes
Proportion of drivers injured on icy or snowy roads relative to clear roads	.77	.83	+8%	No

Table 5.3. Estimated effects of banning studded tires in Michigan and Minnesota (Perchonok 1978).

State	Period	Applicable Group	Effect
Minnesota	December through March	Number of autos in accidents	0.6% increase
Minnesota	December through March	Number of drivers injured	1.4% increase
Michigan	January through March	Number of autos in accidents	0.2% increase
Michigan	January through March	Number of drivers injured	0.4% increase

5.4.1.3 Minnesota

Minnesota banned the use of studded tires in 1971. At the time, studded tire usage was about 40% and the Minnesota Department of Highways (MNDOH) projected usage to increase to 60% by 1973. Primary motivation for prohibiting studded tires was pavement wear. MNDOH (1970) prepared its findings for the Minnesota state legislature. Their conclusions regarding traffic safety included the following:

- Accidents are twice as likely to occur on icy or snowy roads, but are generally less severe when compared to those that occur on all road conditions.
- Fatal accident rates on icy or snowy roads are less than for all road conditions.
- Vehicle performance on ice is significantly improved by studded tires, but does not approach the performance on bare pavement.
- Vehicle performance with studded tires is most improved on warm, clean glare ice. There is less improvement on other types of surfaces.
- There is, as yet, no evidence of consistent reduction in accident occurrence on snowy or icy roads attributable to the increased use of studded tires in Minnesota. Data from current studies are insufficient.

Perchonok (1971) also determined that studded tires reduced the likelihood of a driver being involved in an accident. Other conclusions reached in this study are:

- The likelihood of precipitating an accident due to sliding on icy or snowy roads was least for studded tires.
- In accidents attributed to sliding, loss of directional control was the most frequent problem.
- For driver injury, studded tire vehicles had an apparent advantage.

Perchonok (1978) also contained data and analysis from Minnesota. Table 5.4 shows the before and after changes for three measures of risk for drivers using studded tires ‘before’ and snow tires ‘after’ and drivers who used snow tires in both periods. The snow tire group was the control against which the changes in effect were measured. Table 5.3 includes the estimated effects of banning studded tires in Minnesota with the adjustments mentioned above for the Michigan data.

Perchonok’s other findings in the Minnesota study include:

- For drivers who switched to snow tires there was an increase in accident involvement on slippery roads relative to clear roads.
- For drivers who used standard (summer) tires before and after their accident involvement increases 15%. (At the time there was no explanation for this but would now expect this to be caused by road surface polishing.)
- Drivers using studded tires were less likely to be injured in an accident.

Table 5.4. Before-to-after changes in risk in Minnesota (Perchonok 1978).

	Tire Group		Statistical
Risk Measure	Studs to Snow	Snow to Snow	Significance
Frequency of accident involvement on icy or snowy roads	+7%	-8%	Yes
Accident rate on icy or snowy roads relative to clear roads	+4%	0%	No
Proportion of drivers injured in icy or snowy road accidents	6%	-5%	No

5.4.1.4 Oregon

Oregon passed legislation in 1995 that limited stud weight to not more than 1.5g. Primary motivating factor for the legislation was pavement wear. Studded tire usage had increased from 9.2% in 1974 to 23.8% in 1994 (Brunette and Lundy 1997). There has been no published study addressing the issues of traffic safety and how it relates to studded tires in the state of Oregon.

5.4.1.5 Washington

In 1999 the state of Washington passed legislation that required that studded tires sold within the state may only use ‘lightweight studs.’ Pavement wear was the primary motive for the actions taken. Work done for the Washington State Transportation Center investigated studded tire usage and pavement wear, but there has been no published study that has examined road traffic safety in Washington State (Angerinos et al 1999). The Washington State Department of Transportation (WSDOT) based its recommendations on the Finnish studies by Unhola (1997) and the statute was modeled after similar legislation passed in Oregon in 1995.

5.4.1.6 Canada

The province of Ontario prohibited studded tires after April 30, 1971. At the time usage rates throughout the province ranged from 12 to 48%. Predictions by the Department of Highways, Ontario estimated usage to reach 60% by 1971-72. Severe pavement wear was Ontario’s primary motivation for the prohibition (Smith and Schonfeld 1970).

Smith (1972) compared accident statistics before and after the ban with some of the following conclusions:

- Accidents of all types, in all conditions, year round, increased.
- In the first winter after the ban the proportion of winter accidents occurring on icy roads declined.
- The accident statistics are inconclusive because of the nature of the data available.

- There is a real need for winter driving aids that provide increased traction and better vehicle control in adverse conditions.

Ontario revisited this issue in 1999/2000 and reached the same conclusions as they did in 1971. The main motivating factor remained pavement wear. Their findings include (Ontario Ministry of Transportation 2000):

- Studded tires do not offer safety advantages in comparison to winter tires in road conditions which are either wet or dry for most of the time.
- Studded tires are superior on glare ice near freezing temperatures; these conditions occur in Ontario less than 1% of the time.
- Any safety advantage is lost by even a small increase in speed.
- Lightweight studded tires cause only marginally less damage to the road surface than traditional studs and are less effective.

The findings of this review were printed on the Ministry website. There are no references or details of how the research and review was done.

5.4.2 Europe

5.4.2.1 Estonia

The Estonian Road Administration commissioned an investigation of the socio-economic effects of the usage of different types of winter tires. The following effects were evaluated:

- Road damages (pavement wear and road markings)
- Traffic accidents
- Traffic conditions

At the time of the study, winter usage of studded tires was about 80%. Findings published by Sürje (1999) regarding traffic safety include:

- Based upon Finnish and Swedish research, Estonians conclude that studded tires prevented 20 deaths in 1998. The median economic cost of a traffic death in 1998 was EEK 4.366 million (US$330,000).
- Wear resistance of Estonian pavements is half that of Finnish pavements based upon laboratory tests.
- The number of cars on Estonia’s roads has doubled in the 1990’s without a significant increase in winter accident risk. Studded tires have been credited with the safety record.

Table 5.5 compares the expense of pavement wear due to studded tires with the economy or money saved by accident reduction. Overall, Estonia benefits economically and in safety by continuing to use studded tires.

Table 5.5. Calculated summary effects caused by usage of studded tires in Estonia. Amounts are given in 2003 US dollars (Sürje 1999).

Year	Road Damages, Million US$	Economy, Million US$		All together +economy, -loss Million US$
		Traffic Conditions	Traffic Accidents	
1995	4.02	1.03	2.01	-1.05
1996	4.87	2.15	3.39	+1.43
1997	5.36	4.52	6.11	+5.26
1998	5.63	5.46	7.15	+7.20
1999	5.91	6.31	7.63	+8.03
2000	6.20	7.28	7.77	+8.85

5.4.2.2 Finland

The Finnish National Road Administration (FINNRA) conducted an extensive research program called the “Road Traffic in Winter - Programme” which published a summary of its findings in 1995 (Alppivuori, Leppänen et al. 1995). The program concentrated on five areas of study:

- traffic safety
- environmental effects
- maintenance
- vehicular costs
- road user experiences.

Some findings of the study regarding traffic safety and costs associated with winter driving include:

- Grip of light studs is similar to that of older steel studs.
- Light studs decrease rutting to 40-50% and prohibiting studs to 20-30% of the current rutting level.
- Studded tires perform better in winter conditions than studless winter tires (friction tires). The difference in performance under icy conditions is huge.
- Changing to friction tires did not affect the amount of driving, that is, total kilometers driven. Drivers maintained greater following distances and drove more slowly on curves.
- Drivers with friction tires drove faster in good road conditions resulting in a negative effect on safety.
- As age and experience increase, accident risk decreases. But the risk of severe accidents is greatest for young and old drivers.
- Drivers are not aware of road conditions. They usually consider surface conditions to be less slippery than they really are.
- Drivers did not reduce speeds sufficiently when road conditions were considered slippery.

- Drivers in queues do not keep adequate safety margins. This was true particularly in Helsinki.
- Studded tires in good condition increase safety. In 30% of fatal accidents tires in poor condition were involved. Typically, in normal traffic 3% of cars have poor condition tires.
- During reduced-salting experiments the amount of sanding tripled.
- Reduced-salting resulted in a 5% increase in personal-injury accidents.
- Salting adds significant cost to bridge maintenance due to the corrosion damage to steel-reinforced concrete.
- Fuel consumption increases by 15% on slippery, snowy roads when compared with dry roads.

Table 5.6 shows the total economic impact of decreasing studded tire usage and amount of surface applications. The baseline usages at the start of the study are described as the basic situation. Calculations include the costs to the road authority, motorist, society as a whole and the environment and are based upon the expense of preventing harmful effects, established practice, or if necessary, best estimates. Altogether, 77,000 km of roads were considered.

Table 5.6. Summary of the socio-economic costs of the various scenarios examined in the "Road Traffic in Winter - Programme" (Alppivuori, Kanner et al. 1995). Costs and assessments are based on 1992/1993 prices including taxes.

"Road Traffic in Winter" - Scenarios
Change in Total Costs Compared to the Basic Situation

Changes in total costs Million US$/a	**Salt 120,000 t/a**	**Salt -50%**	**Salt -80%**
Studded tyres in 95% of cars	Basic situation	+36	+36
Studded tyres in 50% of cars	+47	+91	+98
Studded tyres in 20% of cars	+100	+160	+202

Changes in traffic safety were found to be dependent upon the number of vehicle-kilometers driven on slippery roads and the accident risk of different road conditions. Any reduction in studded tire usage and/or road salt would lead to an increase in traffic accidents. Injury accidents increased the most when salting was reduced 80% and studded tires were on 20% of cars. Under that scenario bodily injury accidents would rise 30% equating to an increase cost of US$44 million to $222 million per annum (Alppivuori, Kanner et al. 1995)

Roine (1999) published the results of a detailed statistical accident model. Reliability theory and survival modeling were used to assess wintertime accident risks. Data from the winters of 1987-1993 were used. Driving conditions and total kilometers driven were major contributors to the number of accidents. Drivers using non-studded tires had a somewhat greater accident risk than those with studded tires. However, the difference was not statistically significant.

5.4.2.3 Iceland

Sigthorsson (1998) published research done by the Public Roads Administration (PRA) for which accident data from the urban area of Reykjavík was analyzed. Only data reported by the police were used. Icelandic authorities designate those involved in accidents as “perpetrators” (those whose actions cause the accident) and “victims” (those who are involved in the accident without causing it). Police also report tire classification and road surface conditions.

Tables 5.7, 5.8 and 5.9 show analysis of the data with the end result being the percent increase in safety from the use of studded tires. All of the numbers are percentages except those in parentheses. Numbers in parentheses are the total road users involved in reported accidents. The data collected between 1983-1995 has been divided into two categories because during this period different agencies were responsible for coding and inputting data. Although there were different standards for interpreting data the qualitative results when examining all accidents were consistent; studded tires significantly increased safety.

Table 5.9 details injury accidents only. Studded tires are still beneficial, but the increase in safety is not as great. The reason for this difference may be that drivers with studded tires drive faster, which increases the chance of injury if there is an accident.

Example calculations: Evaluation of weight average was as follows:

- *Columns for winter tires are compared: 19.8/21.8=0.908, which means that these drivers are approximately 10% less safe than expected.*
- *Columns for studded tires are compared: 28.9/26.1=1.107, which means that these drivers are approximately 11% safer than expected.*
- *Winter tires and studded tires are weighted together: 1.107/0.908=1.22, which after subtracting 1 and multiplying by 100 gives 22% safer behavior for drivers* using studded tires.

Table 5.7. Excess safety of studded tires for 1983-1988 (all accidents). From Sigthorsson (1998)

Years 1983-1988 Percent	Perpetrators			‘Victims’			Excess safety of studded tires, %
	Studded tire	Winter tires	Total	Studded tires	Winter tires	total	
Dry or wet	20.9	19.1	40.0% (of 11,830)	22.5	17.0	39.5% (of 10,792)	21
Ice or snow	43.6	31.2	74.8% (of 3491)	51.1	29.6	80.7% (of 352)	24
Weighted	26.1	21.8	47.9% (of 2702)	28.9	19.8	48.7% (of 1889)	22

Table5.8. Excess safety of studded tires for 1989-1995 (all accidents). From Sigthorsson (1998)

Years 1989-1995 Percent	Perpetrators			'Victims'			Excess safety of studded tires, %
	Studded tire	Winter tires	Total	Studded tires	Winter tires	total	
Dry or wet	20.8	19.2	40.0% (of 8058)	22.9	16.7	39.6% (of 1537)	27
Ice or snow	48.9	34.3	83.2% (of 2994)	56.7	30.6	87.7% (of 2730)	30
Weighted	24.4	23.3	51.7% (of 11,052)	31.6	20.3	51.9% (of 10,600)	28

Table 5.9. Excess safety of studded tires for 1983-1995 (injury accidents only). From Sigthorsson (1998)

Years 1983-1995 Percent	Perpetrators			'Victims'			Excess safety of studded tires, %
	Studded tire	Winter tires	Total	Studded tires	Winter tires	total	
Dry or wet	17.5	17.6	35.1% (of 2183)	20.0	18.1	38.1% (of 1537)	11
Ice or snow	49.5	32.2	81.7% (of 519)	54.0	30.1	84.1% (of 352)	16
Weighted	23.6	20.4	44.0% (of 2702)	26.4	20.3	46.7% (of 1889)	12

Conclusions from Sigthorsson are:

- Drivers using studded tires drive more safely in all conditions.
- Behavior is a more significant factor than equipment.

5.4.2.4 Norway

The Norwegian Public Roads Administration initiated their Road Grip Project in 1994 to determine the socio-economic costs for changes in the use of studded tires. Norway's primary motivation was to reduce dust pollution caused by studded tires in their four largest cities, Oslo, Bergen, Trondheim and Stavangar. The research was published by Krokeberg (1998).

The result of the project was to set a goal of an 80% reduction in the use of studded tires by 2002. If, in 1999, the trend was not toward the goal they would consider taxing drivers in those cities with studded tires. There was no benefit to reducing the proportion of studded tires throughout the rest of Norway.

The Road Grip Project evaluated costs that result from reduced studded tire usage in the following areas:

- Road authority’s pavement cost—pavement wear is reduced and the costs change because of the increased time between paving and re-paving.
- Road authority’s maintenance costs—changes in snow clearing costs, road marking, washing road signs and so on.
- Time—drivers with studless tires drive more slowly and reduced speed limits in the winter time in urban areas slow traffic. A value was given to lost time.
- Driving costs—changes in fuel consumption and car washing. The model does not include corrosion caused by road salt.
- Accident costs—model includes personal injury accidents and accidents are given a price that considers death, light injuries, and material damages. Specific findings regarding accident risk are described in greater detail below.
- Health and environmental costs—includes costs due to noise, well-being, and damage of vegetation caused by road salting. Health costs constitute 90% of the total health and environmental costs.

Figure 5.1 is a graphical presentation of the changes in costs as a result of a reduction in the use of studded tires. The first two columns show the changes when studs are reduced from 80% to 50% and 20% throughout Norway. The third column shows changes when stud usage changes regionally; set to 20% in the four cities, 50% in areas close to the cities, 70% in more distant areas and 80% throughout the rest of the nation.

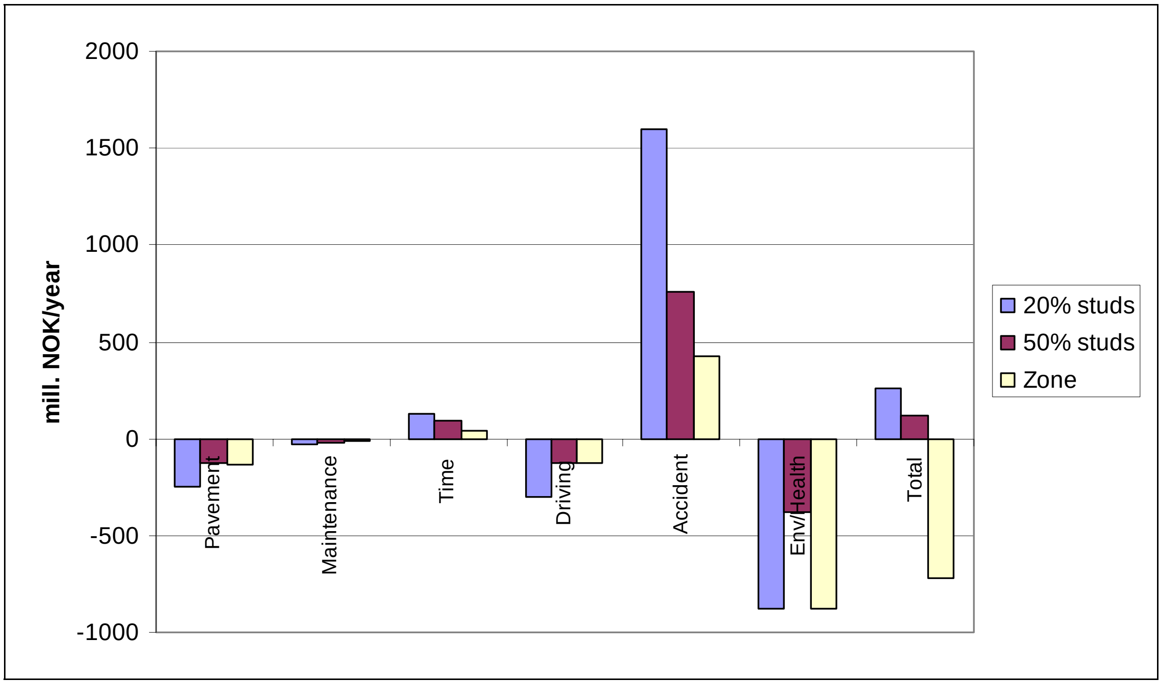

**Figure 5.1. Relative changes in socio-economic costs when the proportion of studded tires is reduced from 80% to 20 and 50% in Norway in general.
“Zone” means reduced usage in the four major cities and increasing usage to 80% as distance from the urban areas increases. Norway’s total road network is included in the results (Krokeberg 1998).**

Accident costs changed the most. The study found road conditions changed when the proportion of studded tire usage was lowered. The changes in road conditions were as follows:

- Slippery roads become more slippery because of a 'polishing' effect caused by studless tires.
- Snow and ice wears more slowly which gives more days with lower risk.
- Accident risk changes for some road conditions.
- Wet roads in summer will be more slippery for some asphalt types.

Differences in friction were found relative to a dry road in summer:

- Hard snow and ice—risk increases up to 25%
- Bare road winter—risk decreases up to 2%
- Wet road summer—risk increases up to 1.5%

In December 1999, Oslo began taxing studded tire users. At that time the usage rate was 35%. Fridstrøm (2001) analyzed daily accident counts for Oslo, Bergen, Trondheim and Stavangar over a period of almost 10 years. The results of his analysis shows the use of studded or non-studded tires had a limited impact on traffic safety. Injury accident frequency increases with snowfall, but decreases in the days following. Fridstrøm went on to study the relationships between weather, studded tires, and vehicle speed. Figures 5.2, 5.3, and 5.4 show these graphical relationships.

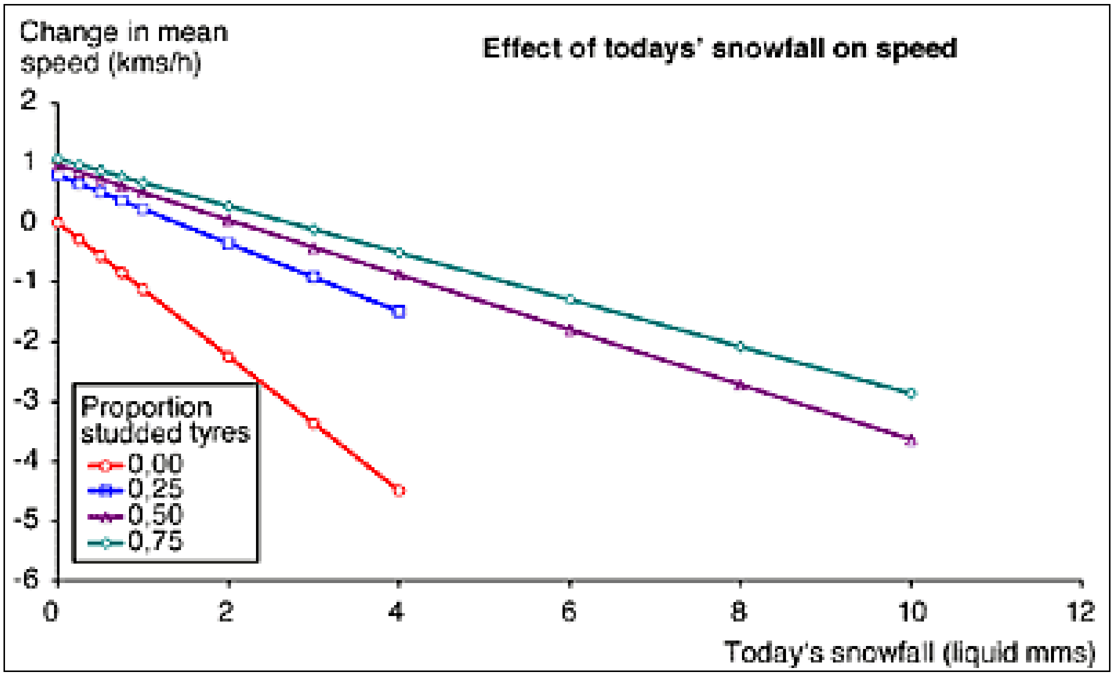

Figure 5.2. Estimated partial relationship between mean daily speed and today's snowfall. Numerical example for days with frost and 5 cm accumulated snow depth. Fridstrøm (2001).

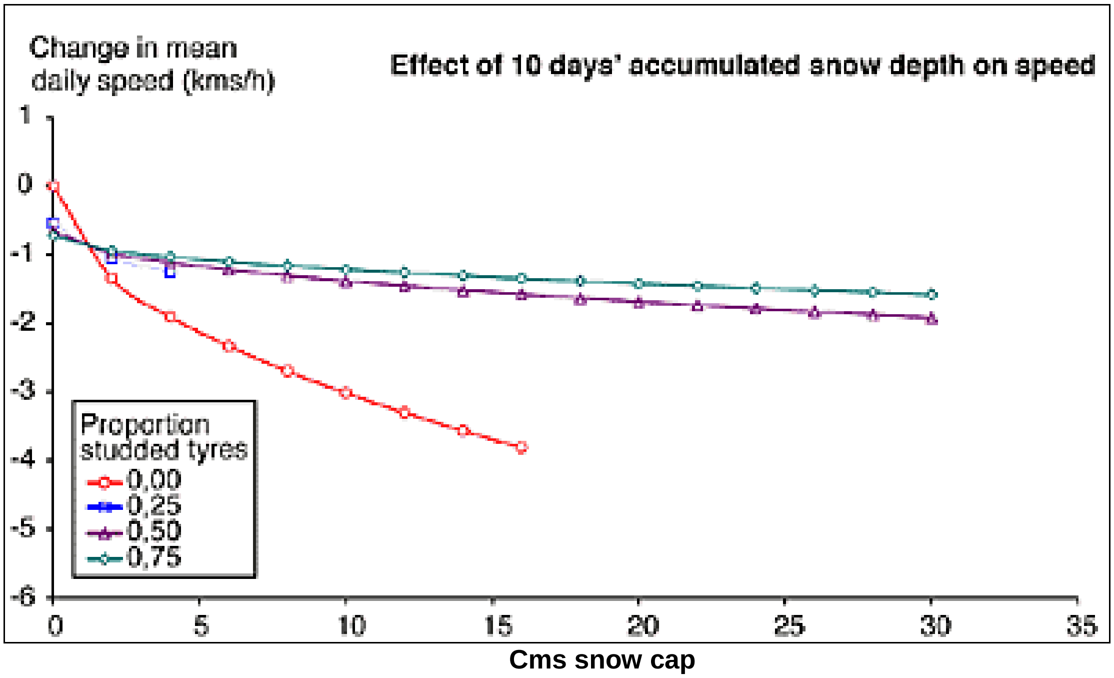

Figure 5.3. Estimated partial relationship between mean daily speed and 10 days' accumulated snow depth. Numerical example for days with frost but no snowfall. Fridstrøm (2001).

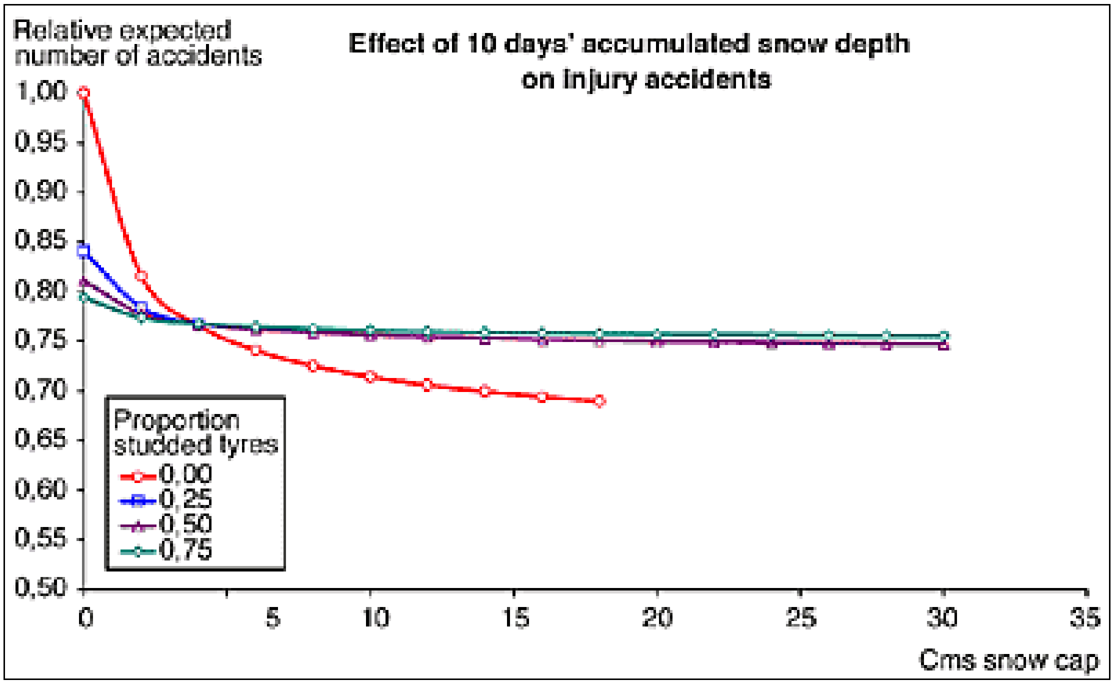

Figure 5.4. Estimated partial relationship between injury accident frequency and 10 days' accumulated snow depth. Numerical example for days with frost but no snowfall. Fridstrøm (2001).

Figures 5.2 and 5.3 show the expected reduction in speed as accumulated snow increases. When Figures 5.3 and 5.4 are compared, driving speed becomes a critical factor in accident risk. Drivers without studded tires drove more slowly and risk of an injury accident was lower, while drivers with studded tires maintained higher speeds and higher accident risk. This is a reasonable expected result; if drivers reduce speed their risk of injury is also reduced.

Fridstrøm also found that studded tires reduced accidents when there was no snow on the ground or in the air. However, weather conditions do not accurately reflect pavement surface conditions. Accident incidence on snowy or icy roads is lower with studded tire usage. Fridstrøm concluded that driver behavior, as well as pavement conditions depend on the level of studded tire usage.

5.4.2.5 Sweden

Carlsson (1981) used traffic data from the winter of 1979/80 and monetary levels of 1980. He assumed that if studded tires were banned drivers would use their summer tires year round. Results show that costs to Sweden would increase by SEK 530-1,230M (million 2003 US$60-142) annually as a result of a prohibition. The increased number of accidents in slippery conditions caused by snow and ice is the completely dominant cost item. Cost savings of a prohibition would be SEK 700-900M (million 2003 US$81-104) annually. The largest savings item is money not spent to purchase the tires themselves. Other savings categories were car washing and road maintenance. Cost savings and expenses are of the same magnitude.

Junghard (1992) collected police accident data from predominantly rural roads in all Swedish counties from December 1, 1989 through February 28, 1990. Two methods of evaluation were used, one involving both accident and exposure data and the other using only accident data.

Junghard made several assumptions to simplify his analysis:

- Studded tires have no effect on non-slippery surfaces.
- Influence of confounding variables is the same on slippery and non-slippery roads. Confounding variables are driver's age, sex and driving experience and vehicle ownership. Variables associated with vehicles include age, antilock braking system (ABS) and four-wheel drive.
- On any given day and at any time the proportion of vehicles with studded tires is constant.

Police data included information on the tires and the road surface conditions. Data on control vehicles was obtained by questionnaires in January and February 1990. The proportion of studded tire usage from the accident data was 65.7% and from the survey, 70%. Overall results show that studded tires reduce the risk of accidents on a slippery road by 20 to 50%. Junghard's study is also discussed below in a review of Elvik's meta-analysis.

Carlsson et al. (1995) determined that studded tires were profitable for Sweden. Using traffic data and previous studies they calculated the economic effects of banning studded tires.

Winter 1993/1994 was a fairly normal winter and was the basis for calculations. Conditions predicted for 1999/2000 are the same, but the assumptions are that all the studded tires will have lightweight studs and pavements would be more wear-resistant. Carlsson used results from earlier studies which found that studded tires decrease accidents by 40% in icy/snowy conditions on rural roads and by 35% in urban areas. Other winter tires reduce accidents by 25% and 20% respectively when compared with summer tires.

Table 5.10 shows the predicted cost effects of banning studded tires. The effects of studded tires on accident occurrence is substantial. Increased expenses due to accidents if studs are banned is not offset by other savings.

Table 5.10. Cost changes resulting from a ban on studded tires (US$ million/year). From Carlsson et al. (1995).

	Increase	**Decrease**	
		1993/94	**1999/2000**
Accidents			
-direct	143-174		
-indirect	29-35		
Road wear			
-pavement		18-24	8-11
-road markings, signs		4-8	2-4
Car costs			
-tires/rims		13	13
-fuel consumption		1	1
-washing		36-84	16-36
Environment			
-car washing		3-6	1-2
-the rest		?	?
TOTAL	172-209	75-136	41-67
		+?	+?

Öberg (1997) used the same 1993/94 Swedish traffic data and some of the same assumptions as Carlsson et al (1995). However, he tabulated costs of all cars using studded or snow tires and comparing that with all cars using summer tires. Table 5.11 shows Öberg’s calculations. Table 5.12 lists the cost changes if all tires used during the winter months were snow tires.

Öberg’s conclusions were that requiring cars to be equipped with winter tires during slippery road conditions produced a cost savings. He recommended that the Swedish government legislate such a requirement.

Table 5.11. The use of winter and studded tires entails the following cost changes compared to if all cars use summer tires (US$ million/year) (Öberg 1997).

	Decrease	Increase	
		1993/94	1999/2000
Accidents			
-direct	330-404		
-indirect	29-35		
Road wear			
-pavement		18-24	8-11
-road markings, signs		4-8	2-4
Car costs			
-tires/rims		40	40
-fuel consumption		11	11
-washing		36-84	16-36
Environment			
-car washing		3-6	1-2
-the rest		?	?
TOTAL	359-439	112-173 +?	77-104 +?

Table 5.12. Cost changes incurred by requiring winter tires in slippery road conditions compared to the use of tires in the winter 1993/1994 (US$ million/year) (Öberg 1997).

	Decrease	Increase	
		1993/94	1999/2000
Accidents			
-direct	46-58		
-indirect	9-11		
Road wear			
-pavement		3-4	1-2
-road markings, signs		1	1
Car costs			
-tires/rims		24	24
-fuel consumption		4	4
-washing		6-14	2-6
Environment			
-car washing		0.1-1	0-1
-the rest		?	?
TOTAL	55-70	38-49 +?	32-37 +?

In 1999, the Swedish government legislated that all vehicles are required to be equipped with winter tires or similar equipment. The usage of both winter tires and studded tires increased such that 100% of vehicles were equipped with one or the other type. Data collected over the following two winters show that injury and fatality accidents decreased by 8%. These results have not been statistically verified (Öberg, Velin and Wiklund 2002).

A comparative study examined the accident risk for heavy vehicles using winter tires compared to summer tires found that winter tires do not improve safety. Winter tires give better gripping power than summer tires on ice, but are appreciably inferior to good quality studded tires (Öberg et al. 2002).

A documentary review concerning the effects of weather and road conditions and winter road maintenance measures found that, in rural areas, studded tires reduce the risk of accidents on slippery roads by about 40% compared to summer tires. The reduction with winter tires is about 25%. The effect is expected to be less in urban areas (Wallman et al. 2002).

5.4.3 Japan

The Japanese banned the use of studded tires in phases based upon location starting in 1991 and ending with complete nationwide prohibition in 1997. The motivations for the ban were air pollution, pavement abrasion, and summer traffic accidents due to ruts. Pollution was the most serious problem for the Japanese and the concentration of suspended particulate matter was reduced dramatically to acceptable levels after the ban (Takagi and Tsutae 1997).

Detailed studies have been published regarding the effect of the studded tire ban on traffic on Hokkaido. According to Takagi and Tsutae (1998), the restriction had the following effects:

- Road surfaces covered with ice and snow became very slippery. Examination of the surface accumulation shows packed snow covered with layers of ice films. The relatively smooth studless tires cause the ice films and then tend to polish its surface. Asano et al (2001) found that the coefficient of friction of snowy surfaces was reduced almost 70%.
- Skidding accidents increased significantly, particularly rear-end collisions at intersections. Only accidents resulting in injury or death are considered. Winter-type accidents, those caused by skidding, rut-related and visual obstructions caused by snowstorms and drifts, increased 2.2 times from 1989 to 1993.
- Improved road surface applications to prevent freezing and skidding were required. Applications of antiskidding and antifreezing agents were increased 15 times and 7 times, respectively, over the period 1992-1996.

Regarding the economic impacts of the prohibition Asano et al. (2002) published the results of an extensive benefit-cost analysis for Sapporo for the ten years since the restriction was enacted. The Sapporo area includes four cities and three towns with an estimated population of two million people. The analysis calculated changes in costs for travel, traffic accidents, increased nitrogen oxides (NOx), noise levels, environmental improvements and road maintenance. It is the most recent, most detailed examination of the economic effects of studded tires.

Cost estimations of traffic accidents were calculated using a probability model to account for increasing traffic volumes during the study period. Again, only accidents that resulted in injury or fatality were considered. Rear-end collisions are, typically, low-velocity accidents and the per-incident cost is less than a head-on collision. The cost of head-on collisions ranges from $1.7 million to $2.1 million (Japan Research Institute 1999). Table 5.13 compares the incidence of car accidents/million vehicle-kilometers for the studded and studless periods.

Incidences of head-on collisions did not change significantly. However, there was a significant increase in the number of low-velocity accidents with rear-end collisions increasing the most.

Table 5.13. Cost of increased traffic accidents after banning studded tires on Hokkaido (Asano et al. 2002).

Accident Type	Incidence of Accidents (time/million vehicle km)		Unit Cost ($)	Total Cost ($)		
	Before studded tire ban	After studded tire ban				
	1989-1991	1996-1998		Period of Studded Tires	Period of Studless Tires	Difference
Rear-end Collision	0.075	0.136	725,200	3,178,707	5,780,457	-2,607,750
Intersection Collision	0.011	0.027	1000	656,607	1,535,493	-878,885
Head-on Collision	0.035	0.050	2,132,600	4,423,796	6,269,323	-1,845,527
Human and Vehicle Collision	0.006	0.008	1,737,700	650,800	784,932	-134,132
Construction Collision	0.005	0.010	251,000	73,400	151,654	-78,253
Deviation Accidents	0.004	0.006	2300	563,839	750,654	-186,816
Total						-5,725,364

Travel speeds were reduced by 16% after studded tires were banned. This resulted in decrease traffic throughput and increased traffic congestion. The results of increased congestion had cost benefits in the following areas:

- Travel costs—net increase based on increases in travel time, tire costs and reductions in fuel expenses.
- Increased NOx emissions—increase in costs based upon average cost of environmental damage.
- Noise Levels—reduction in cost based on environmental assessments.
- Air pollution—reduction in costs due to reduction in dust pollution.
- Road maintenance—increase in costs. Reductions in costs for repair and resurfacing were greatly outweighed by increases in the costs for surface treatments of antifreezing and antiskidding agents.

The conclusion of the benefit cost analysis performed by Asano and his colleagues was a net increase cost of $137,000,000/year on Hokkaido.

5.5 Meta-Analysis of Evaluation Studies

Elvik (1999) published a meta-analysis for the Institute of Transport Economics in Oslo in which he assesses a collection of studies to determine a best estimate of the effect of studded tires on traffic safety. His work includes some of the papers previously mentioned as well as several that are not available in English including Pucher (1977), Steen and Bolstad (1972), Ernst and Hippchen (1974), Roosmark et al. (1976), Ingebrigtsen and Fosser (1991), Fosser (1994), and Fosser and Sætermo (1995), and Hvoslef (1997).

Studies were separated into two types:

1. The effects of studded tires on the accident rate of cars using them. These studies try to answer the question, ‘Is there any difference between the accident rates of cars with and without studded tires?’ The general measure that is used is the accident rate ratio which is defined as follows:

$$\textit{Accident rate ratio} = \frac{\dfrac{\text{\# of accidents involving cars with studded tires}}{\text{Vehicle kilometers driven with studded tires}}}{\dfrac{\text{\# of accidents involving cars without studded tires}}{\text{Vehicle kilometers driven without studded tires}}}$$

   If the accident rate ratio is less than 1.0 studded tires reduce the accident rate. If the rate is greater than 1.0 studded tires increase the accident rate.

2. The effects of laws prohibiting the use of studded tires. This type attempts to answer the question, ‘How do such laws affect the number of accidents?’ The most common measure is the relative change in the expected number of accidents defined as:

$$\begin{array}{l}\textit{Relative change in}\\ \textit{expected number of accidents} = \dfrac{\text{Recorded number of accidents after passage of law}}{\text{Expected \# of accidents if law had not been passed}}\end{array}$$

   If the ratio is less than 1.0 safety has been improved, if it is greater than 1.0 safety has deteriorated.

Statistical weights were applied to the estimates in the studies. Weights were defined in terms of the number of accidents.

Table 5.14 shows the results of research that has evaluated the effects of studded tires on accident rates. There is a large variation in the size of the effect but all the studies agree that there is a safety benefit on snow- or ice-covered roads.

Table 5.14. Results of studies that have evaluated the effects on automobile accident rates of using studded tires. From Elvik (1999)

Study	Percent change in accident rate attributed to studded tires by road surface condition		
	Snow- or ice-covered roads	Bare (dry and wet) roads	All road surface conditions
	Best estimate	Best estimate	Best estimate
Normand (1971)	-43	-47	-45
Steen and Bolstad (1972)	-18	-29	-22
Ernst and Hippchen (1974)			-39
Roosmark et al. (1976)	-25	-7	-16
Perchonok (1978)	-72	-68	-70
Ingebrigtsen and Fosser (1991)	-5	-4	-5
Junghard (1992)	-49	-17	-37
Konagai et al. (1993)			-57
Fosser (1994)	-25	+151	+10
Fosser and Sætermo (1995)	-4	+3	-4
Roine (1999)	-14	-41	-28

Because of the wide variation in study methods, findings and explanations Elvik further evaluated the studies for quality using the following variables:

- Size of the accident sample,
- Whether the studies specify road surface conditions,
- Whether the studies specify the type of tire (non-studded winter, standard tires) to which studded tires are compared,
- Number and type of confounding variables for which the studies account. These would be variables related to both the use of studded tires and the accident rate that can distort the effects attributed to studded tires.

Superior studies have large accident samples, specify both road surface condition and type of comparison tires and control a large number of confounding variables. The patterns of the studies were inconsistent and so were divided into 3 groups, strong, weak, and inadequate. Figure 5.5 is a chart of the accident rate change based upon study quality. Table 5.15 lists Elvik's classification of the individual studies.

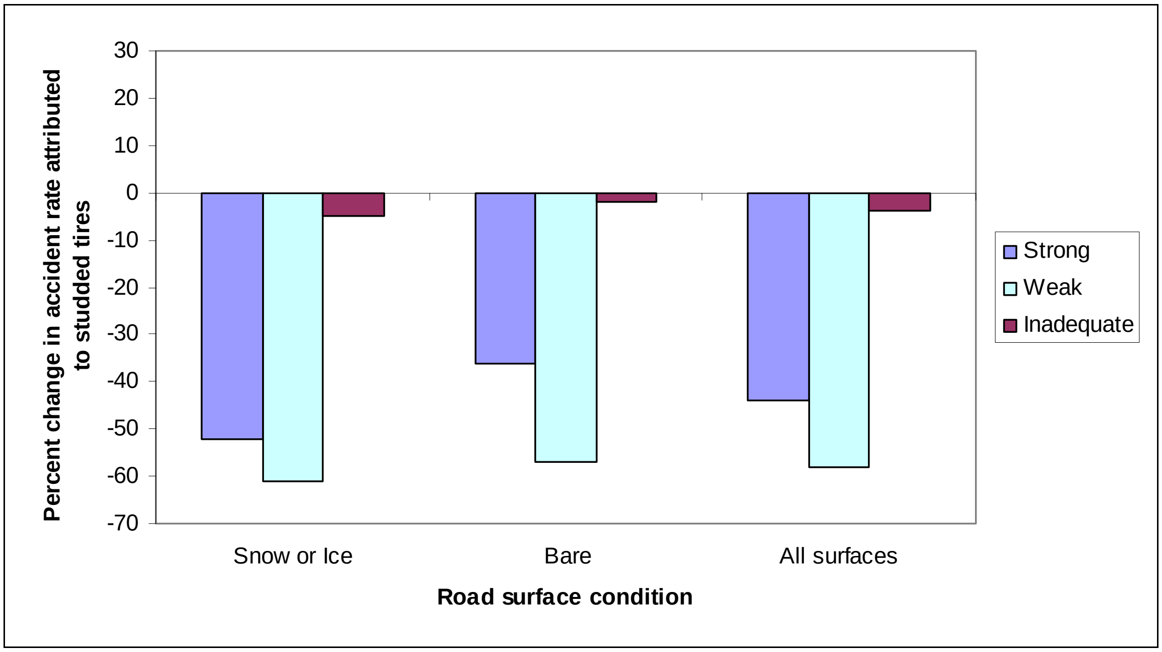

Figure 5.5. Estimated change in automobile rates attributed to studded tires by study quality and road surface condition. From Elvik (1999).

Table 5.15. Quality of studies based upon sample size and whether each addressed road conditions, types of comparison tires and confounding variables. From Elvik(1999).

Strong	**Weak**	**Inadequate**
Ingebrigtsen and Fosser (1991)	Steen and Bolstad (1972)	Normand (1971)
Fosser and Sætermo (1995)	Roosmark et al. (1976)	Ernst and Hippchen (1974)
Roine (1999)	Junghard (1992)	Fosser (1994)
	Michigan results of Perchonok (1978)	Konagai et al. (1993)
		Minnesota results of Perchonok (1978)

Elvik concluded the following:

- Studded tires do improve road safety, anywhere from 1% to 10% depending upon the quality and interpretation of the study. Laws banning studded tires are likely to lead to an increase in the number of accidents.
- Results of the studies done in the 1970's which show 40-70% declines in accident rates are difficult to believe because they also found large declines in accident rates with studded tires on bare roads. These studies had no driver variables controlled.
- Driver behavior is an important factor.

5.6 Conclusions and Recommendations

The consensus of these studies is that studded tires do improve traffic safety in winter driving conditions. Studies done in the early 1970's in North America showed increased safety from studded tires, but pavement repair costs motivated bans in Minnesota and Ontario. Substantial improvements in tire and stud design and pavement design make the results of those studies inapplicable today.

For studies and economic analyses performed more recently, accident costs are usually the overwhelming factor in the sum of economic effects. Pavement wear caused by studs is very expensive as well. However, when studded tires are prohibited the savings in pavement repair may be entirely offset by the increased costs of surface applications. This was true on Hokkaido where the cost of surface applications was greater than the cost of pavement repair. In the Nordic countries lightweight studs are now the norm and pavement wear has been reduced by almost half with no change in accident risk (Unhola 1997).

Recommendations for the State of Alaska are:

- Mandate that all studded tires sold in the state have lightweight studs. This includes working with stud manufacturers to determine the best lightweight stud for heavier US vehicles.
- Continue enforcement of the seasonal restrictions on studded tire usage.
- The types of vehicles that are commonly driven in Europe, Japan and Alaska may be different. It is possible that cars and trucks in Alaska are more likely to be four-wheel drive and heavier. Further research is needed to determine the increase in safety that studded tires add to these types of vehicles.
- Future research to determine the extent to which rutting contributes to summertime accidents. The studies presented are local, that is, they are evaluating practices, conditions and vehicles common to a particular region or nation. To empirically evaluate the safety effects of studded tires in Alaska local research within the state should be done. In this way Alaska's conditions, pavements, and vehicles are then taken into account.

5.7 Executive Summary

Pavement repair costs resulting from pavement wear caused by studded tires is a significant problem in the State of Alaska. To gain an understanding of the relationship between studded tires and traffic safety available publications pertaining to studded tires and traffic safety were reviewed. Studies from North America, Europe and Japan were reviewed along with the government policies.

- All of the studies reviewed with one exception concluded that studded tires reduce accident risk.
- Although pavement repair costs are significant, accident costs are the overwhelming factor in economic analyses of studded tire effects. Recent studies in Finland and Japan found that prohibiting studs produced a net increase in costs. Pavement repair costs are

greatly reduced but accident costs plus the increased requirement of surface applications resulted in an overall increased financial burden.

- Motivating factors for restrictions or bans on studded tires were pavement wear and air pollution. These problems were mitigated when studded tires were prohibited.
- Recent studies have resulted in legislation that continues restricted studded tire usage but allows only lightweight studs to be used. Lightweight studs reduce pavement wear by almost half.
- Drivers using studded tires behave differently than drivers without studded tires.
- There are few published studies available that address a relationship between rutted pavement and summer hydroplaning accidents.
- North American research from the 1970's is not very applicable to today's situations because of substantial improvements in tire and vehicle design along with more wear-resistant pavements. Increased tort liability also greatly changes the economics of studded tire usage.

Table 5.16 is a summary of the studies and results, and the governmental regulation by location.

Table 5.16. Summary of studies and policies pertaining to studded tires.

Location	**Year(s)**	**Economic Analyses**			**Studded Tire Policy**		
		Type of Study[1]	**Economic Analysis Performed**	**Economics Favorable to Studded Tires**	**Studded Tire Usage**	**Other**	**Motivating Factor for Policy**
United States							
Alaska	None				Restricted		Pavement wear
Michigan	1978	A	No		Restricted		Pavement wear
Minnesota	1970, 1971, 1978	A, B	Yes	No	Prohibited		Pavement wear
Oregon	None				Restricted	Lightweight studs only	Pavement wear
Washington	None				Restricted	Lightweight studs only	Pavement wear
Canada							
Ontario	1970, 1972	A, B	Yes	No	Prohibited		Pavement wear
Estonia	1999	A	Yes	Yes	Restricted		Pavement wear
Finland	1995, 1999	A	Yes	Yes	Restricted	Lightweight studs only	Pavement wear
Iceland	1998	A	No		Restricted		
Norway	1994-1998, 2001	A	Yes	Yes	Restricted	Lightweight studs only	Pavement wear and air pollution
Sweden	1981, 1992, 1995, 1997	A	Yes	Yes	Restricted	Lightweight studs only	Pavement wear
Japan	1997, 1998, 2002	B	Yes	Yes	Prohibited		Air pollution

[1] A: Study of the effects of studded tires on the accident rate of cars using them.
B: Study of the effects of laws prohibiting the use of studded tires.

6. Pavement Wear

6.1 Goals and Objectives

The purpose of this section is to provide a review and summary of published literature on the subject of pavement wear and its economic effects. The objectives are as follows:

- Identify the significance of pavement wear and associated costs related to road maintenance and remediation.
- Investigate means to reduce pavement wear.

6.2 Significance of Pavement Wear

According to Barter and Johnson (1996, 1997) Alaska has, historically, spent $5 million annually to repair stud-related pavement damage. From 3 to 6% of vehicles use the studs during summer that causes an estimated 20% of pavement wear. These vehicles are responsible for $1 million annually in pavement rehabilitation costs. These calculations are based on Alaskan wear rate average of 3.3 mm (0.13 in) or 22 tons of lost road materials per million studded tire passes. In the other words, 250,000 cars on four conventional studded tires driving one mile each wears enough pavement to fill a large dump truck per lane. Barter and Johnson state that while the problem is severe, the situation in "Scandinavia" was at least as serious when those countries began to research and address the problem of studded tire related pavement wear. They further state that currently heavily trafficked 4 to 5 years old roads in Scandinavia show pavement wear comparable to heavily trafficked Alaskan roads after just one year.

Unhola (1997) reports that in Finland a car with four studded tires driving 100km at 100 km/h wore 11 kg of pavement material in the 1960s, and only 2.5 kg in the 1990s. The current wear is only 22% of the wear in the 1960s.

According to Lampinen (1993), the reduction in pavement rutting in Finland is an end result of an effective pavement management system, stud regulation, reduced winter speeds and use of high quality aggregate. The pavement damage was estimated to be $45 - $100 in 1980 and $35 - $50 million in 1990. Lampinen estimates that about 70 – 80 % of the pavement rutting in Finland is due to wear by studded tires.

Jacobson (1997) reports that the wear in Swedish pavements was 100 g/vehicle-km in 1975, whereas in 1995 it was only 20 g/vehicle-km. Gustafson (1997) reports that in the winter of 1988/1989, 450,000 tons of pavement material had disappeared from Swedish pavements costing the Swedes about SEK 300 (about $35 million). The total wear in the winter of 1994/1995 was reduced down to 300,000 tons per winter, which costs Sweden about SEK 200 million (about $23 million). Öberg (1997) reports these values, too, and states that additional annual costs resulting from wear on road markings and dirt spray on road signs has decreased from SEK 35-70 ($4 - 8) to SEK 20-35 ($2 - 4) million. Jacobson and Hornwall (1999) estimated that 60-90% of pavement rutting is due to studded tires on heavily trafficked roads. This value may decrease due to the reduced wear from studs. According to the Swedish Road and Transport Research Institute's (VTI) Road Simulator testing, the lightweight studs (1.0g) result in about half as much wear as tires with heavier steel studs (1.8g) (Jacobson and Wågberg 1998).

The Swedish government currently mandates the use of studded tires during the winter months in slippery conditions (Öberg et al. 2002). However, even with the increased studded tire usage, the pavement wear has decreased significantly (Jacobson and Hornwall 1999).

According to Løberg (1997), on 63,000 km of paved Norwegian roads, 300,000 tons of pavement material is worn annually by studs. If the rut depth is more than 25 mm for more than 10% of a road section, it will be repaved according to the maintenance rules. In the urban areas with speed limits less than 60 km/h the rut depth shall never exceed 35 mm.

Brunette and Lundy (1997) report that the Oregon Department of Transportation estimated the pavement damage in 1974 as $1.1 million. This amount has significantly increased with the studded tire usage more than doubling from 1974 to 1994. The estimation of the total annual damage in 1994 for the state network was $37 million and for the whole road network $70 million. The pavement life expectancy for flexible pavements was 14 years but has decreased due to the wear of studded tires, as a 19 mm rut triggers pavement rehabilitation. With 120,000 annual daily traffic (ADT), a 19 mm rut is developed in less than 10 years (Brunette and Lundy 1997).

More recent research by Malik (2000) gives the following findings regarding the studded tire wear induced damage in Oregon:

- The mitigation costs of total pavement damage in 1995 were about $30 million for the state highway system and almost $20 million for county and city roads.
- Estimated effective pavement damage, that is damage sufficient to reduce the useful pavement life, caused by 1995 studded tire traffic will cost over $10 million for the state highway system.
- Actual expenditures for repairing studded tire damage for 11 years are projected to total about $103million by 2005 for the state highway system.
- Increased use of lightweight studs may reduce annual expenditures by as much as one-half, $52 million, and as little as one-third, $34 million.

The state of Minnesota has banned the use of studded tires and their decision is based on the research conducted in the 1970 by the Minnesota Department of Highways (1970). During the study, 40% of the passenger cars were using studded tires mostly on the rear wheels only. The average measured rut depths for asphalt pavements varied from 6.1 to 6.6 mm (0.24 to 0.26 in) per millions of studded tire passes for regular and high type asphalt concrete mixtures, respectively and 5.1 mm (0.20 in) for concrete pavements.

On the basis of the cited literature, it can be concluded that the pavement damage due to the wear by studded tires is significant, and causes millions of dollars annually to the governments and consequently taxpayers. Figure 6.1 gives an example of rutting formed mainly by studded tires.

Figure 6.1. Pavement rutting in Anchorage, Alaska (Photo: Stan Porhola)

6.3 Recent Pavement Wear Research in Nordic Countries and U.S.

The following sections summarize the factors affecting pavement wear and their test methods. Finland, Sweden and Norway have conducted independent research and have also cooperated in their efforts. Each of these countries reports that great progress has been made in significantly reducing pavement wear while at the same time increasing the beneficial properties of studded tires (Unhola, 1997)

6.3.1 Finland

Lampinen (1993) collected temperatures and precipitations and measured rut depths annually between 1982 and 1988 for 8,000 to 10,000 km for roads in Finland. He investigated factors affecting rutting and determined their relative significance. He also investigated the economical effects of rutting and modeled the rutting phenomenon.

Lampinen concluded that rutting is caused mainly by wear due to studded tires (70-80%), initial rutting of freshly placed pavement (10-20%) and plastic deformation due to heavy vehicles. In general, one heavy vehicle causes as much rutting as 3 to 5 passenger cars with studded tires. From 90 to 95% of cars and less than 50% of heavy vehicles use studded tires from December to February. Based on his findings, Lampinen concluded that it is possible to reduce rutting by regulating the studded tires and their usage.

The rutting of Finnish roads has been decreasing in this time period (1982 – 1988) evenly and the magnitude of the difference is significant. In 1982 the average rut depth was 9.5 mm where as in 1988 it was only 5.9 mm. Reasons for the decrement were an increase in paving projects and an effective pavement management system that directed the new overlays to road sections with deepest ruts. The average annual rutting (increase in cross sectional area) was measured to be 487 mm^2 per 1000 vehicles AADT. The average annual growth in rut depth is 0.36 mm per 1000 vehicles AADT. One car wears an average 24 g/km of the pavement and one stud impact removes 100 micro grams of pavement. Total annual cost is estimated to be 140 million FIM ($840 million).

Based on the test results from test roads and laboratory tests, the rutting is significantly affected by the stud type (Lampinen 1993).The wear is caused by the stud impact and abrasion caused by scratching when the stud leaves the pavement surface. The impact energy is dependent on the stud mass and vertical speed. The vertical speed is about 10 to 15% of the vehicle speed and depends on the tire type and the stud protrusion. The abrasion is affected by the stud's impact force that depends on the stud protrusion and structure. Abrasion is also affected by the vehicle speed and driving, i.e. straight or curved section, acceleration and deceleration.

The stud technology research and development has concentrated on the stud mass protrusion and stud force (Lampinen 1993). One of the original analyses most often referenced (e.g. Unhola 1997, Saarela 1993, Lampinen 1993, Kurki 1998) was conducted by Sistonen and Alkio (1986). They installed a metal frame into an asphalt concrete pavement. The frame had a plywood mold containing a total of 44 cylindrical rock cores: 22 granite cores and 22 quarz-feldspar cores. The cores were not able to move as a passenger car with a studded tire drove across them 100 times from each direction (total of 200 passes). The studded tire was installed at the front left wheel of the front propelled car. The other tires were summer tires. The rock samples were wet and the temperature varied between 4 to 8°C. The reported wear is the total loss in weight converted to volume (cm^3) for fair comparison of the different aggregates. The test was repeated at 100 km/h for three stud masses, 1.0, 2.3 and 4.1 g. Another set of tests was conducted using a 2.3 g stud at different vehicle speeds, 60, 80, 100 and 120 km/h. Figure 6.2 shows the effect of the mass on the wear. The lighter the stud, the smaller the wear. The effect of the aggregate type on the wear was found to be significant. The effect of the vehicle speed on the wear is given in Figure 6.3. The measured protrusions and stud forces were close to each other and did not seem to have significant effect on wear after the affect of aggregate type, stud mass and velocity were considered. (Sistonen and Alkio 1986).

Unhola (1995 and 1997b) continued Sistonen's and Alkio's work with a similar test setup, the "run-over method." He determined in a round robin study (Unhola 1997) that the run-over test method is accurate to determine pavement wear with different factors relating to tire or stud technology and different materials. The test parameters of the study included four tire types, two stud types, granite aggregate, and 400 total passes at 100 km/h on dry surface. The new tires were driven 400 km on dry asphalt pavement before the test. Then the protrusions and stud forces were measured. The stud force was measured in the laboratory with a special gauge. A loading plate with a hole for the stud is pressed against the tire with a standard static pressure. The plate is attached to a frame with a load cell. The stud presses a shaft connected to the load cell and the stud force is measured after 10 s from applying the load (Unhola 1996).

Unhola's test results show (1995 and 1997) that the stud mass and aggregate type dominate the pavement wear and there is no constant evidence that the protrusion or stud force have significant effect on pavement wear. The studies were conducted at 100 km/h.

The increasing maximum aggregate size and the increasing amount of aggregate greater than 8 mm, improves the pavement's resistance to wear significantly. The specific area of the aggregates should be as small as possible. (Lampinen 1993)

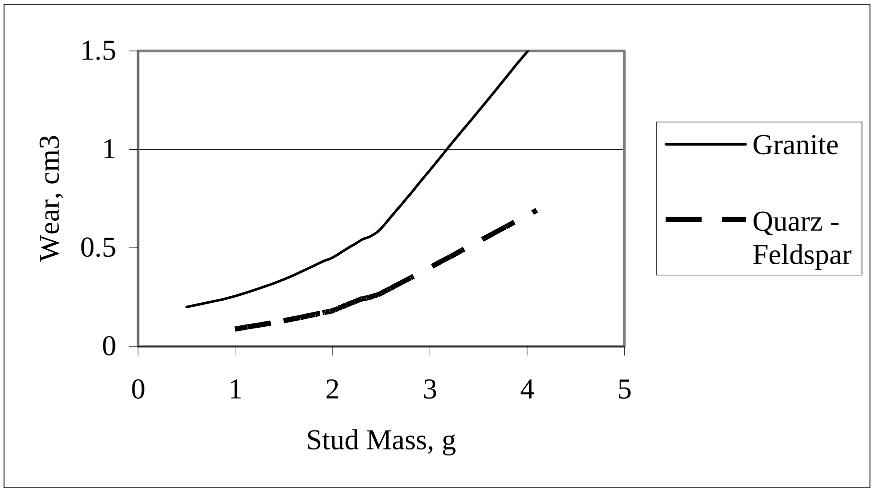

Figure 6.2. Effect of stud mass on pavement wear at vehicle speed 100km/h (Sistonen and Alkio 1986)

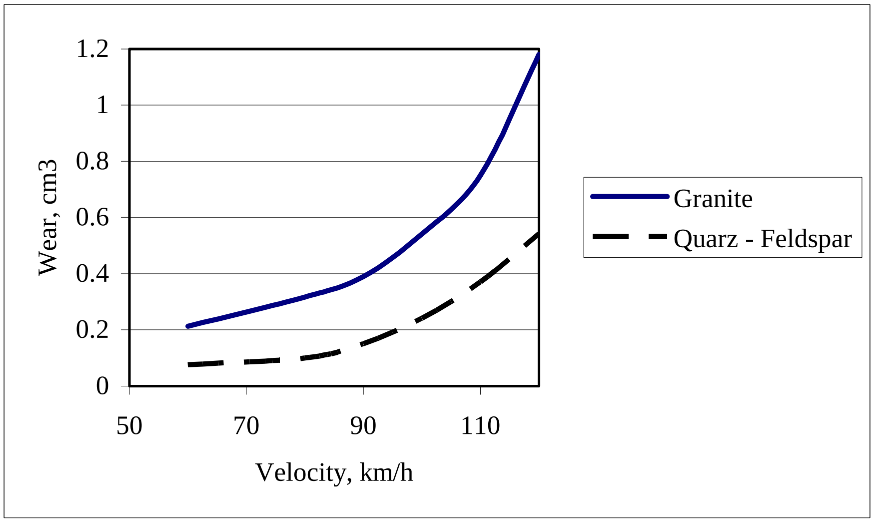

Figure 6.3. Effect of traffic speed on pavement wear with 2.3-g stud (Sistonen and Alkio 1986)

Lampinen (1993) analyzed the weather effects on rutting from his extensive field data from Finnish pavements from 1982 to 1988. The rutting increases with decreasing temperature below

0°C and with wet pavement surface when compared to dry surface. The wet surface affects rutting more than cold temperatures.

Rutting can be modeled with two methods: rut depth method and rut growth method (Lampinen 1993). The rut depth method models the rut depth in a given year. It does not consider the initial rutting or the weather history, because the pavements have different ages and histories. Many of the past researches have used the rut depth method. Lampinen uses the rut growth method that gives the change in the rutting for a time period. It accounts for weather data if the period is short, and the initial rutting can be eliminated. The model shows that the rut depth is greater on the left wheel path than on the right wheel path. Lampinen concudes that the left wheels of all vehicles travel at the same track, whereas the right wheels do not due to the different axle widths. The best models are given in Equations 6.1 to 6.3.

$$\text{Depth of left rut (mm/1000 veh/year)} = 10^{-7.33}\Sigma AADTc^{1.01}R^{0.61}V^{1.73}P^{-0.19} \qquad \text{Equation 6.1}$$

$$\text{Depth of right rut (mm/1000 veh/year)} = 10^{-5.41}\Sigma AADTc^{1.07}R^{0.33}V^{0.81}P^{-0.37} \qquad \text{Equation 6.2}$$

$$\text{Cross sectional area (mm}^2\text{/1000 veh/year)} = 10^{-2.75}\Sigma AADTc^{1.02}R^{0.53}V^{1.02}P^{-0.24} \qquad \text{Equation 6.3}$$

where ΣAADTc = total amount of passenger car traffic for the time period (veh),
R = percentage of heavy vehicles of the total traffic for the time period,
V = average vehicle velocity (km/h), and
P is the width of the shoulder (m).

Lampinen (1993) suggests that the rutting of pavements could be reduced by decreasing the amount of stud strikes, i.e. reducing the amount of vehicles using studded tires and the amount of studs per tire, reducing the initial rutting by focusing on the paving techniques, developing studs that wear pavements less without reduction in friction and developing pavement types that are have lower rutting tendency.

The Finnish Government funded an extensive study on asphalt pavements, ASTO, in 1987 to 1992. Saarela (1993) edited the final report from the work of teams of researchers in several research institutes and the Finnish national oil company. The final report titled as “Design of Asphalt Pavements” states that the rutting resistance is the most important pavement factor due to the wearing of pavements by studded tires. In addition to pavement factors, the most important factors are the amount of traffic and presence of water on the pavement surface. In some special cases, the vehicle velocity and cold climate needs to be considered in the design.

The wear of pavement by studs is tested in the laboratory by the “SRK” method, where three miniature studded tires are rotating around a wet 100-mm Marshall mix design sample at 5°C for two hours. The volume loss in the test in cm^3 is the test result, an abrasion value (European Standard 2000).

The service life of a pavement can be determined with the SRK-value, if the amount of traffic is known. The most important pavement factor in regards to wear is the quality of the selected aggregate (Figure 6.4). For example, if good quality aggregate would yield a service life of about 5 years, poor quality aggregate would yield a service life of only 2 years, all other factors remaining the same.

Selecting aggregate according to its mineral composition is not recommended, for its suitability as a pavement material varies greatly within the minerals. The aggregate needs to be selected on the basis of laboratory testing. Several test methods exist, but the Ball Mill Test, renamed in the U.S. as the Nordic Abrasion Test, remains the main aggregate test currently used in Finland (Alkio et al. 2001). About 1000-g aggregate sample is rotated in a standard mill with 7 kg of 15-mm diameter steel balls and 2 liters of water for one hour at 90 RPM. The particle size of the aggregate tested is from 11.2 mm to 16.0 mm. The ball mill value is defined as the particle size percentage that is finer than 2 mm after the test. The smaller the value is, the better the wearing resistance. Figure 6.5 shows the relationship between the Nordic Abrasion Test Value and the wear in the SRK-test.

Current guidelines set forth by the Finnish Road Administration (Finnra) for the Nordic Abrasion Test are given in Tables 6.1 and 6.2 (Alkio et al. 2001). Aggregates are divided in four classes depending on their soundness. The soundest aggregates are recommended for roads with the AADT greater than 5,000 at the areas with speed limit greater than 60 km/h and 10,000 at the areas with speed limit smaller than 60 km/h.

Another aggregate material test, Point Load Test, is commonly used in Finland (Saarela 1993). A core sample of a rock is fractured between two pyramid tips with 60° angle and radius of 5 mm. The tips are made of metal with Vickers number > 1200. The Point Loading Index, PLI, is obtained with Equation 6.4. There is a correlation between the rutting of the ASTO test roads and the point bearing index. This test is part of the Finnish Asphalt Pavement Specifications.

$$PLI = (D/50)^{0.45} F/D \qquad \text{Equation 6.4}$$

where, PLI = point loading index (MPa),
D = core diameter, and
F = fracture force (N).

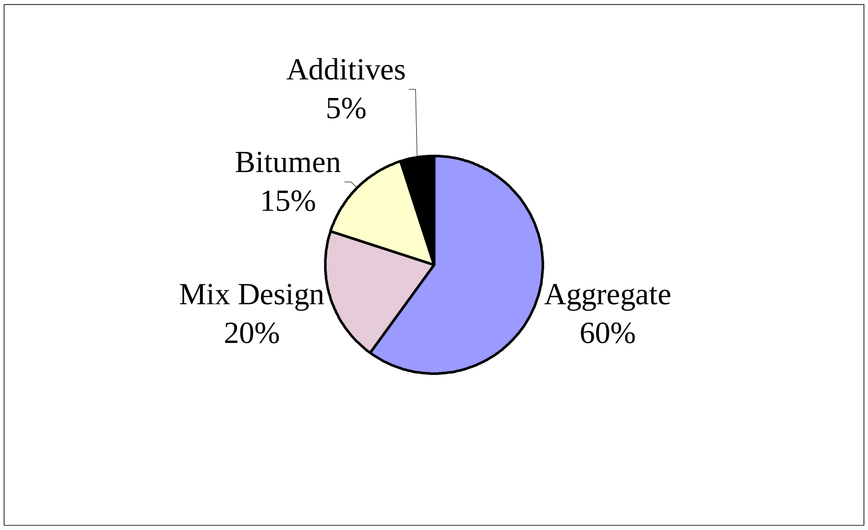

Figure 6.4. Relative importance of pavement factors to wearing by studded tires (Saarela 1993)

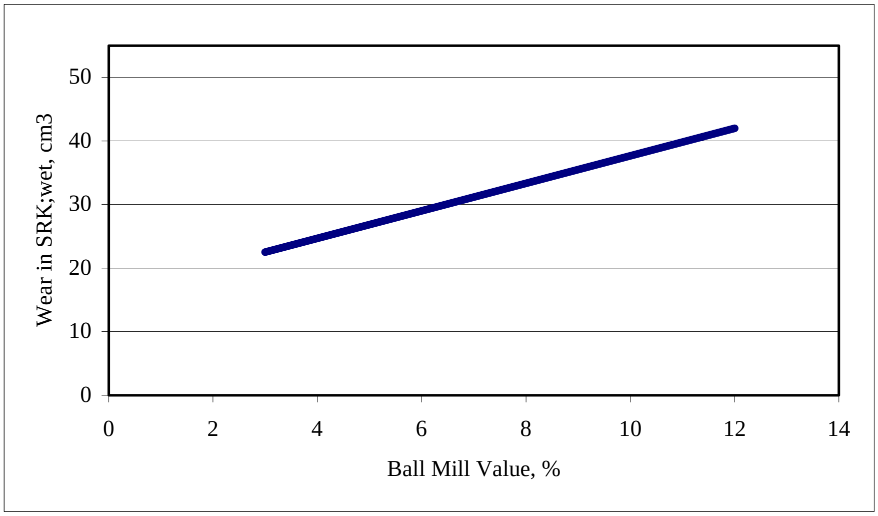

Figure 6.5. Relationship between Ball Mill Value and wear in SRK test (Saarela 1993)

Table 6.1. Quality classification for pavement aggregates (Alkio et al. 2001)

Class	I	II	III	IV
Ball Mill Value (Nordic Abrasion Value)	≤ 7.0	≤ 10.0	≤ 14.0	≤ 19.0

Table 6.2. Selection of the aggregate quality (Alkio et al. 2001)

Class	I	II	III	IV
AADT range for roads with speed limit > 60 km/h	> 5,000	2,500-5,000	1,500-2,500	500-1,500
AADT range for roads with speed limit < 60 km/h	> 10,000	5,000-10,000	2,500-5,000	500-2,500

The mix design is the next significant pavement factor after the aggregate. According to the ASTO test roads, the dense graded pavement mixture with 20 mm maximum aggregate size (AB20) wore 10% faster than Stone Mastic Asphalt (SMA) mixture with 16 mm maximum aggregate size (SMA16). Therefore, Finnra recommends the use of SMA for roads with high traffic. The mix design guidelines for AB16 and SMA16 are given in Table 6.3 and Figure 6.6 (Finnish Asphalt Specifications 2000) Figure 6.7 gives the relationship between the percentage of aggregate that is larger than 8 mm and wear in the SRK test. The more large size aggregate the mixture has, the smaller the wear.

Table 6.3. Mix design guidelines for AB16 and SMA16 (Finnish Asphalt Specifications 2000)

	AB16	SMA16
Min. amount of crushed rock, %	50-70	85
Asphalt Cement	From Pen 35/50 to Pen 160/220, or Polymer modified binders KB65 or KB75	From Pen 35/50 to Pen 100/150, or Polymer modified binders KB65 or KB75
Asphalt content, weight %	5 to 6	6 to 7
Stabilizer content, weight %	NA	0.3 to 0.5
Max. voids, %	5	5

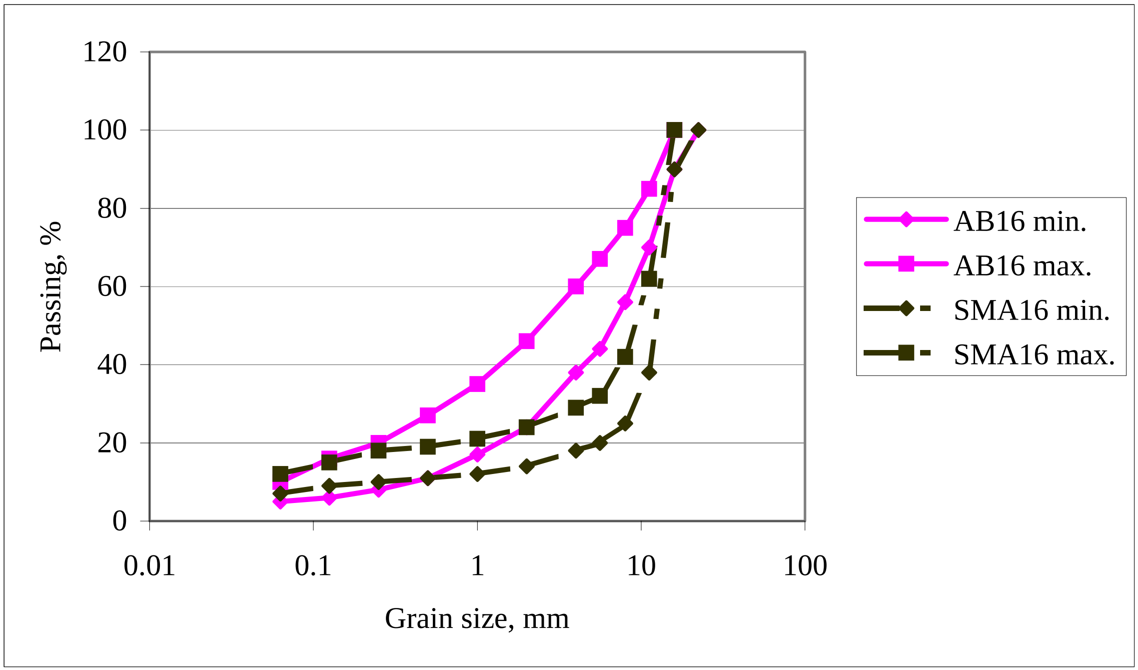

Figure 6.6. Grain size distribution for AB20 and SMA16 (Finnish Asphalt Specifications 1995)

The selection of asphalt cement does not affect the wear significantly. The wear resistance is increased slightly if hard asphalt cement is used instead of a soft asphalt cement. The additives do not affect the amount of wear directly. They are used typically to improve other properties. However, the wear resistance can be improved with additives in some cases, i.e. the aggregate gradation is modified to include more large size aggregates than in typical dense graded asphalt, which is only possible by using additives. These additives include fibers, natural asphalt and polymers. Polymers improve the wear resistance directly in extremely cold winters. (Saarela 1993)

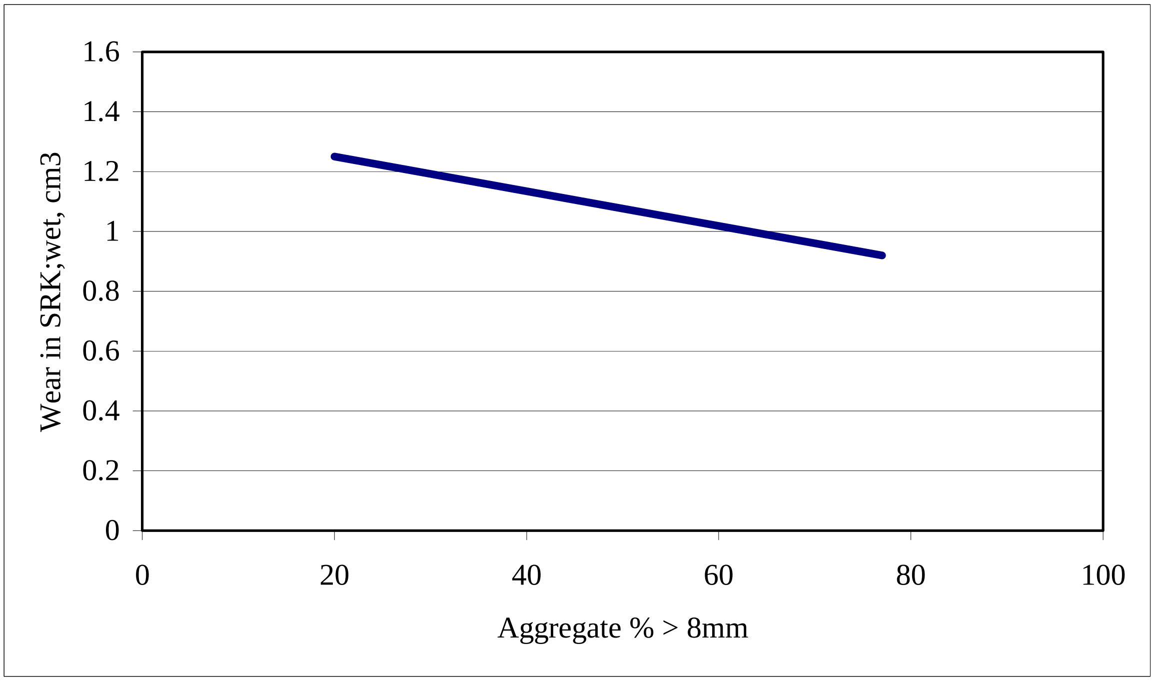

Figure 6.7. Affect of percentage of > 8mm aggregate on wear in SRK test (Saarela 1993)

Kurki (1998) summarizes the results from 14 ASTO test roads. These test roads include pavement sections with varying properties, such as aggregate types, aggregate gradations, asphalt cements, asphalt contents, use of anti-strip additives, fillers, fibers, Gilsonite and natural asphalt. Each test road had a reference section in the beginning and the end. The reference mix (AB20/IV) had a maximum nominal aggregate size of 20 mm and was dense graded as the AB20 mix given in Figure 6.6. The aggregate was grano-diorite and the binder was a straight run Arabian Heavy asphalt with 120 penetration grade. The profile of the pavement was measured with a profilometer. Rut depth was then determined from the surface profile. The wear is given as an area (cm^2) or as a wear ratio. The wear ratio is defined as the wear of a test section divided by the average wear of the two reference sections. The wear could also be given as a rut depth, but according to the test results, the accuracy is not as good as the wear area or the wear ratio.

The analysis of the test results indicate that the wear of these pavements is reduced 20% from the average of three winters of 90-91, 91-92 and 92-93 to winter 96-97. This is purely accounted for by the use of lightweight studs. In 1990 no lightweight studs were used, as in 1997 43% of vehicles used lightweight studs. The wear in cold winters was about 10% smaller when compared to warm winters. The wear was also smaller in interior Finland when compared to coastal Finland. The climate in the interior Finland is colder and dryer than in coastal Finland.

The relationship between the wear area and rut depth depended on the road width. Models for the rut depth as a function of wear area with different road widths are given in Equations 6.5 to 6.8.

Rut depth (mm) = 0.071*area (cm^2) – 3 width < 8.5 m Equation 6.5
Rut depth (mm) = 0.089*area (cm^2) – 9 10 m > width > 8.5 m Equation 6.6
Rut depth (mm) = 0.077*area (cm^2) – 8 width > 12 m Equation 6.7

$$\text{Rut depth (mm)} = 0.071 \cdot \text{area (cm}^2) - 3 \qquad \text{multi lane road (right lane)} \qquad \text{Equation 6.8}$$

The rut depths on the test roads correlated well with the SRK-test, from which Kurki (1998) concludes that aggregate affects the rutting significantly. The relationship between the rut depth and the SRK-value is given in Equation 6.9.

$$\text{Rut depth (mm)} = 3.31 \cdot SRK + 8.14 \ (R = 0.80) \qquad \text{Equation 6.9}$$

Equation 6.9 was then used to convert the rut depth to SRK value. Aggregate material tests were then compared to the converted test road SRK-values. It was shown again that the Ball Mill value and the Point Load Index correlated well with the test road wear, whereas Los Angeles abrasion test did not. (Kurki 1998)

The effect of asphalt cement on pavement wear is much smaller than that of aggregate. This makes it difficult to determine the effect of binder to wear. It was concluded however, that polymer modified asphalt cement had about 10% better wearing resistance than non-modified asphalt cements. (Kurki 1998)

The use of fillers did not affect the wear resistance. The use of anti-strip additives improved the wear resistance of certain aggregates. Kurki (1998) recommends that the use of anti-strip additive needs to be determined as a part of the mix design.

Kurki (1998) developed a model to predict the SRK-value with material properties. He reports that the model correlated well with the test road wear measurements. The model is given in Equation 6.10.

$$SRK = G \cdot B \cdot (1.15 \cdot BM - 1.25 \cdot PLI + 33.01) \qquad \text{Equation 6.10}$$

where BM is the Ball Mill value, PLI is the Point Load Index, G is a correction coefficient for aggregate gradation (Equation 6.11) and B is a correction coefficient for asphalt cement (B = 0.9 for polymer-modified asphalts and 1 for all others).

$$M = 0.0069 \cdot A + 0.004 \cdot B + 0.496 \qquad \text{Equation 6.11}$$

where A = passing % of 8-mm sieve, and B = passing % of 16-mm sieve.

The effect of traffic volume, speed or climate could not be verified with the test road results due to the quantity of the test roads and road conditions (Kurki 1998).

Leppänen (1997) has studied the effects of winter maintenance policy on pavement wear. She reports that the simultaneous use of salt and studded tires causes accelerates pavement wear. This is due to the fact that the pavement surface remains wet longer with salt than without salt, and as a consequence, wet pavement wears faster than dry pavement. Use of salt as a skid prevention method also causes corrosion related problems and has a negative impact on groundwater quality. However, according to $3.5 million research program on winter maintenance policy of Finnish roads, simultaneous use of present lightweight studs and salt on main roads is still worthwhile, as the accident costs become the most important economic factor.

6.3.2 Sweden

Jacobson (1997) reports that the wear in Swedish pavements was 100 g/vehicle-km in 1975, whereas in 1995 it was only 20 g/vehicle-km. Based on the development and research, a reduction of 20 g/vehicle-km accounted for more abrasion resistant pavement, 20 g/vehicle-km for use of SMA mixes, 10 g/vehicle-km for adapting the Ball Mill test for aggregate testing, and 30 g/vehicle-km for regulating the maximum stud mass. The total effect of selecting better aggregate of the wear was 38%. The aggregate factors affecting the wear were the quality and percentage of coarse aggregate and maximum aggregate size. Other factors affecting pavement wear include compaction of the pavement, traffic volume and amount of studs per tire, traffic speed, road width, presence of water on the road surface, stud type, protrusion and stud force. Wet wear is significantly greater than dry wear, but is dependent on the aggregate type. Lightweight studs (0.7 to 1.0 g) reduce the pavement wear to half when compared to 1.8 g steel studs (Jacobson 1997; Jacobson and Wågberg 1998).

Gustafson (1997) agrees that the ideal pavement as refers to wear must contain the largest proportion of coarse and wear-resistant aggregate possible, bound together with strong mastic. However, the maximum aggregate size should be limited to 16 mm, as larger aggregates increase the rolling resistance and noise to unacceptable levels. The current Swedish National Road Administration’s strategy is to use SMA mixes with good quality aggregate for highways with high traffic volumes and speed limits of 90 to 110 km/h.

In Gustafson’s 1997 paper he refers to Jacobson’s work and states that the annual wear on current SMA pavements with high quality aggregate is 0.2 to 2 mm. Slightly poorer aggregate results in average annual wear of 3 to 4 mm. For high traffic volumes, wear from studded tires causes about 50 to 70% of the total rutting. Gustafson also refers to Carlsson’s research that shows that the wear is about 6 g/vehicle-km for good SMA type mixes and 37 g/vehicle-km for ordinary dense graded asphalt concrete with local aggregates. Gustafson (1997) concludes that the deep ruts, more a rule than exception in the late 1980s and early 1990s are mainly gone due to wear resistant pavements, less aggressive studs and stud usage regulation.

The pavement wear is considered in Swedish pavement performance specifications (Safwat and Stjernberg 2003). The specified test that is used to test asphalt aggregate mixtures in laboratory is the Prall test. The required Prall-value is dependent on the adjusted AADT and is given in Table 6.4. The AADT is adjusted using coefficients for usage rate of studded tires, traffic speed, lateral distribution of passenger cars and winter maintenance policy.

Table 6.4. Swedish specifications for Prall-value with traffic (Safwat and Stjernberg 2003)

Adjusted AADT	Prall-value, cm^3
> 7,000	< 25
3,500- 7,000	25-32
1,500-3,500	33-39
500-1,500	40-50
< 500	NA

In the Prall test, a cylindrical specimen (Figure 6.8) having a diameter of 100 ± 1 mm and a height of 30 ± 1 mm is conditioned at 5 ± 2°C and then hammered for 15 minutes with forty bouncing steel spheres at 950 rpm. Water is circulated continuously at 5°C, which rinses the worn pavement particles out of the testing chamber. The loss of volume in cm^3 is the Prall or abrasion value. It is defined as the ratio of the mass difference of surface dry water stored specimens weighted in the air before and after the test to the bulk density of the specimen. (European Standard 2000)

Figure 6.8. A cylindrical asphalt mixture sample after Prall testing.

According to the studies by Jacobson and Viman (1998), there is a good relationship between the Prall-values and wear measured either in the VTI Road Simulator or in the field for most of the studied 19 mixture types (correlation coefficient r = 0.87 – 0.96). For the mixtures with poor wear resistance, the correlation is not quite as good. The Prall test gives slightly better values than the Road Simulator in most cases. In practice however, the difference is not significant, as the method is used to select the best possible materials and not the worst. When the wear resistance becomes critical (medium to high volume roads), a wearing course with good wear resistance (Prall value < 40) is often selected, and the Prall method works fine within this interval.

Jacobson and Hornwall (1999) studied studded tire related rutting on five test roads with wearing courses of SMA or porous asphalt concrete, and six control sections with SMA or dense graded asphalt concrete. The rut profiles were measured using a laser profilometer. Continuous readings about the surface distress were measured with a Road Surface Tester (RST) vehicle. The pavements were monitored for eight years from 1990 to 1998. The test results show that the pavement wear due to studded tires has decreased considerably during the 1990s. Jacobson and Hornwall (1999) explain this with new wear resistant pavements, the use of high quality mineral aggregates and the introduction of less damaging studded tires. The SPS values from the test roads are in the range of 2-4 for the SMA mixtures with high quality aggregate. The quality of the aggregate has the greatest influence in the wear resistance followed by the stone content and lightweight studs. The binder type, i.e. modified or conventional, did not seem to affect the wear resistance (Jacobson and Hornwall 1999).

The pavement with high wear resistance, i.e. SMA and high quality aggregate mixtures, did not deteriorate otherwise with time either. The survey included mild and cold winters. The porous pavements demonstrated comparatively good wear resistance and durability at traffic speeds up to 70 km/h. At speed 110 km/h the SMA mixture may perform better. (Jacobson and Hornwall 1999)

Wågberg (1985) researched the porous pavements, too. He reports that pervious macadam pavements are used to minimize the risk of accidents caused by hydroplaning on heavily trafficked roads connected with the occurrence of ruts. The first experiments with pervious macadam were carried out during the 1940s, but with no success. Currently, however, the development of better construction techniques and effective adhesion agents have made it possible to construct open graded pavements that will fulfill other pavement performance requirements, such as riding quality and long service life.

Jacobson and Wågberg (1998) developed prediction models for rut formation caused by studded tires. The models are based on ten years of work at the VTI (the Swedish National Road and Transport Research Institute) in the 1990s. Their models consist of three parts:

- A model that calculates the magnitude of wear per number of vehicles with studded tires.
- A model that calculates how the wear is distributed across the width of the driving lane (wear profile).
- A model that calculates annual cost based on materials used and estimated service life.

The magnitude of wear was found to be affected by Nordic Abrasion Test (Ball mill value), aggregate maximum size, gradation and air void ratio. Several models were developed, out of which two are given in Equations 6.12 and 6.13.

$$S_d = 2.179 + KV*0.167 – HALT4*0.047 + HM*0.287\ (R^2 = 0.84) \qquad \text{Equation 6.12}$$

$$S_s = 1.547 + KV*0.143 – MS*0.087\ (R^2 = 0.71) \qquad \text{Equation 6.13}$$

where S_d and S_s = relative wear for dense graded and SMA mixtures, respectively,
KV = Nordic Abrasion value,
HALT4 = aggregate content > 4 mm,
HM = air void ratio from Marshall mix design,
MS = maximum aggregate size.

According to Jacobson and Wågberg (1998) the distribution of wear across the width of the traffic lane provides very important information to use the model to calculate the service life of a pavement, as it is the rut depth that determines when maintenance has to be carried out. The distribution model developed is based on the measured lateral distribution of traffic (passenger vehicles) and is close to the normal distribution. On roads with wide lanes and roads with shoulders, the standard deviation of the transverse distribution is close to 0.45m, whereas on the roads with narrow lanes and on multilane expressways and highways the standard deviation is close to 0.25 m. On roads with extremely high traffic volume the standard deviation approaches 0.20 m.

The two models were combined into a computerized version that predicts the rut depth, service life and annual cost. The input data includes:

- Aggregate properties: aggregate content > 4 mm (%), maximum nominal aggregate size (mm), and the Ball Mill value for the large aggregate fraction.
- Traffic and road characteristics: six standard cross sections with respective standard deviations (mm), traffic speed (km/h) with associated wear factors from 0.65 for 50 km/h up to 1.5 for 110 km/h, average annual daily traffic (vehicles/day), number of winter days when use of studded tires is more than 5% (normally 180 days), studded tire share (%), share of lightweight studs with associated wear factor starting at 1.4 for no lightweight studs down to 0.75 for 100 lightweight studs, yes/no indicator for salting and deicing, service life (number of winters), allowable rut depth, estimated rut depth from other than studded tire use.
- Cost data: aggregate, asphalt cement, additives, production, mobilization, transportation, paving, possible other costs (monetary unit/m^2). The production cost is divided with service life to obtain annual cost. Interest is not considered, but could be added.

The output data from the models include abrasive wear profile, service life and annual cost. The model was validated with field data for 16 pavements for winter 1996-1997. The test roads were from 1 to 6 years old with varying type and quality wearing courses, road categories and speed limits. The validation shows that the model is reasonable. The fact that the old steel studs are still used in old tires before they are replaced with the mandated lightweight studs makes any validation very hard. (Jacobson and Wågberg 1998)

The background studies for the model included a large laboratory research program using the VTI's road simulator. The factors listed in Table 6.5 were studied and their significance to the pavement wear reported. Durability of the pavement materials is not reflected in the models.

Table 6.5. Factors studied in VTI's Road Simulator and their significance (other than traffic volume, stud usage, lateral traffic distribution, and surface conditions [wet/dry or snow covered], Jacobson and Wågberg 1998)

Materials	**Less**	**Sometimes great**	**Great**	**Very great**
Aggregate				
Quality				X
Coarse aggregate content				X
Nominal maximum size		X		
Mix design (dense or SMA)				X
Binder type	X			
Production				
Crushing procedure (elongation)		X		
Degree of compaction		X		
External factors				
Vehicle speed			X	
Climate	X			
Type of stud, stud force			X	

6.3.3 Norway

Løberg (1997) reports that the depth of the wheel tracks in Norway depends on the mix design and construction of the pavement, type of traffic, speed, climate, and the pavement parameters, the quality of the aggregate being the most important. The Norwegian highway administration measures the pavement rutting for their 63,000 km of paved road twice a year. The test result of these measurements is "specific resistance value" for each pavement section. The specific resistance value is the average weight in grams of pavement that a car with 4 studded tires wears off while traveling 1 km. The value relates to the quality of aggregate used.

The Norwegians regard the mechanical strength as the most important paving aggregate property. They measure the mechanical strength with three methods, impact value, abrasion value and the CEN Studded Tire Test (Nordic Abrasion Test), the abrasion value being the most important. It measures how many cubic centimeters are worn off the aggregate under given circumstances. Particularly, aggregates for highways with more than 3,000 AADT undergo this test. The laboratory tests are in accordance with the rutting on the roads. However, Løberg (1997) states that even the good aggregates will not make the pavement last long if the construction is not done properly.

6.3.4 Japan

Japan banned the use of studded tires in 1990 based on mainly the health impact of the worn material from the road. Therefore, it is important for the Japanese to keep their road surfaces clean from ice and compacted snow. Nishizawa et al. (1997) investigated the ice bonding effects of asphalt aggregate mixture containing rubber particles. They claim that ice or compacted snow on a pavement containing protruding rubber particles easily debonds and can be removed by traffic. Thus, paving with this kind of special mixture is considered to be an effective way to provide improved safety in wintertime. According to their questionnaire study results, the ice debonding can be expected in climates with an average minimum air temperature higher than –10°C (14°F) and a maximum depth of snow cover less than 200mm (7.9 in), or an average minimum air temperature higher than –5°C (23°F) and a maximum depth of snow cover less than 500 mm (19.7 in). Based on the laboratory and modeling results, the maximum snow depth on the pavement for debonding to occur is 40 mm (1.6 in).

6.3.5 North America

Recent studded tire research in the United States has been conducted in Alaska, Oregon and Washington. The research is based in a major part on the literature found from the Nordic Countries reported above. The following sections summarize the field results of these states.

Barter and Johnson (1996, 1997), or Johnson et al. (1996) have presented options for reducing stud-related pavement wear. They traveled to Norway, Sweden and Finland and collected the test results relating studded tire induced pavement wear. Based on the research in these Nordic Countries and their Alaskan experience, Barter and Johnson estimate that the use of lightweight studs (≤ 1.1 g) can reduce pavement wear by 50% compared with conventional studs (≥ 1.9 g). They state that the remaining pavement wear can be reduced an additional 30% with wear-resistant SMA using high quality aggregates.

The AKDOT&PF has also conducted other research since the work of Johnson and Barter. Scott Gartin has been working on a project "Development and Validation of Urban Rutting Models". Bruce Brunette has conducted studies about the use of hard aggregates and the use of Prall equipment on Alaskan mixtures. However, their work is not published yet to be referenced in this report.

Kavussi and Edgar (1997) report that the aggregates play a major role in wearing of Oregon pavements by studded tires. According to their findings, the LA Abrasion test does not correlate with the field rutting, whereas the Ball Mill testing (Nordic Abrasion Test) seems more reliable.

Brunette and Lundy (1997) measured the rut depths of Oregon pavements in 1995 and compared them to the values before the stud regulation in 1974. The wear has decreased to less than half of the value in 1974.

Malik (2000) studied pavement wear and costs of mitigating studded tire damage in Oregon. He found a wide range of wear rates for various sections of Portland Cement Concrete (PCC) and asphalt pavements. PCC is more resistant to rutting; its average wear rate is 0.236 mm (0.0093 in) per 100,000 studded tire passes. The wear rate of asphalt pavement is about 0.980 mm (0.0386in) per 100,000 studded tire passes. Within asphalt pavements, there was no obvious advantage of open-graded mixes over dense-graded mixes.

Malik's conclusions about the wear resistance of concrete roads agree with the findings of the Transportation Research Board (TRB 1975). The TRB collected test results from across the U.S. and show that asphalt concrete pavements wear from two to four times faster than concrete pavements.

The Minnesota Department of Highways (1970) reports that they did not find any significant improvements with different traditional asphalt aggregate or Portland Cement mixtures. In Washington State, however, the use of open graded asphalt concrete wearing courses was virtually eliminated because of accelerated wear due to studded tires (Angerinos et al. 1999). This type of a wearing course was used to enhance pavement friction and reduce splash and spray during wet weather. Its wear rate was reported to be 5.1 mm (0.2 in) per million studded tire passes in 1990s.

Angerinos et al. (1999) conclude that the change from 88 km/h (55mph) to 113 km/h (70 mph) on the rural Interstate Highways in Washington State has potentially increased pavement wear due to studded tires by a factor of two.

The Washington State Department of Transportation (WSDOT) uses a guideline that any pavement with rutting greater than 9 mm (1/3 in) requires rehabilitation to reduce hydroplaning accidents. About 8% of the pavements in 1998 did not meet the guideline representing 2,253 km (1,400 mi). The WSDOT recognizes that a major portion of this rutting and wear is due to studded tires based on the width of the wheel track. According to a survey conducted in 1996-1997, an average of 10% of vehicles use studded tires in Western Washington and an average of 32% in Eastern Washington (Angerinos et al. 1999).

Moh's hardness scale has been suggested to be used to demonstrate the damaging effect of studs on pavement aggregate. Its value as a tool to investigate pavement wear due to studded tires is evaluated as a part of this study. The findings are given in the following sections.

The Moh's scale is commonly used for field identification of minerals (Hurlbut and Klein 1977). Ten readily available minerals are ranked according to their hardness as shown in Table 6.6. Each mineral will scratch a mineral of lower rank. Hardness of other items is given a ranking on the scale. For example a fingernail is 2.5 and glass is 5.5. If a mineral can scratch glass its hardness is greater than 5.5.

Table 6.6 Moh's Hardness Scale

Hardness	Mineral	Hardness	Item
1	Talc		
2	Gypsum		
		2.5	Fingernail
3	Calcite	3.0-3.5	Coin
4	Fluorite		
5	Apatite		
		5.5	Glass
6	Orthoclase		
7	Quartz		
		7.5	Steel file
8	Topaz		
9	Corundum		
10	Diamond		

Relative hardness is simple to determine and very useful when used in combination with other physical and chemical characteristics to identify a mineral. However, the method has its weaknesses and is not useful for any engineering purposes for the following reasons:

- It is a qualitative not quantitative evaluation of hardness. The steps between each mineral on the scale are not equal; the difference between 9 and 10 are much greater than between 1 and 2.
- Many minerals in a crystal form have hardness characteristics that vary with the crystal face. In other words, different faces of the same crystal have significantly different hardness.
- Aggregate used for pavement is not a mineral but a rock and so its hardness is not easily evaluated. The most common mineral in the earth's crust is quartz. An average hardness for a good quality aggregate could be considered to be between 6 and 7.

Hardness can be measured using a sclerometer and calculated in several ways (Gordon England Co. 2003):

- Brinell Hardness Test: a 1.0-cm hardened steel ball is pressed into the material under a standard load for 5-10 seconds to allow plastic deformation. The spherical indentation is measured. Hardness is expressed as the load divided by the surface area of the indentation.
- Vicker Hardness Test: similar procedure to the Brinell Test but instead uses a square-based diamond pyramid tip with 136 degree angle. The diagonal of the square indentation is measured. May be a more accurate test because it is easier to measure the square than the circular indentation. Test generates a Vickers number (HV) for a sample. A plot of the Vickers number as it relates to the minerals of Moh's hardness scale is shown in Figure 6.9.
- Knoop Hardness Test: A micro-hardness test used to determine hardness of specific locations on non-homogeneous or very thin samples. Uses an elongated diamond pyramid tip as the indenter.

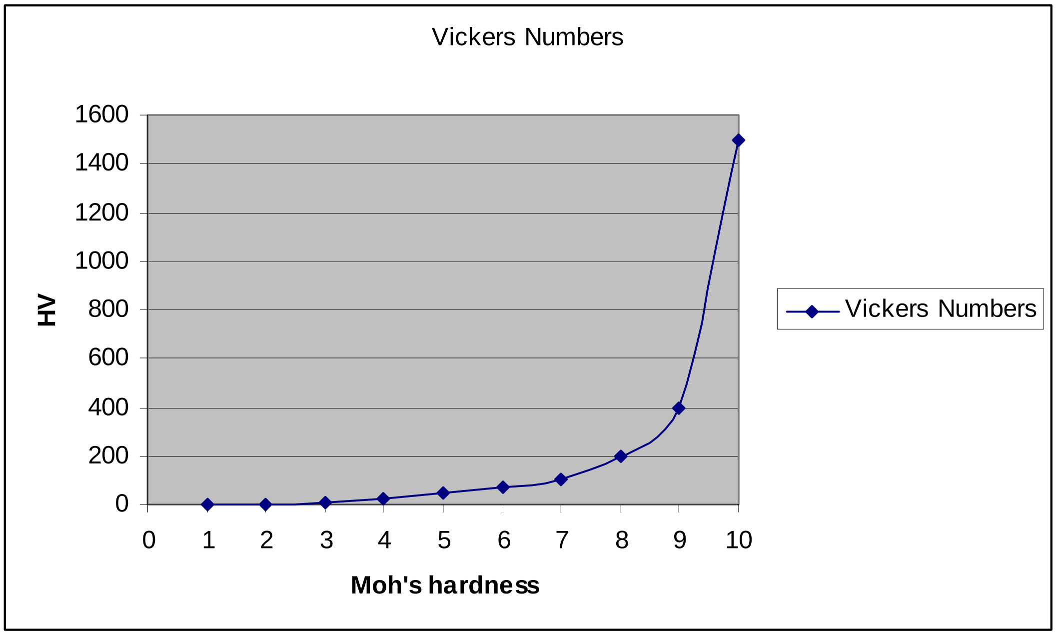

Figure 6.9. Relationship of Vickers number to Moh's hardness

For engineering purposes, the hardness difference between studs and aggregate can be roughly quantified. If carbide studs are considered to have a Vickers number of 400 and aggregate an average number of 85 as shown in Figure 6.9, the carbide studs are assumed to be 4.7 times harder than the aggregate.

There are other factors that are more difficult to quantify:

- Another important physical characteristic of a mineral or rock is its tenacity, that is, its ability to resist bending or breaking. Hardness is not an indicator of tenacity. Although diamond is many times harder than corundum it is much more fragile than corundum which is one of the toughest materials found in nature.

- The extent to which a rock or mineral is abraded is directly related to the force that is applied to the surface. For pavement aggregates this varies with vehicle size and velocity.

As a conclusion it can be said that the carbide studs are harder than aggregate. They will abrade the aggregate and the mastic between the coarse aggregates. However, it is not possible to determine using Moh's hardness how much an aggregate and thus a pavement will abrade. The use of the Nordic Abrasion Test or the Prall test is recommended to investigate the suitability of aggregates as pavement materials.

6.4 Means to Reduce Pavement Wear

As the research results described above state, the pavement wear is affected by factors relating to traffic, road geometry, pavement characteristics, environment and quality of construction. Some of these factors have larger effect than others, and the magnitude of the effect may be site specific. The following sections summarize the factors and their effect on pavement wear, and explain how to reduce the pavement wear.

6.4.1 Traffic

All literature reviewed report that the rutting is directly related to the traffic volume, the percentage of vehicles using studs, stud types and vehicle speed. Increasing traffic volumes, proportion of vehicles using studs and vehicle speed increase the amount of rutting.

To reduce pavement wear without risking the safety of travelers, the following measures are suggested:
- Reduce traffic volumes on highly trafficked roads by policy, e.g. transit, traffic channeling, etc.
- Regulate the use of stud types and frequency in the tire.
- Decrease winter speed limits.

6.4.2 Pavement Materials

Pavement materials and mixture types are reported to be one of the main factors affecting road wear by studded tires. Aggregate is stated to be the most important pavement factor. The abrasion resistance and the content of the coarse aggregates are the significant aggregate characteristics. Use of aggregates that perform well in the Nordic Abrasion test or the Prall test are recommended. The larger the coarse aggregate content, the smaller the wear. The adhesion of an aggregate with a specific asphalt cement and the need of anti-stripping agents has to be determined during the mix design.

The next most important pavement factor after aggregate is the mix design. The SMA mixtures are reported to be more wear resistant than dense graded asphalt mixtures.

The asphalt cement has significantly smaller effect on pavement wear than the aggregate and mix design, which has made it difficult to determine the specific effect of asphalt cement on rutting resistance. It has reported, that in some cases, the use of polymer-modified asphalts reduce pavement wear.

PCC pavements are found to have greater wear resistance than asphalt concrete pavements. However, they are not typically used in cold regions, such as Alaska, for frost-related reasons.

6.4.3 Environment

The rutting increases with decreasing temperature below 0°C and with wet pavement surface when compared to dry surface. The wet surface affects rutting more than cold temperatures. As deicing of the roads causes the road surface being wet for longer periods than without deicing, the whole winter maintenance policy needs to be considered keeping in mind all the socio-economic effects.

The most important factor to reduce the pavement wear is to enforce the usage of studded tires only when needed, during the winter months when pavements may be icy or have slick compacted snow.

6.4.4 Road Geometry

The wear by studded tires is reported to be higher where the vehicles are accelerating or decelerating. These areas include curves, uphills, downhills and intersections. The lane width affects the rut depth due to the channeling of the traffic. The narrower the lane, the deeper the rut.

Avoiding sharp curves, steep up and downhill grades, short accelerating and decelerating lanes and narrow lanes can reduce the rutting by studded tires.

Since water accelerates the wear by studded tires, drainage is an important factor in the cross section design. Use draining materials in the structural unbound pavement layers and lead the surface waters away from the pavement.

6.4.5 Construction

The quality of construction is reported to be very important in keeping the ruts from the roads. The following factors will decrease rutting by studded tires:

- Specify and meet the required density.
- Use proper equipment to produce and construct special mixtures, e.g. SMAs.
- Pave only when there is no moisture (either water or ice) on the pavement surface, and the ambient air temperature is warm enough.
- Use extensive quality control and assurance policies.

7. Stud Usage in Anchorage

The objectives of this section are to determine the current studded tire usage rate in Anchorage and the proportion of vehicles that have lightweight studs. The objectives were accomplished by the following methods:

- reviewing available literature on past usage surveys,
- visiting tire retailers in Anchorage to determine state of practice for studded tires available to the public, and
- performing a visual survey of studded tire usage at various parking lots and garages in Anchorage.

7.1 Tire Dealership Survey

A survey of six local tire dealerships was performed to determine tire brands and stud types available in Anchorage. The survey results are summarized in Table 7.1. Johnson's Tire Service is the only vendor surveyed that offers lightweight studs and has been offering lightweight studs since the mid 1990's (MacPherson 2001).

Table 7.1. Anchorage tire dealers surveyed

Dealer	Type of stud	Tire Brands
Alaska Tire & Auto	Conventional	BF Goodrich, Bridgestone, Cooper, Goodyear, Hankook
Alaska Tire & Rim	Conventional	Chaparral A/T, Cooper, Yokohama
Alaska Tire Service	Conventional	Bridgestone, Firestone, Hankook
Anchorage Tire Factory	Conventional	Goodyear, Hankook, Kelly
Johnson's Tire Service	Lightweight	Chaparral A/P, Glacier Grip, Nordman, Hakkapeliitta
TDS (Tire Distribution Systems)	Conventional	Cooper

7.2 Stud Usage Surveys and Methods

The survey methods used to determine stud usage rates in previous studies vary. Three methods have been commonly used:

1. Telephone survey—Malik (2000)
2. Mail questionnaire—Fosser (1996), Junghard (1992)
3. Visual counting—Minnesota Department of Highways (1970), Smith and Schonfeld (1970), Brunette[2].

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[2] Brunette, Bruce at Alaska DOT/PF, personal communication, April 2004

Telephone and mail surveys were used to acquire additional data beyond whether or not a driver used studded tires. Visual inspecting and counting of cars in parking lots was determined to be the most cost effective method of attaining studded tire usage rates. Past usage rates collected by the AKDOT&PF (1973) and Hicks et al. (1990) for Alaska are given in Table 7.2. These studies did not report the survey method used to acquire the data. Brunette's data from 2004[1] is from a 500-car sample of parked cars from various locations in Juneau.

Table 7.2. Previous stud usage surveys in Alaska

Location	**Date**	**Stud Usage[2] (%)**	**Reference**
Anchorage	1973	73	AKDOT&PF, 1973
Fairbanks	1973	60	AKDOT&PF, 1973
Sitka	1973	50	AKDOT&PF, 1973
Valdez	1973	85	AKDOT&PF, 1973
Anchorage	Nov. 1989	48.3	Hicks et al. 1990
	Feb. 1990	49.4	Hicks et al. 1990
Juneau	Mar. 1990	42.9	Hicks et al. 1990
	Jan. 1991	57.5	Hicks et al. 1990
Fairbanks	Apr. 1989	40.4	Hicks et al. 1990
	Mar. 1990	31.2	Hicks et al. 1990
	Jan. 1991	29.1	Hicks et al. 1990
Juneau	Feb 2002, 2003, 2004 average	62.7	Brunette[1]

[2] Usage rate includes 2 and 4 studded tires per vehicle.

7.3 Vehicle Survey

The visual inspection and vehicle counting method was used to determine the stud usage rate in this study. Parked vehicles were visually inspected and counted in parking garages and in parking lots across Anchorage. In all, 2174 vehicles were surveyed, 214 in December, 550 in January, 950 in February, 240 in March and 220 in April. The following information was recorded:

Type of Vehicle. Vehicles were divided into four categories: car, sport utility vehicle (SUV), truck or van.

Tire Brand. Tire brands were recorded for studded tires and the studless Bridgestone Blizzak tires. Tire brands were used to determine if the tire had conventional or lightweight studs. This was possible due to the facts that only one Anchorage retailer sold lightweight studs and certain tire brands (see Table 7.1). Otherwise it is impossible to determine the stud type when the tire is in the service. Lack of corrosion in studs is an indication of a lightweight stud. However, a new steel stud may not have corrosion either, which makes corrosion not a good identification method.

Survey Areas. The goal in choosing survey sites was to collect a representative population of vehicles for the Anchorage area. The survey areas are listed in Table 7.3.

Table 7.3. Anchorage vehicle survey areas

Site	**Location**
Veco Building (offices)	949 36th Ave.
Frontier Building Parking Garage (offices)	3601 C St.
Sixth Avenue Parking Garage (shopping)	700 W. 6th Ave.
Dimond Center parking lots (shopping)	800 E. Dimond Blvd.
Seventh Avenue Parking Garage (downtown)	700 W. 7th Ave.
UAA parking lots (education)	3211 Providence Dr.
University Center parking lot (shopping)	3901 Old Seward Hwy.
Northway Mall parking lot (shopping)	3101 Penland Parkway

A summary of the survey results is given in Table 7.4 and 7.5 and Figure 7.1. The use of studded tires on only one axle is uncommon (< 1%). Very few vehicles had missing or broken studs. The broken studs usually showed signs of corrosion. The average usage rate from December to March was largest for passenger cars and vans (about 60%) and lowest for pickup trucks (40%). The average studded tire usage rate for all vehicles in Anchorage from December 2002 to February 2003 was 53.1%. The average usage rate dropped to 42.7% during March and April of 2003.

The usage rate of tires with lightweight studs was 14.6% out of all vehicles or 28.9% out of vehicles with studded tires. The usage rate for Blizzak tires was 0.5%.

The studded tire usage has remained about the same from 1990 to 2003. The usage rate in February 1990 was 49.4 (Table 7.2) and in February 2003 it was 50.9% (Table 7.5).

Table 7.4. Stud usage rates for vehicle types (for months December 2002 – March 2003)

		All Vehicles Using Each Type of Tire, %				
		Percent of Vehicles with Studs that Use each Type of Stud				
Type of Vehicle	Percent of Vehicles Using All Types of Studs	Lightweight	Conventional	Percent Light-weight Studs	Percent Conventional Studs	Tires with No Studs
Car	59.2%	34.8%	65.2%	20.6%	38.6%	40.8%
SUV	42.7%	38.0%	62.0%	16.2%	26.5%	57.3%
Truck	39.8%	18.1%	81.9%	7.2%	32.6%	60.2%
Van	60.1%	24.5%	75.5%	14.7%	45.4%	39.9%
Average	50.4%	28.9%	71.2%	14.6%	35.9%	49.6%

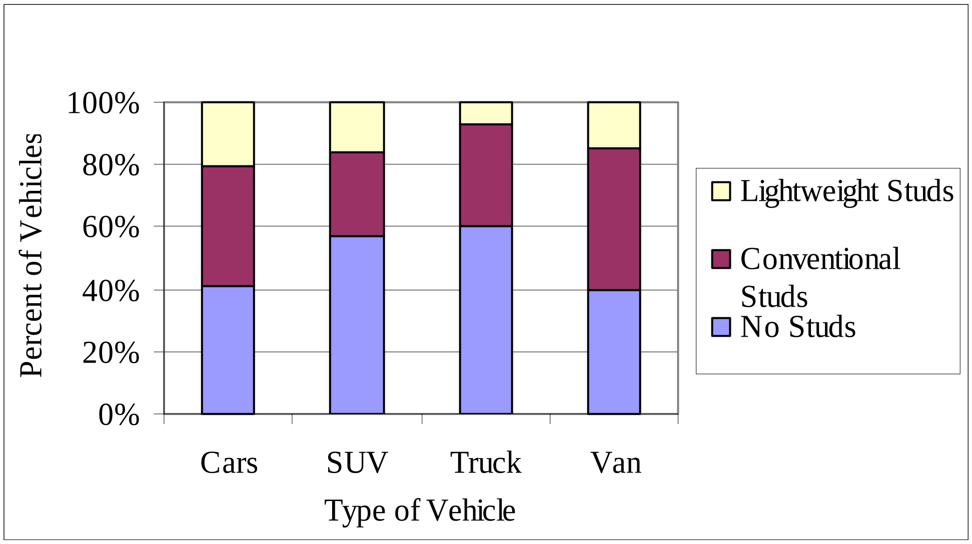

Figure 7.1. Percent of vehicles using different tire types in Anchorage, Alaska in winter 2002-2003

Table 7.5. Snowfall and stud usage rates for each month

	Snowfall[1], mm (in)	Vehicles using studs, %	Average, %
October 2002	0 (0)	0	-
November 2002	46 (1.8)	0	-
December 2002	650 (25.6)	53.3	53.1
January 2003	76 (3.0)	55.1	
February 2003	8 (0.3)	50.9	
March 2003	191 (7.5)	41.7	42.7
April 2003	0 (0)	43.6	
May 2003	0 (0)	0	1.0
June 2003	0 (0)	0	
July 2003	0 (0)	0.4	
August 2003	0 (0)	0.8	
September 2003	0 (0)	4.0	

[1] http://pafc.arh.noaa.gov/

7.4 Conclusions

Several conclusions were made from the gathered data:

- Stud usage rates in Anchorage have remained about the same from February 1990 to February 2003.
- Usage rates for passenger cars, SUV's, trucks and vans are 59, 43, 40 and 60%, respectively.
- Based on the data from December 2002 to April 2003, the highest rate for studded tire usage was for January.
- Stud usage during the summer months have decreased from 1996.

- Lightweight studs have been available for Anchorage since 1995.
- Twenty-night percent (29%) of studded tires have lightweight studs.
- Almost every vehicle with studs has them on all four tires.

8. Economic Impact of Studded Tires in Alaska

8.1 Introduction

Studded tires in Alaska create economic impacts for vehicle owners, the state government, and the community as a whole. For each of these groups, this chapter describes and estimates the economic impacts of studded tires. These impacts include spending for studded tires, revenues collected from the tire tax, the costs of road maintenance, and the savings from traffic crashes avoided by the use of studded tires.

8.2 Vehicle Owners

8.2.1 Spending for Studded Tires

The most direct economic impact of studded tires is the *additional* cost to vehicle owners of purchasing studded tires instead of non-studded tires. Based on a survey of tire prices in three retail tire stores in Anchorage, the retail price of studded tires is about $10 to $20 more than non-studded winter tires. This price differential varies substantially across the quality of the tires, the quality of the studs, the different retailers, the size of the tires, and the type of vehicle using the tires.

In addition to the higher retail price for studded tires, effective July 1, 2004, the State of Alaska will assess a $5.00 tax on all conventional studded tires sold in the state. Therefore, starting in 2004, each conventional studded tire would be about $15 to $25 more expensive (including the studded tire tax) than a non-studded tire. Lightweight studded tires would be about $10 to $20 more expensive than non-studded tires.[3]

An additional expense to drivers is the seasonal changeover. There is a wide range for this cost. If a driver pays a garage to mount and balance the tires twice a year the cost is around $150. Many car owners acquire a second set of rims and change their own tires. A garage typically charges $40 to change over tires that are already mounted. Used rims retain salvage value. Twenty dollars per tire is added to the purchase cost to account for this expense (Table 8.1).

Table 8.1. Additional annual additional cost per tire for studded tires

Type of Tire		Purchase Price	Changeover Cost	Total
Conventional Studded	High	$25	$20	$45
	Low	$15	$20	$35
Lightweight Studded	High	$20	$20	$40
	Low	$10	$20	$30
Price for conventional studded tire includes $5 tax effective July 1, 2004.				

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[3] The tire tax for both lightweight studded tires and non-studded tires is $2.50. There is no additional $5.00 studded tire tax for lightweight studded tires.

In order to estimate the total additional cost of studded tires, the following three assumptions are made: 1) The total additional cost of all studded tires is the additional cost per tire multiplied by the total number of tires sold in the state; 2) Total tire sales is the sum of vehicles using each type of tire multiplied by the percent of vehicles buying new tires each year; and 3) The number of vehicles using each type of tire is the total number of registered vehicles multiplied by the percent of vehicles using each type of tire.

Based on the survey of tire use reported in Chapter 7 (see Table 7.4), about 21% of cars use lightweight studs, 39% use conventional studs, and 41% use other types of tires in the winter. It is assumed that all cars and trucks use their winter tires only in the winter months, and that all vehicles use a second pair of (non-studded) summer tires in the summer months. Because there is no comprehensive information about studded tire use in areas outside Anchorage, it is also assumed that studded tire use in the rest of the state is the same as observed in Anchorage. There is no information on studded tire use by commercial trucks, busses, motorcycles, or trailers and it is assumed that all of these types of vehicles use non-studded tires.

The percent of vehicles using each type of tire (Table 7.4) multiplied by the total number of registered vehicles (Table 8.2) equals the number of vehicles using each type of tire. Based on this calculation, about 85,000 cars and trucks in Anchorage use conventional studded tires (Table 8.3). Assuming similar studded tire usage statewide, about 211,000 cars and trucks statewide use conventional studded tires, and an additional 94,000 cars and trucks statewide use lightweight studs.

Table 8.2. Number of registered vehicles

	Region		
Type of Vehicle	Anchorage	Rest of State	State Total
Passenger Cars	170,315	218,934	389,249
Pickup Trucks	58,546	126,859	185,405
Commercial Trucks	12,136	23,897	36,033
Bus	682	2,266	2,948
Trailers	35,009	68,174	103,183
Motorcycle	7,504	10,659	18,163
Total	284,192	450,789	734,981

Source: Division of Motor Vehicles, Alaska Department of Administration, *2002 Currently Registered Vehicles,* http://www.state.ak.us/dmv/research/curreg02.htm

Table 8.3. Estimated number of vehicles using each type of tire in winter

Type of Vehicle	Type of Winter Tire	Region		
		Anchorage	Rest of State	State Total
Cars	No Studs	69,489	89,325	158,814
	Conventional Studs	65,739	84,505	150,244
	Lightweight Studs	35,088	45,104	80,192
Pickup Trucks	No Studs	35,245	76,369	111,614
	Conventional Studs	19,084	41,351	60,435
	Lightweight Studs	4,218	9,139	13,356
All Cars and Pickup Trucks with Studs	Conventional Studs	84,823	125,856	210,679
	Lightweight Studs	39,305	54,243	93,548
Commercial Trucks, Busses	No Studs	12,818	26,163	38,981
Motorcycles and Trailers	No Studs	42,513	78,833	121,346

Source: The number of vehicles using each type of tire is the product of the percent of vehicles using each type of tire from Table 8.1 multiplied by number of registered vehicles from Table 8.2. These estimates of numbers of vehicles using each type of tire are for the winter months only. It is assumed that all cars and trucks use a second set of (non-studded) summer tires during the summer months.

Vehicle owners using studded winter tires do not buy new tires every year. About 11% of cars and trucks get replacement tires each year (see Table 8.4). It is assumed that the same percentage (11%) of vehicles using non-studded winter tires also buy new non-studded winter tires. In addition, it is assumed that the same percentage (11%) of all car and truck drivers also buy (non-studded) summer tires each year. It is also assumed that when the studs are worn out and removed, the tires serve their remaining life as non-studded tires.

Table 8.4. Percent of vehicles having new tires per year

Type of Vehicle	Percent of Vehicles
Cars and Trucks	11.11%
Commercial Trucks and Buses	20.00%
Motorcycles and Trailers	20.00%

Note: The percent of vehicles buying replacement tires assumes that each set of tires lasts nine years. This is about twice the average lifetime of a set of tires if the tires were used year round. However, it is assumed that cars and trucks use two sets of tires -- one set of winter tires and one set of summer tires (i.e. studded and non-studded, or two sets of non-studded). Each set is assumed to be used about half the year. If each vehicle, on average, replaces both sets of tires about every nine years, then one ninth (1/ 9) or about 11% of all vehicles replace their tires in a specific year.

It is assumed that commercial trucks, busses, motorcycles and trailers use the same tires year round so they will replace their tires more often than cars and trucks that use two sets of tires during the year. It is assumed that commercial trucks, busses, motorcycles, and trailers replace tires about every five years. So, in any particular year about 20% (=1/ 5) of these vehicles buy replacement tires.

The percentages of the number of cars buying new or replacement tires (Table 8.4) multiplied by the total number of cars using each type of tire (Table 8.3) equals the number of tires purchased each year (Table 8.5). Based on these calculations vehicle owners buy roughly 94,000 conventional studded tires and 42,000 lightweight studded tires statewide.

Table 8.5. Estimated number of tires purchased each year for cars and light trucks

Type of Tire	Number of Tires/Vehicle	Anchorage	Rest of State	State Total
Cars and Trucks				
Conventional Studded Tires	4	37,699	55,936	93,635
Lightweight Studded Tires	4	17,469	24,108	41,577
Non Studded Winter Tires	4	46,548	73,642	120,190
Summer Tires	4	101,716	153,686	255,402
Truck and Bus Tires	6	15,382	31,396	46,777
Motorcycle and Trailer Tires	2	17,005	31,533	48,538

The number of each type of tire purchased is the percent of vehicles buying each type (Table 8.4) multiplied by the number of vehicles using each type of tire (Table 8.3).

The total additional cost of studded tires is the product of these total tire sales multiplied by the additional cost per tire (Table 8.1). As listed in Table 8.6, the additional annual cost to vehicle owners of purchasing conventional studded tires (including the studded tire tax) is between $3.3 million and $4.2 million annually. The additional cost of buying lightweight studded tires is about $1.3 million to $1.7 million per year.

Table 8.6. Additional annual cost of purchasing studded tires

Type of Tires		Estimate	Region		
			Anchorage	Rest of State	Total
Conventional Studded Tires					
	Additional Cost per Tire	High	$45	$45	$45
		Low	$35	$35	$35
	Number of Tires Sold		37,699	55,936	93,635
	Cost for all tires	High	$1,696,453	$2,517,125	$4,213,577
		Low	$1,319,463	$1,957,764	$3,277,227
Lightweight Studs					
	Additional Cost per Tire	High	$40	$40	$40
		Low	$30	$30	$30
	Number of Tires Sold		17,469	24,108	41,577
	Cost for all tires	High	$698,758	$964,312	$1,663,071
		Low	$524,069	$723,234	$1,247,303
All Studded Tires					
	All Studded Tires	High	$2,395,211	$3,481,437	**$5,876,648**
		Low	$1,843,532	$2,680,998	**$4,524,530**
	All Studded Tires excluding tire tax	High	$2,068,796	$3,001,647	**$5,070,443**
		Low	$1,517,117	$2,201,208	**$3,718,325**

8.2.2 Additional Fuel Costs

Carlsson (1981) found that vehicle fuel costs increase by 2% for studded tires. Alppivuori (1995) reports that fuel consumption is 1.2% greater with studs than without them. Using these percentages, the additional fuel cost for Alaska is calculated to be between $1.4 million and $2.3 million annually (Table 8.7). These costs are borne by the vehicle owners who purchase the fuel.

Table 8.7. Additional annual fuel costs due to studs

	Anchorage	Rest of State	State Total
Vehicle Miles Traveled with studs (millions of miles)	335	921	1256
Cost per gallon of fuel	$1.70	$1.90	$1.80
Miles per gallon of fuel	20	20	20
Estimated total fuel cost for all miles driven on studs	$28,456,944	$87,541,624	$113,065,051
Additional cost of fuel from use of studs			
Low estimate	$341,483	$1,050,499	$1,356,781
High estimate	$569,139	$1,750,832	$2,261,301

Vehicle miles traveled with studs from Table 8.8. Cost per gallon from informal ISER survey in October 2003. Total fuel cost is assumed to be vehicle miles traveled with studs multiplied by cost per gallon divided by miles per gallon. Additional fuel cost is 1.2% (Low estimate) or 2% (high estimate) of total fuel cost. These percent increases in fuel costs due to studs are from Alppivouri (1995) (low estimate) and Carlsson (1981) (high estimate)

8.2.3 Savings in Travel Time

Several studies found that cars with studded tires drove faster than when they did not have studs (Asano 2002; Carlsson 1981)). This increase in travel speed saves on travel time for the driver and their passengers. Carlsson (1981) found that vehicles travel 2 to 3 km/h faster with studded tires. He does not report the mean travel speed for his study. If we assume the average urban speed of 56 km/h (35 mph), this implies a 6% to 9% increase in travel speed for those using studded tires.

These improvements in travel speed would occur primarily on days when the roadways are snowy or icy. A Transportation Research Board study of winter travel in Minnesota (Perchonok 1978) found that travel in urban areas in Michigan and Minnesota on complete or partial coverage by snow or ice occurs 26% of the time during the winter.[4]

Based on these rough estimates of the increased travel speeds using studs and road snow and ice coverage, this current study developed estimates of the time saved from the use of studded tires for *only* the vehicles using studs and *only* for the days that roads are covered in snow or ice. Table 8.8 summarizes low, medium, and high estimates of dollar value of travel time savings to vehicle owners using studded tires. The total travel cost savings statewide to vehicle owners

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[4] Table B-13, p 26, and Table B-27, p 35 of Perchonok (1978). There are no estimates of snow and ice coverage of roads available for Alaska. It is likely that the percentage of time traveling on snow and ice covered roads varies considerably across regions of Alaska and also across different areas within Anchorage.

using studs amounts to $5.5 million to $6.4 million annually. These travel cost savings are borne by those who travel in vehicles with studded tires.

Table 8.8. Travel time savings from use of studded tires

	Anchorage	Rest of State	Total
Number of Vehicles Using Studs			
	124,128	180,099	304,227
Million Vehicle Miles Traveled by Vehicles with Studs			
Winter Total	335	921	1256
On Snow and Ice Only	87	240	327
Average Speed with Studs (mph)			
Low	30	30	
Mid	35	35	
High	40	40	
Percent Increase in Speed with Studs			
Low	6%	3%	
Mid	8%	4%	
High	9%	5%	
Average Speed without Studs (mph)			
Low	28	29	
Mid	32	34	
High	36	38	
Average Hours Traveled on Snow and Ice with Studs			
High	2,901,492	7,986,253	10,887,746
Mid	2,486,993	6,845,360	9,332,353
Low	2,176,119	5,989,690	8,165,809
Average Hours Traveled on Snow and Ice without studs			
High	3,086,694	8,233,251	11,319,945
Mid	2,688,642	7,112,062	9,800,704
Low	2,391,340	6,271,927	8,663,267
Hours Saved in Travel Time by Using Studs			
Low	185,202	246,998	432,199
Mid	201,648	266,702	468,350
High	215,221	282,237	497,457
Average Value of Time			
	$12.85	$12.85	$12.85
Total Value of Travel Time Savings Due to Use of Studs			
Low	$2,379,841	$3,173,918	$5,553,759
Mid	$2,591,178	$3,427,125	$6,018,303
High	$2,765,584	$3,626,742	$6,392,326

Source: Number of Vehicles Using Studs from Table 8.3. Number of vehicle miles traveled with studs is the total vehicle miles traveled in Alaska (AKDOT 2002) times the number of vehicles with studs divided by the total number of registered vehicles. The number of vehicles miles traveled with studs on snow and ice is 26% of the total vehicle miles traveled by vehicles with studs. This 26% is the average percent of driving time on roads completely or mostly covered with snow or ice in Minnesota and Michigan as reported in Table B-13, p 26 and Table B-27, p 35 of Perchonok (1978). Percent change in driving speed is from Carlsson (1981). Average travel speeds are based on informal ISER survey of major arterials in Anchorage during October 2003, including Tudor Road, Northern Lights, and Arctic Boulevard. Actual travel speeds vary substantially across the city. Hours traveled on snowy and icy roads with studs is total vehicle miles traveled on snowy and icy roads divided by average travel speed in miles per hour with studs. Hours traveled on snowy and icy roads without studs is total vehicle miles traveled on snowy and icy roads divided by average travel speed in miles per hour without studs. Hours saved with the use of studs is the difference between the hours traveled on snowy and icy roads without studs minus the hours traveled on snowy and icy roads with studs. Average value of time from Schrank and Lomax (2003). Total value of travel time savings equals hours saved traveling with studs multiplied by the average value of time.

8.2.4 Avoided Crash Costs for Vehicle Owners

Studs provide additional traction on icy and snowy streets. Studs reduce the number of traffic crashes and so reduce the costs due to traffic crashes. Vehicle owners, drivers and passengers of vehicles with studs are the direct beneficiaries of some of these avoided costs of crashes. Section 8.4 of this chapter discusses the avoided costs of crashes in detail, including the benefits to vehicle owners and passengers.

8.2.5 Car Washing

Studded tires increase road grime which results in dirtier cars that need to be washed more frequently. Carlsson (1981) estimates two additional washes per winter are required per vehicle. A typical cost per wash of $10 for a total additional expense per year of $20/vehicle is used. Table 8.6 shows the total estimated annual cost for additional washing is $1.5 million.

Table 8.9. Additional annual cost for car washing

Number of cars & trucks with studded tires	Cost per vehicle per year, $	Total, $
304,227	20	6,084,540

8.3 State Government

8.3.1 Tax Revenue Collections

The new state tire tax will collect $2.50 for every tire sold and an additional $5.00 for every conventional studded tire sold. The tax applies both to original tires on new cars and to replacement tires purchased for vehicles. The number of tires sold (Table 8.5) multiplied by the tire tax per tire equals the total tax revenues generated from tire sales (Table 8.10). Tire sales would raise annually about $1.5 million (Table 8.10). Sales of conventional studded tires would raise additional $0.5 million annually assuming that the percentage of conventional studded tire users will remain constant. Total revenues from the tire tax would amount to about $1.9 million. This estimate is comparable to the estimate of tire tax revenues developed by the Alaska Department of Revenue for the current year. As shown in Figure 8.1, about 76% of the tire tax revenues would come from all tire sales, and the remaining 24% of the tax revenues would come from the additional tax from conventional studded tire sales.

Table 8.10. Total tax revenue collected by state government

	Anchorage	Rest of State	Total
Estimated Number of Tires Purchased Each Year			
Cars and Trucks			
Conventional Studded Tires	37,699	55,936	93,635
Lightweight Studded Tires	17,469	24,108	41,577
Non Studded Winter Tires	46,548	73,642	120,190
Non Studded Summer Tires	101,716	153,686	255,402
Truck and Bus Tires	15,382	31,396	46,777
Motorcycle and Trailer Tires	17,005	31,533	48,538
Tire Tax per Tire			
All Tires	$2.5	$2.5	$2.5
Additional Tax for Conventional Studded Tires	$5.0	$5.0	$5.0
Total Revenues			
All Tires	$589,547	$925,751	$1,515,298
Additional Tax for Conventional Studded Tires	$188,495	$279,681	$468,175
Total	$778,042	$1,205,431	$1,983,473
Alaska Department of Revenue Estimate of Tire Tax Revenues			
Current year			$1,900,000
First full year tax is in effect			$2,300,000
Several years after tax is in effect			$3,300,000

Source: Number of Tires purchased each year is from Table 8.5. Tax per tire and DOR Estimates of Revenue from Alaska Department of Revenue (Dickinson et al. 2003). Total revenue is product of number of tires purchased multiplied by tax per tire.

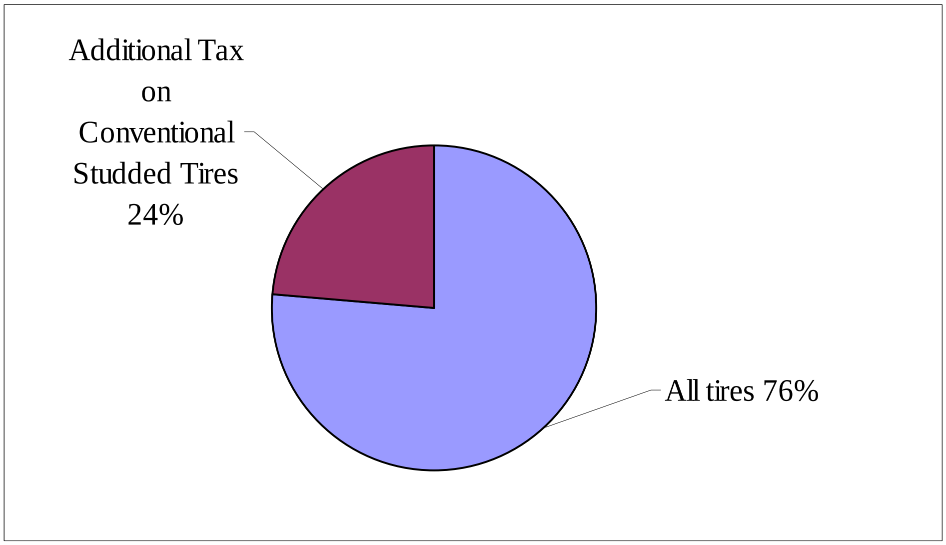

Figure 8.1. Source of revenues from Alaska tire tax

8.3.2 Spending on Road Maintenance

The Alaska Department of Transportation and Public Facilities estimated the additional cost of road maintenance due to studded tires at $5 million annually in 1996 (Barter and Johnson 1996). In order to update these figures this current study estimated the cost of repairing rutted roads in Alaska based on the number of lane miles affected by rutting and the average annual cost per lane mile of repairing the ruts.

Table 8.11 summarizes the total number of lane miles affected by rutting in Alaska. The lane miles that experience the most rutting are arterials in urban areas (CTP arterials) where traffic is heaviest. As shown in Figure 8.2, roughly one third of all lane miles in the state have ruts of 6.3 mm (0.25 in) or more. About 6% of the lane miles in the state have rut depth of 12.7 mm (0.5 in) or more.

Table 8.11. Lane miles by depth of rutting by region by road class in Alaska in 2002

		Rut Depth						Percent of Lane Miles Affected	
	Road Class	< 6.3 mm (0.25 in)	6.3 to 12.7 mm (0.25 to 0.5 in)	12.7 to 19.1 mm (0.5 to 0.75 in)	19.1 to 25.4 mm (0.75 to 1.0 in)	More than 25.4 mm (1.0 in)	All	Lane Miles with Rut Depth ≥6.3 mm	Lane Miles with Rut Depth ≥ 12.7 mm
Central	Interstate NHS	806	647	123	24	4	1603	50%	9%
	Non-Interstate NHS	173	137	55	19		384	55%	19%
	CTP Arterials	191	200	69	69	11	540	65%	28%
	CTP Collectors	823	391	67	21	4	1305	37%	7%
	Local Roads and Streets	170	37			1	208	18%	0%
	Total	2163	1412	314	133	19	4040	46%	12%
Northern	Interstate NHS	1739	413	9			2161	20%	0%
	Non-Interstate NHS	744	220	2	2		968	23%	0%
	CTP Arterials	276	69	5			350	21%	1%
	CTP Collectors	771	121	6	2		899	14%	1%
	Local Roads and Streets	144	7				151	5%	0%
	Total	3674	829	23	3		4529	19%	1%
Southeast	Interstate NHS	0	0	0	0	0	0	0%	0%
	Non-Interstate NHS	162	84	5	3	1	256	37%	4%
	CTP Arterials	64	84	32	3		183	65%	19%
	CTP Collectors	296	123	15	2		436	32%	4%
	Local Roads and Streets	14	11	1			26	47%	3%
	Total	536	303	53	8	1	900	40%	7%
State	Interstate NHS	2545	1059	132	24	4	3764	32%	4%
	Non-Interstate NHS	1080	441	63	23	1	1607	33%	5%
	CTP Arterials	531	353	106	73	11	1073	51%	18%
	CTP Collectors	1890	635	88	24	4	2640	28%	4%
	Local Roads and Streets	327	56	1	0	1	385	15%	0%
	Total	6372	2543	389	143	20	9468	33%	6%

Source: ISER Tabulations of number of lane miles with each rut depth database provided by R. Scott Gartin, Statewide Pavement Management Engineer at Alaska Department of Transportation and Public Facilities. According to the R. Scott Gartin, Angela Parsons, June Finkbinner, John Rajek, and Newt Bingham, Alaska DOT/PF, 2002 *Road Pavement Condition Report*, the lane miles included in this database do not include freeway interchange ramps. Ruts are measured in inches of displacement or wear in the wheel paths. Lane miles are units of area one 12 foot lane wide and one mile long equal to 63,360 square feet. NHS stands for National Highway System. CTP means Community Transportation Program (non-NHS) State roads.

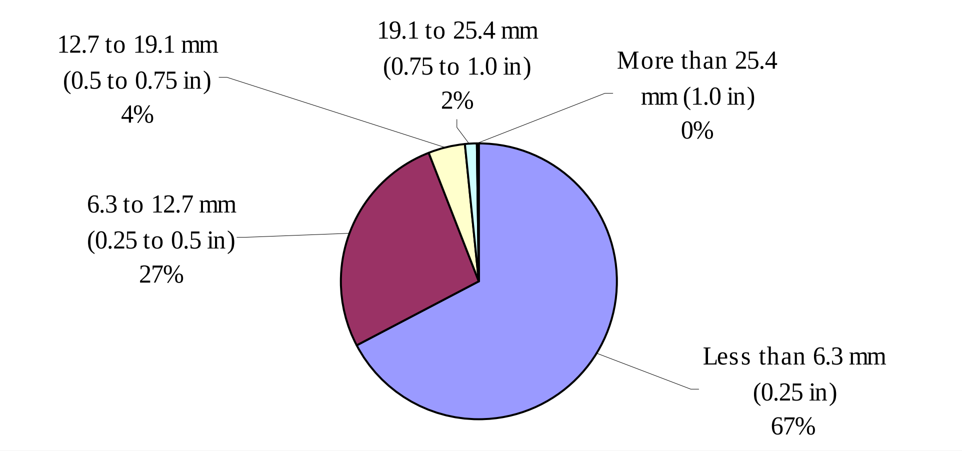

Figure 8.2. Percent of lane miles of each rut depth in Alaska

The Alaska Department of Transportation 2002 Road Pavement Condition Report (Gartin et al. 2002) recommends that ruts of depth 6.3 mm (0.25 in) or more receive “preventative or corrective maintenance.” To estimate the cost of repairing these rutted lane miles, this current study relied on estimates of the cost of repairing ruts from McHattie and Elieff (2001). They estimate the current cost of maintaining rutted roadways at about $93,500 per lane mile over the thirty-five year lifetime of a roadway. Based on this estimate, the average annual cost per lane mile is about $2,671 (= $93,500 / 35).

Table 8.12 summarizes the average annual cost of repairing all lane miles of different rut depths in Alaska. If the state were to repair all lane miles of rut depth 6.3 mm (0.25 in) or more each year, the average annual cost over the lifetime of the road would be about $8.3 million annually. Repairing all ruts of 7.6 mm (0.3 in) or more would cost on average about $5.7 million annually over the lifetime of the road. If the state repaired only the lane miles with rutting of 12.7 mm (0.5 in) or more, the cost would be about $1.5 million annually over the lifetime of the road.

Table 8.12. Estimates of annual cost of filling ruts in Alaska roads after initial setup costs are reached

Rut Depth	Lane Miles with this depth or more	Average Cost per Lane mile for 35 years	Average Annual Cost per lane Mile	Average Annual Cost for All Lane Miles
6.3 mm (0.25 in) or more	3,096	$93,500	$2,671	$8,269,941
7.6 mm (0.30 in) or more	2,132	$93,500	$2,671	$5,694,417
10 mm (0.40 in) or more	981	$93,500	$2,671	$2,621,473
12.7 mm (0.50 in) or more	552	$93,500	$2,671	$1,475,697
Cost per lane mile from McHattie and Elieff (2001). Lane Miles Affected tabulated from database of lane miles of each rut depth in Alaska provided by R. Scott Gartin, DOT/PF Pavement Engineer to ISER in October 2003.				

It is important to note that actual expenditures may be higher or lower than these estimates of the *annual average* costs over the lifetime of the road. Actual annual expenditures vary year to year depending on availability of state funding, the severity and extent of existing ruts, changes in the amount of traffic, the construction of new lane miles constructed, and other factors.[5]

Not all of these rut repair costs can be attributed to studded tire wear. Lampinen (1993) found that 70% to 80% of rutting is due to studded tires, and the rest is due to plastic deformation by heavy vehicles. This is based on 90% to 95% stud usage for passenger cars and less than 50% for heavy vehicles. The data for Lampinen's study is from 1982 through 1988, before Finland started using improved pavement materials on highly traveled roads. The Alaska Department of Transportation and Public Facilities does not differentiate between rutting due to studded tires and plastic deformation. They assume that most of the rutting is due to studded tires.

This current study found lower stud usage in Alaska than reported by Lampinen (1993) in Finland. Therefore, it is expected that studded tires would cause a *lower* percentage of total rut wear in Alaska than Lampinen (1993) found for Finland. To account for the possibility that plastic deformation causes some of the rutting in Alaska, this current study considers three scenarios: that studded tire wear causes 60%, 70% and 80% of the road rutting, and that plastic deformation causes the remainder.

Table 8.13 lists estimates of the cost of repairing ruts that are attributable to studded tire wear for these three scenarios. If studded tires cause 80% of the rutting, then the costs attributable to studded tires are $1.2 to $6.6 million depending on the depth of the ruts repaired. If studded tires cause only 60% of the rutting, then the repair costs attributable to studded tires is $0.9 to $5.0 million, depending on rut depth repaired (Figure 8.3).

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[5] Bingham, Newton at Alaska DOT/PF, personal communication, October 2003.

Table 8.13. Estimates of annual cost of filling ruts attributable to studded tires

Rut Depth	Total Cost	Costs Attributable to Studded Tire Wear		
		Low: 60%	Mid: 70%	High: 80%
6.3 mm (0.25 in) or more	$8,269,941	$4,961,965	$5,788,959	$6,615,953
7.6 mm (0.30 in) or more	$5,694,417	$3,416,650	$3,986,092	$4,555,534
10 mm (0.40 in) or more	$2,621,473	$1,572,884	$1,835,031	$2,097,178
12.7 mm (0.50 in) or more	$1,475,697	$885,418	$1,032,988	$1,180,558

Costs attributable to studded tire wear is total cost for each rut depth multiplied by percent of costs attributable to studded tires for low, mid, and high scenarios. Total cost from Table 8.12. Percent of costs attributable to studded tires based on estimates from Lampinen (1993) and allowance for lower studded tire usage in Alaska.

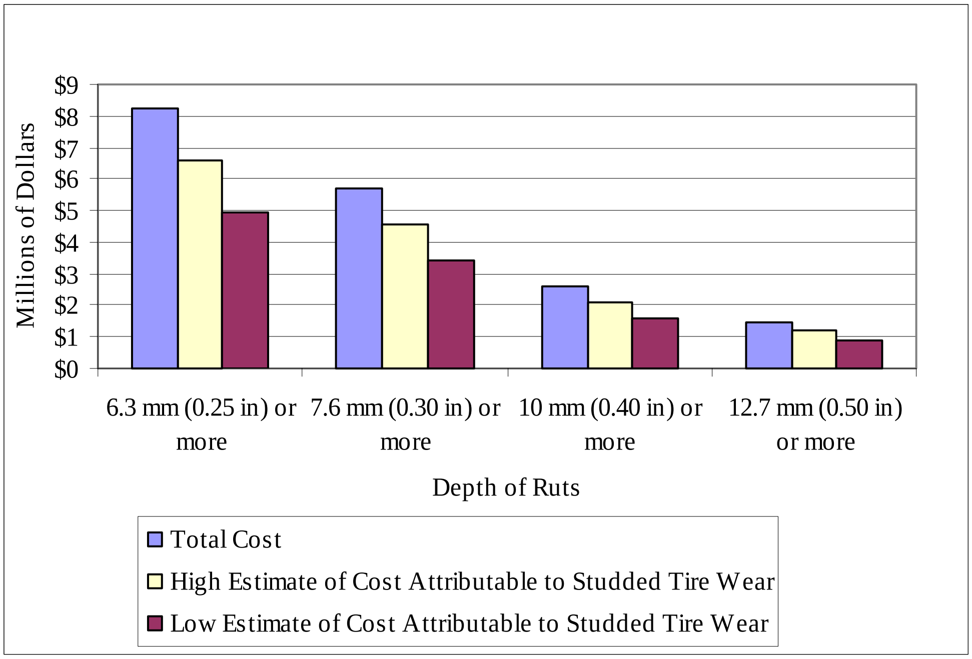

Figure 8.3. Average annual cost of repairing ruts in Alaska over the lifetime of the roadway

Table 8.14 lists rough estimates of rut maintenance costs for several states (Malik 2000). In order to compare the estimates from different states, the estimates are adjusted for the effects of inflation and population growth. Table 8.14 also lists the average annual costs per urban lane mile and the annual cost per million urban vehicle miles traveled for each state. These rough calculations suggest, but do not confirm, that the cost per urban lane mile and cost per million vehicle miles traveled in Alaska is comparable to the costs in Minnesota and Wisconsin.

Table 8.14. Comparison of Alaska Studded Tire Costs to Studies in Other States

State	Year of Study	Reported Cost of Studded Tires	Time Period	Percent Change in Population since Study	Percent Change in Prices since Study	Average Annual Cost in Constant 2002 Dollars, after adjusting for population growth	Estimated Affected Lane Miles	Estimated Million Vehicle Miles Traveled Causing Ruts	Cost Per Lane Mile Affected	Cost per Million VMT Contributing to Rutting
Washington	1984	$3,500,000	Annual Costs	33%	73%	$8,064,941	20,669	18,064	$390	$446
Missouri	1976	$170,000,000	Costs for Thirty Years	15%	216%	$20,514,208	17,445	17,800	$1,176	$1,152
Minnesota	1971	$55,200,000	Costs for Eight Years	22%	344%	$37,387,134	17,742	13,600	$2,107	$2,749
Massachusetts	1973	$3,370,000	Annual Costs	11%	305%	$15,182,589	24,666	21,987	$616	$691
Wisconsin	1977	$12,000,000	Annual Costs	15%	197%	$40,892,385	18,450	12,960	$2,216	$3,155
Alaska	High Estimate						3,096	1,120	$2,137	$5,909
(from Table 8.12)	Low Estimate						2,132	1,120	$1,603	$3,051

Sources: Barter and Johnson (1996) and Malik (2000), Urban Lane Miles and Urban VMT from “Highway Statistics 2001,” Federal Highway Administration (2003).

These calculations assume that half of urban lane miles are affected, that half of urban vehicle miles traveled (VMT) contribute to rutting, and that costs increase proportionally with population. Lane Miles affected in Alaska and cost per lane mile for Alaska are from Table 8.12. High estimate assumes that 80% of rutting costs are attributable to studded tire wear. Low estimate assumes that 60% of rutting costs are attributable to studded tire wear.

8.3.3 Changes in State Government Costs

The maintenance costs reported in Table 8.12 for Alaska are for the *current* level of road maintenance. Table 8.15 summarizes the per lane mile costs for alternative maintenance scenarios based on a recent engineering study by McHattie and Elieff (2001)**.** This study estimates the average annual cost for four different maintenance alternatives, and concludes that the "Super Fill" option is the best alternative. This alternative implies *annual* maintenance costs attributable to studded tires of $0.6 million to $4.9 million over the lifetime of the roadways, depending on how many lane miles are repaired and how much of the rutting can be attributed to studded tire wear. In the future, the number of vehicles and number of lane miles will grow and change the amount of wear and maintenance costs. This current study did not attempt to estimate these future changes in costs since reliable estimates of the lane miles to be built are not available.

Maintenance costs would also change under different policy alternatives. As shown in Chapter 6, rutting and subsequent maintenance costs depend on pavement materials and characteristics, traffic, road geometry, environment and quality of construction. Sufficient information to update the economic impact of these effects is currently not available.

Table 8.15. State maintenance costs for studded tire wear

		Lane Miles Affected		Estimated Average Annual Cost over Lifetime of Roadway attributable to Studded Tire Wear	
Scenario	Average Annual Costs over 35 Year Lifetime	High: rut depth ≥ 6.3 mm (0.25 in)	Low: rut depth ≥ 12.7 mm (0.5 in)	High Scenario: 6.3 mm or deeper ruts repaired and 80% of costs are attributable to studded tires	Low Scenario: 12.7 mm or deeper ruts repaired and 60% of rut costs are attributable to studded tires
Scenario 1: Fill	$2,665	3096	552	$6,601,173	$883,440
Scenario 2: Mill and Fill	$2,618	3096	552	$6,483,839	$867,737
Scenario 3: Super Fill	$1,961	3096	552	$4,856,386	$649,934
Scenario 4: Mill and Super Fill	$3,598	3096	552	$8,911,584	$1,192,644
Source: Lane Miles Affected by rutting from Table 8.12 and average costs of repair derived from McHattie and Elieff (2001). Estimated annual cost is the product of the average annual cost multiplied by the number of lane miles affected. High estimate assumes that 80% of rutting costs are attributable to studded tire wear. Low estimate assumes that 60% of rutting costs are attributable to studded tire wear.					

8.3.4 Tort Liability Costs

The October 22, 2001 Alaska Journal of Commerce (MacPherson 2001) reports that some vehicle owners have sued the state for the costs of crashes caused by rutted roads. No estimates of those potential tort liability costs are available.

8.4 Avoided Crash Costs

A variety of studies summarized in Chapter 5 of this report have estimated the effect of studded tires on highway safety. Several studies have found that studded tires do reduce the number of crashes; however, estimates of the actual percent reduction in crashes due to use of studs varies dramatically across studies. The most reliable and comprehensive study is Elivik's "meta" study that surveyed the results of many other studies from various countries (Elvik 1999). According to Elvik's study, studded tires reduce accident rates by one percent to ten percent.

If studs reduce crashes by ten percent, then as many as 600 traffic crashes statewide are *avoided* by the use of studs in Alaska every year (see Table 8.16 and Figure 8.4). These avoided crashes *would* have involved about 1070 vehicles and about 1700 people, including about 3 fatalities. However, if studs reduce the number of crashes on snowy and icy roads only by only 1%, then about 60 traffic crashes are avoided by the use of studs. These avoided crashes would have involved about 107 vehicles and 170 people.

Table 8.16. Avoided vehicle crashes due to use of studs

		Number of Each Type of Crash				
		Property Damage	Minor Injury	Major Injury	Fatal	All Crashes
Total Number of Crashes on Snow and Ice Road Conditions in 2000						
Anchorage		2635	823	31	9	3480
Rest of State		1772	571	71	21	2453
Total Number of People Involved in Traffic Crashes with Snow and Ice Road Conditions in 2000						
Anchorage		9356	1174	36	10	10172
Rest of State		5700	864	87	24	6488
Total Number of Vehicles Involved in Traffic Crashes with Snow and Ice Road Conditions in 2000						
Anchorage		4755	1543	51	15	6332
Rest of State		3199	1072	119	34	4464
Percent of Crashes Avoided with Use of Studs						
High	Anchorage	10%	10%	10%	10%	10%
	Rest of State	10%	10%	10%	10%	10%
Mid	Anchorage	6%	6%	6%	6%	6%
	Rest of State	6%	6%	6%	6%	6%
Low	Anchorage	1%	1%	1%	1%	1%
	Rest of State	1%	1%	1%	1%	1%
Avoided Crashes						
High	Anchorage	263	82	3	1	350
	Rest of State	177	57	7	2	244
Mid	Anchorage	145	45	2	1	192
	Rest of State	97	31	4	1	134
Low	Anchorage	26	8	0	0	35
	Rest of State	18	6	1	0	24
Number of Vehicles in Avoided Crashes						
High	Anchorage	476	154	5	2	636
	Rest of State	320	107	12	3	442
Mid	Anchorage	262	85	3	1	350
	Rest of State	176	59	7	2	243
Low	Anchorage	48	15	1	0	64
	Rest of State	32	11	1	0	44
Number of People in Avoided Crashes						
High	Anchorage	936	117	4	1	1058
	Rest of State	570	86	9	2	668
Mid	Anchorage	515	65	2	1	582
	Rest of State	313	48	5	1	367
Low	Anchorage	94	12	0	0	106
	Rest of State	57	9	1	0	67

Source: Total Number of people, vehicles, and crashes avoided is the product of the total number of crashes multiplied by the percent of crashes avoided. Number of crashes is from Alaska DOT/PF *Alaska 2000 Traffic Accidents* (2002). High and Low estimates of percent of crashes avoided from Elvik (1999).

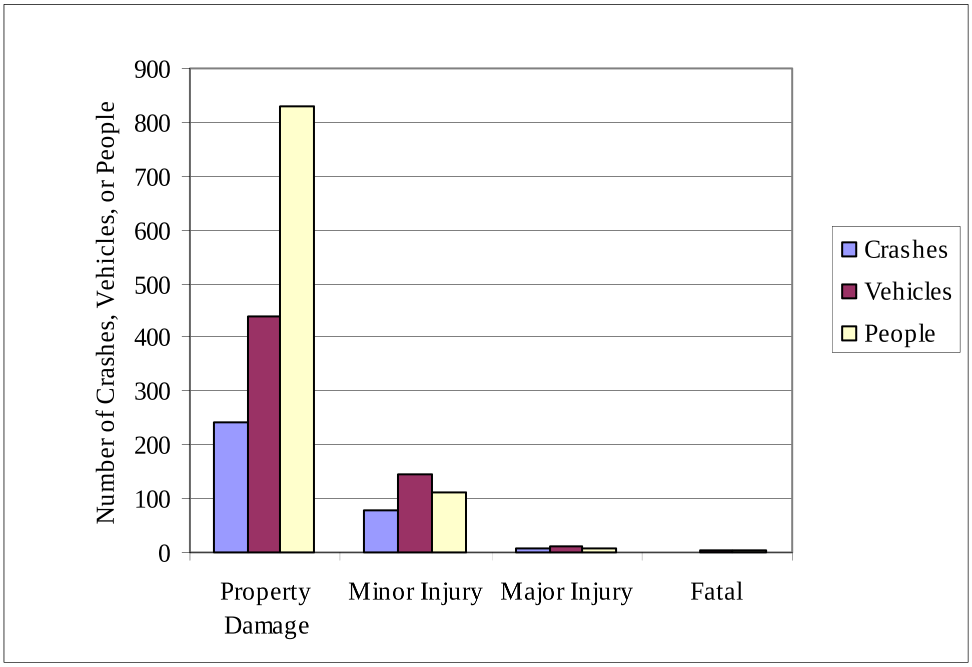

Figure 8.4. Number of crashes avoided by use of studs and the number of people and vehicles involved

In order to estimate the dollar value of these avoided costs, this current study relied on estimates of the cost per person of traffic crashes developed by the National Highway Transportation Safety Board (NHTSB) by Blincoe et al. (2002). As listed and described in Table 8.17, the economic costs of crashes include medical costs, emergency services, vocational rehabilitation, market productivity, household productivity, insurance administration, workplace costs, legal costs, travel time, and property damage. Table 8.18 summarizes the average cost per person for these economic costs.

Table 8.17. Definitions of economic costs included in crash costs

Type of Cost	**Definition**
Medical Costs	The cost of all medical treatment associated with motor vehicle injuries including that given during ambulance transport. Medical costs include emergency room and inpatient costs, follow-up visits, physical therapy, rehabilitation, prescriptions, prosthetic devices, and home modifications.
Emergency Services	Police and fire department response costs.
Vocational Rehabilitation	The cost of job or career retraining required as a result of disability caused by motor vehicle injuries.
Market Productivity	The present discounted value (using 4 percent discount rate for 2000 dollars) of the lost wages and benefits over the victim's remaining life span.
Household Productivity	The present value of lost productive household activity, valued at the market price for hiring a person to accomplish the same tasks.
Insurance Administration	The administrative costs associated with processing insurance claims resulting from motor vehicle crashes and defense attorney costs.
Workplace Costs	The costs of workplace disruption that is due to the loss or absence of an employee. This includes the cost of retraining new employees, overtime required to accomplish work of the injured employee, and the administrative costs of processing personnel changes.
Legal Costs	The legal fees and court costs associated with civil litigation resulting from traffic crashes.
Travel Time	The value of travel time delay for persons who are not involved in traffic crashes, but who are delayed in the resulting traffic congestion from these crashes.
Property Damage	The value of vehicles, cargo, roadways, and other items damaged in traffic crashes.

Source: Blincoe et al. (2002). *The Economic Impact of Motor Vehicle Crashes 2000*, National Highway Traffic Safety Administration, US Department of Transportation.

Table 8.18. Units costs of crashes

	Type of Crash			
	Property Damage	Minor Injury	Major Injury	Fatal
Type of Cost	Cost per vehicle	Cost per person	Cost per person	Cost per person
Medical	$0	$2,380	$131,306	$22,095
Emergency Services	$31	$97	$830	$833
Market Productivity	$0	$1,749	$106,439	$595,358
Household Productivity	$47	$572	$28,009	$191,541
Insurance Administration	$116	$741	$32,335	$37,120
Workplace Costs	$51	$252	$4,698	$8,702
Legal / Court	$0	$150	$33,685	$102,138
Travel Delay	$803	$777	$999	$9,148
Property Damage	$1,484	$3,844	$9,833	$10,273
Quality of Life	$0	$4,455	$383,446	$2,389,179
Total	$2,532	$15,017	$731,580	$3,366,388

Source: Blincoe et al. (2002).

The costs listed in Table 8.17 are the *economic* costs that result from goods and services that must be purchased or productivity lost because of motor vehicle crashes. The NHTSB notes that these costs "do not represent the intangible consequences of these events to individuals or family, such as pain and suffering and loss of life" (Blincoe et al. 2002). Blincoe et al.'s NHTSB (2002) study bases quality of life costs on estimates of the "qualify of life years" (QALYs) lost because of crashes. QALY is determined by the duration and severity of health problems. As listed in the second to last line of Table 8.18, the QALY cost for fatalities is about $2.4 million per person. The QALY cost of traffic crashes declines as the severity of injury declines.

Estimates of the number of avoided crashes from Table 8.16 and the estimates of the average cost per person from Table 8.18 provide the basis for estimating the cost *savings* from crashes *avoided* due to the use of studded tires. Table 8.19 lists the direct costs of crashes avoided due to use of studded tires. These avoided direct costs amount to between $1.2 million to $11.8 million, depending on whether studs reduce crashes by 1% or 10%. Comprehensive cost savings, including Quality of Life measures and direct costs, amounts to $2.6 million to $25.6 million (Figure 8.5).

Table 8.19. Estimated avoided crash costs attributable to use of studs in Alaska in 2000

Estimate	Type of Cost	Property Damage	Minor Injury	Major Injury	Fatal	All Crashes
High	Direct Costs	$2,013,983	$2,152,844	$4,294,192	$3,341,421	$11,802,440
	Quality of Life	$0	$908,059	$4,729,762	$8,169,451	$13,807,272
	Total	$2,013,983	$3,060,903	$9,023,954	$11,510,872	**$25,609,712**
Mid	Direct Costs	$1,107,691	$1,184,064	$2,361,806	$1,837,781	$6,491,342
	Quality of Life	$0	$499,432	$2,601,369	$4,493,198	$7,593,999
	Total	$1,107,691	$1,683,496	$4,963,175	$6,330,979	**$14,085,341**
Low	Direct Costs	$201,398	$215,284	$429,419	$334,142	$1,180,244
	Quality of Life	$0	$90,806	$472,976	$816,945	$1,380,727
	Total	$201,398	$306,090	$902,395	$1,151,087	**$2,560,971**

Source: Calculations based on number of avoided crashes from Table 8.16 and unit costs of crashes from Table 8.18. Cost savings is the product of the unit cost savings multiplied by the number of avoided crashes.

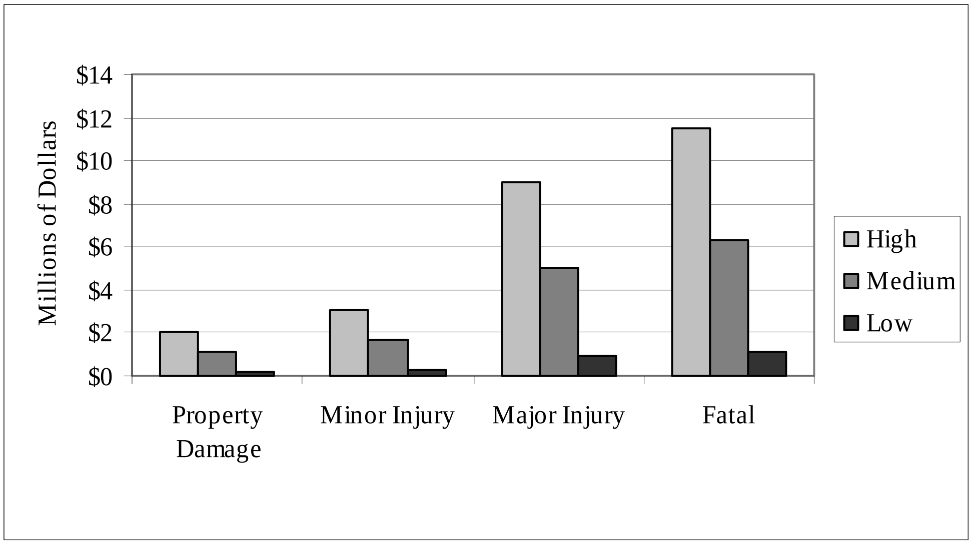

Figure 8.5. Cost savings from crashes avoided due to use of studs in Alaska

These avoided crash cost savings are borne by several different groups, including the individuals involved in the crash, government, health insurance companies, and others in the community (including other drivers, insurance payers, and employers). The National Highway Traffic Safety Board has developed estimates of the percent borne by each group (Blincoe et al. 2002). These estimates of the distribution of costs provide the basis for calculating the cost savings to each group from avoided crashes in Alaska. Table 8.20 lists the direct economic costs avoided by each group due to the use of studs.

Table 8.20. Who benefits from the cost savings from crashes avoided due to the use of studs in Alaska

Estimate	Who Bears Cost	Property Damage	Minor Injury	Major Injury	Fatal	All Crashes
High	Federal Government	$1,775	$129,718	$449,867	$341,909	$923,269
	State Government	$19,149	$74,052	$208,204	$72,480	$373,884
	Insurer	$877,226	$1,152,176	$2,458,924	$1,644,691	$6,133,016
	Others in Community	$680,283	$248,264	$199,161	$107,595	$1,235,304
	Driver and passenger	$435,550	$548,634	$978,037	$1,174,746	$3,136,967
Mid	Federal Government	$976	$71,345	$247,427	$188,050	$507,798
	State Government	$10,532	$40,728	$114,512	$39,864	$205,636
	Insurer	$482,474	$633,697	$1,352,408	$904,580	$3,373,159
	Others in Community	$374,156	$136,545	$109,539	$59,177	$679,417
	Driver and passenger	$239,552	$301,749	$537,920	$646,110	$1,725,332
Low	Federal Government	$178	$12,972	$44,987	$34,191	$92,327
	State Government	$1,915	$7,405	$20,820	$7,248	$37,388
	Insurer	$87,723	$115,218	$245,892	$164,469	$613,302
	Others in Community	$0	$54,863	$97,804	$117,475	$270,142
	Driver and passenger	$43,555	$54,863	$97,804	$117,475	$313,697

The amount borne by each group is the product of the total avoided crash costs multiplied by the percent of those costs borne by each group. Avoided Crash Costs from Table 8.19 and percent of costs borne by each group from Blincoe et al. (2002)

Insurance companies benefit most from the use of studs because they do not have to pay insurance for crashes avoided by the use of studs (Figure 8.6). Drivers and passengers in vehicles using studs also benefit from the cost savings of avoided crashes due to studs because they avoid the personal injury and quality of life costs. The state and federal governments also receive some of the cost savings from avoided crashes due to studs because the government pays for police, fire, and emergency services that respond to traffic crashes.

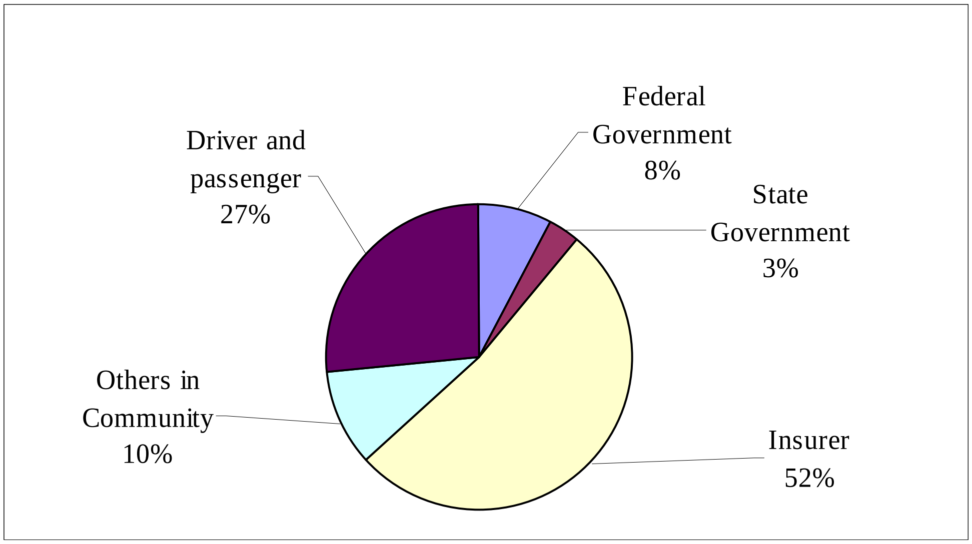

Figure 8.6. Who receives cost savings from crashes avoided due to studded tire use in Alaska

These estimates of the cost savings from avoided crashes do not include several other effects of studded tires on traffic safety. Several studies have noted that rough surfaces improve traction for all drivers and could potentially reduce crashes further. However, studded tires also wear ruts in the road, and those ruts can cause crashes. Other studies have shown that ruts can cause hydroplaning accidents or accidents from difficulty in handling or steering vehicles in and out of the ruts (Start, Kim and Berg 1998). Reliable estimates of the number of crashes (and the associated costs) that may have been caused by rutted roads are not available. Based on a six year study on Swedish roads, Ihs, Velin and Wiklund (2002) could not prove that the amount of traffic accidents depend on rut depth. The rut depth varied from 0 to 30 mm in this study.

8.5 Health Costs

Chapter 4 of this report concluded that health costs from dust due to studded tire wear are not significant in Alaska. This current study did not attempt to estimate the dollar value of these costs.

8.6 Summary

8.6.1 Costs and Benefits for each Group

Table 8.21 and Figure 8.7 summarize the economic costs and benefits due to use of studded tires felt by each group. The economic impacts felt by vehicle owners, the state government, and others are distinctly different. Vehicle owners bear the direct cost of studded tires by paying additional $5 tax for conventional studded tires and a higher price for all studded tires. However, vehicle owners are also the primary beneficiaries of cost savings from avoided crashes. Other drivers who do not use studs also benefit from avoided crashes. The state government bears the costs of road maintenance, but benefits from the tire tax revenues and cost savings from avoided crashes.

Using the stated assumptions, the use of studded tires seems to have a positive impact on the overall Alaskan economy. Tire tax money moves from the hands of vehicle owners to the state government. The state government spends the money in another part of the Alaska economy. Therefore, the money moves from one part of the economy to another and the overall net economic impact on Alaska from the tire tax is small. The savings from avoided crashes are the most substantial impacts and benefit the broadest range of groups, including the state government, vehicle owners, passengers, and insurance companies (and their policy holders). The quality of life benefits of avoided crashes benefit mostly drivers and passengers of vehicles.

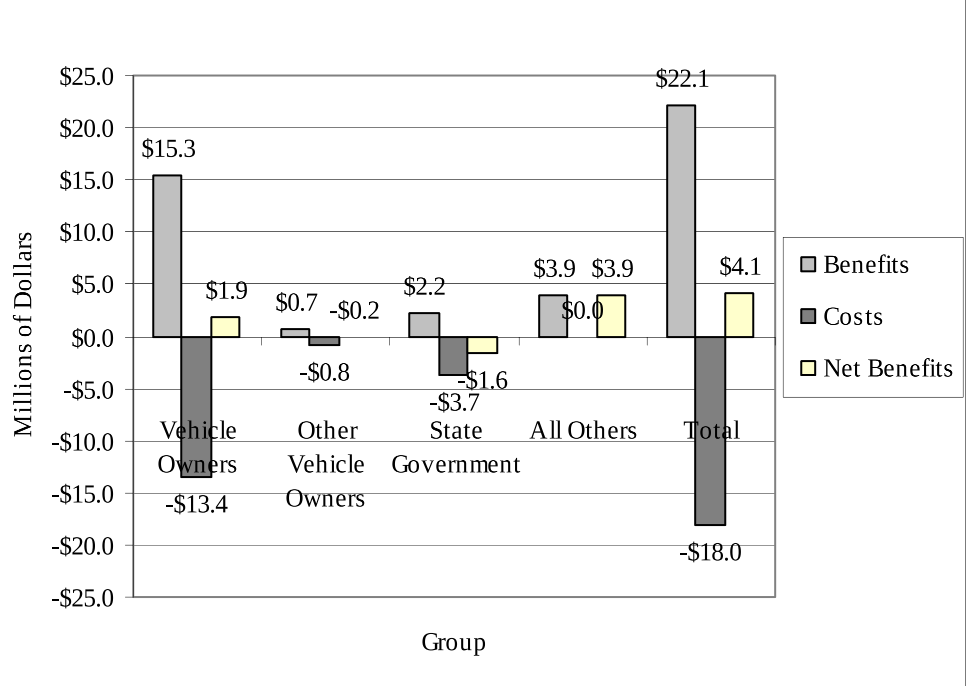

Figure 8.7. Costs and benefits of studded tires for each group

8.6.2 Change in Impacts for Alternative Policy Scenarios

Table 8.21 also summarizes the changes in costs and benefits for alternative policy scenarios:

- **Scenario B: Only Lightweight Studs Allowed:** If the state required all vehicles with studded tires to use lightweight studs, maintenance costs would decrease and the net benefits to Alaska would likely increase. This assumes that lightweight studs cause less rutting but provide the *same* traction and *same* reduction in traffic crashes as conventional studs.

- **Scenario C: Ban Studs and Improve Maintenance of Snowy and Icy Roads:** If the state banned all studs and instead used sand, salt, and improved plowing, the net benefits are ambiguous. The change in benefits depends critically on whether sand, salt, and improved plowing can reduce traffic crashes as much as studded tires. Increased use of traction sand and salt may also have an affect on community health and the environment.

- **Scenario D: Better Pavement Materials:** Using improved pavement materials would reduce rutting and reduce maintenance costs. Jacobson (1997) estimates that Sweden has reduced pavement rutting by 25% by implementing use of improved pavement materials. However, the cost of constructing roadways with the improved pavement materials would be higher. Therefore, the net benefits over the lifetime of the roadway are unknown.

- **Scenario E: Reduced Winter Driving Speed** could reduce the number and cost of traffic crashes. Reduced speed could be enforced either by better enforcement of existing speed limits or by reducing the posted speed limit on highways. When cars move slower, they are less likely to get into crashes. Furthermore, if they are moving at slower speeds when a crash occurs, the cost of property damage and severity of injuries are lower. Slower traffic would also likely reduce the amount of rutting on roads since slower moving studded tires cause less rutting. This would reduce overall maintenance costs. The net effect of reduced winter driving speeds would be greater benefits for the state as a whole.

- **Scenario F: Enforce Seasonal Ban:** If the state more actively enforced the seasonal ban on studded tires, the amount of wear on the road would decrease and maintenance costs would decrease. The costs of more state troopers and local police to enforce the ban would increase. The change in net benefits for the state is ambiguous.

- **Scenario G: Improve Rut Repair:** If the state more actively repaired ruts, it could reduce the number of crashes caused by ruts. The cost of maintaining the roads would increase, and the benefits of avoided crashes would increase. The net change in benefits for the state is ambiguous.

Table 8.21. Summary of changes in costs and benefits for alternative policy scenario

		Policy Scenarios					
	Scenario A: Current Condition	Scenario B: Require Use of Lightweight Studs	Scenario C: Ban Studs and Use Sand, Salt, and Improved Plowing	Scenario D: Improved Pavement Materials	Scenario E: Reduced Winter Speed	Scenario F: Enforce Seasonal Ban Better	Scenario G: Improved Road Maintenance to Repair Ruts
Vehicle Owners Using Studs							
Benefits							
Avoided Crash Costs on snowy and icy roads, mid (19)	$1.7	$1.7	Unknown	$1.7	Larger benefits	$1.7	$1.7
Quality of Life of avoided crashes, mid (18)	$7.6	$7.6	Unknown	$7.6	Larger benefits	$7.6	$7.6
Travel Time savings from increased speed, mid (8)	$6.0	$6.0	Unknown	$6.0	Smaller benefits	$6.0	$6.0
Costs							
Additional Cost of Studded Tires excluding tax, ave. (6)	-$4.4	-$4.4	$0.0	-$4.4	-$4.4	-$4.4	-$4.4
Additional Tire Tax on Conventional Studded Tires (10)	-$0.5	$0.0	$0.0	-$0.5	-$0.5	-$0.5	-$0.5
Fuel Costs, ave. or low (7)	-$1.8	-$1.4	Unknown	-$1.8	Smaller Costs	Smaller Costs	-$1.8
Additional Cost of Vehicle Washing (9)	-$6.1	Smaller costs	Unknown	Smaller Costs	Smaller Costs	Smaller Costs	-$6.1
Crashes caused by rutting	Unknown	Smaller Costs	Smaller Costs	Smaller Costs	Smaller Costs	Smaller Costs	Smaller Costs
Crashes caused by hydroplaning in ruts	Unknown	Smaller Costs	Smaller Costs	Smaller Costs	Smaller Costs	Smaller Costs	Smaller Costs
NET including only direct avoided crash benefits	-$5.1	Smaller net costs	Smaller net costs	-5.1	Smaller net costs	-5.1	Smaller net costs
NET including Quality of Life Benefits	$2.6	$3.5	Unknown	$2.6	Larger benefits	$2.6	$2.6
Other Vehicle Owners without Studded Tires							
Benefits							
Avoided Crash Costs on snowy and icy roads, mid (19)	$0.7	$0.7	Unknown	$0.7	Larger benefits	$0.7	$0.7
Costs							
Crashes caused by rutting	Unknown	Smaller Costs	Smaller Costs	Smaller Costs	Smaller Costs	Smaller Costs	Smaller Costs
Crashes caused by hydroplaning in ruts	Unknown	Smaller Costs	Smaller Costs	Smaller Costs	Smaller Costs	Smaller Costs	Smaller Costs
NET	$0.7	$0.7	Unknown	$0.7	Smaller net costs	$0.7	Smaller net costs

	Scenario A: Current Condition	Policy Scenarios					
		Scenario B: Require Use of Lightweight Studs	Scenario C: Ban Studs and Use Sand, Salt, and Improved Plowing	Scenario D: Improved Pavement Materials	Scenario E: Reduced Winter Speed	Scenario F: Enforce Seasonal Ban Better	Scenario G: Improved Road Maintenance to Repair Ruts
State Government							
Benefits							
Tire Tax Revenues from Additional Tax on Conventional Studded Tires(10)	$0.5	$0.0	$0.0	$0.5	$0.5	$0.5	$0.5
Avoided Crash Costs on snowy and icy roads, mid (19)	$0.2	$0.2	Unknown	$0.2	Larger benefits	$0.2	$0.2
Costs							
Tort liability for crashes caused by ruts	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Smaller Costs
Road Construction Costs		Unchanged	Unchanged	Larger Costs	Unchanged	Unchanged	Unchanged
Road Maintenance Costs, Scenario 1: Fill, ave. (15)	-$3.7	-$2.6	Unknown	Smaller Costs	Smaller Costs	-$3.0	Larger Costs
NET	-$3.1	-$2.4	Unknown	Unknown	Unknown	-$2.3	Unknown
Other							
Benefits of Avoided Crashes on snowy and icy roads							
Federal Government , mid (19)	$0.5	$0.5	Unknown	$0.5	Larger Benefits	$0.5	$0.5
Insurers, mid (19)	$3.4	$3.4	Unknown	$3.4	Larger Benefits	$3.4	$3.4
NET	$3.9	$3.9	Unknown	$3.9	Larger Benefits	$3.9	$3.9
Total							
Direct Benefits, total	$13.0	$12.5	Unknown	$13.0	Larger benefits	$13.0	$13.0
Avoided Crashes (18)	$6.5	$6.5	Unknown	$6.5	Larger Benefits	$6.5	$6.5
Travel Time	$6.0	$6.0	Unknown	$6.0	Smaller Benefits	$6.0	$6.0
Tire Tax Revenues Collected	$0.5	$0.0	$0.0	$0.5	$0.5	$0.5	$0.5
Quality of Life Benefits (18)	$7.6	$7.6	Unknown	$7.6	Larger benefits	$7.6	$7.6
Costs, total	-$16.5	-$14.9	Unknown	Smaller Costs	Smaller Costs	Smaller Costs	Smaller Costs
Additional Cost of Studded Tires	-$4.4	-$4.4	$0.0	-$4.4	-$4.4	-$4.4	-$4.4
Fuel Costs	-$1.8	-$1.8	Unknown	-$1.8	Smaller Costs	Smaller Costs	-$1.8
Additional car washing	-$6.1	Smaller Costs	Unknown	Smaller Costs	Smaller Costs	Smaller Costs	-$6.1
Maintenance Cost of Roads	-$3.7	-$2.6	Unknown	Smaller Costs	Smaller Costs	-$3.0	Larger Costs
Tire Tax Revenues Paid	-$0.5	$0.0	$0.0	$0.5	$0.5	$0.5	$0.5
Costs of crashes caused by Ruts	Unknown	Unknown	Unknown	Smaller Costs	Unchanged	Smaller Costs	Smaller Costs
NET	-$3.5	$3.7	Unknown	Unknown	Larger benefits	Larger benefits	Larger benefits
Net with Quality of Life Benefits	$4.1	$11.3	Unknown	Unknown	Larger benefits	Larger benefits	Larger benefits

The numbers in parentheses after particular line items in the table refer to the table numbers in Chapter 8 of this report from which the data is taken. All of the estimates in this table assume the "high" scenarios from each table in this chapter. All of the estimates in this table would be lower for the "mid" or "average of low and high" scenarios reported in previous tables in this chapter.

9. Conclusions and Recommendations

9.1 Conclusions

Findings from a study of alternative technologies to studded tires include:

- The winter tire technology improves continuously as the manufacturers release their newest tire models.
- Several tire manufacturers supply both factory-installed studded tires and non-studded winter tires. Some of them are on the market in Alaska.
- According to the Finnish test results, studded tires provide in average better traction on ice than non-studded friction tires. On snow or on wet pavement there are no significant differences.
- Alternatives to winter tires, chains and special equipment, are currently not practical for Alaska, where snowy and icy roads occur regularly.

The regulatory overview revealed the following facts:

- Six states (Colorado, Kentucky, New Hampshire, New Mexico, Vermont, and Wyoming) allow virtually unrestricted use of studded tires on state roads and highways.
- Thirty-six states (including the District of Columbia) allow studded tires but restrict their use seasonally, geographically, or through equipment specifications.
- Seven states (Alabama, Florida, Hawaii, Illinois, Louisiana, Mississippi, and Texas) currently prohibit the use of studded tires under any circumstances; however, out of these states only Illinois has significant amount of ice and snow. Several states, including Minnesota and Wisconsin, prohibit studded tires with exceptions.
- Recent studies in Finland and Japan found that prohibiting studs produces a net increase in total costs. Pavement repair costs are greatly reduced, but costs of accidents plus the increased requirement of surface applications to improve surface traction (e.g. sand, salt) result in an overall increased financial burden at the state level. These studies have lead to legislation that continues the use of studded tires during winter months, but limits that use to lightweight studs to minimize adverse effects.

When the effect of studded tires on the air quality was studied, the following conclusions were made:

- While scientific evidence is overwhelming that studded tires do generate increased levels of road dust by “grinding” the pavement into smaller particles, the use of studded tires in Alaska does not appear to present an unacceptable respiratory health risk.
- In urban and rural areas of Alaska alike, the most severe particulate level episodes are attributed to natural sources of particulate matter, not to dust associated with studded tire use. Road dust associated with studded tire pavement wear is only a fraction of Alaska’s total particulate matter issue.
- Alaska’s data indicates that while road sources are a contributor to the overall levels of dust, violations of the PM_{10} National Ambient Air Quality Standards (NAAQS) are most commonly triggered by natural particulate matter episodes such as volcanic activity and wild land fires rather than road sources of particulate matter. Correspondingly, violations of the

$PM_{2.5}$ NAAQS are most commonly associated with either combustion sources or natural sources of particulate and not with studded tire generated dust.

- Alaska's biggest problem with road dust is the large number of unpaved roads. Elevated particulate matter due to unpaved roads still adversely impacts roughly half of Alaska's population. Banning studded tires in areas that predominately contain unpaved roads will have no appreciable human health respiratory benefit, compared to the obvious human health respiratory benefit of road paving. Socioeconomic analysis will be necessary to determine the optimal number of paved roads versus unpaved roads in rural Alaska.
- Road dust generated by studded tires is an urban phenomenon, and generally only applicable to Alaska's major cities, where significant stretches of pavement exist, along with a higher density of sensitive human receptors along the paved roadway. Even in urban areas of Alaska, where pavement is more predominant, studded tire dust is only one piece of the Alaskan urban dust puzzle, as other anthropogenic and natural sources of road dust also play a key role.
- Key variables such as pavement type, population density along the roadway, traffic speed and volume, roadway maintenance practices, precipitation trends, and meteorological conditions all weigh into the severity of studded tires' contribution to roadway dust, and the ultimate human health impact of that dust on the receptor population. These variables must be evaluated on a site-specific basis.
- Dust generated by studded tires is only a sub-set of the overall paved road dust level, and is not currently causing violations in the NAAQS for particulates. There does not appear to be a significant human health benefit associated with banning studded tires in urban areas of Alaska, as a reduction in roadway particulate levels due to the ban would likely be offset by increased dust levels due to increases in the volume of winter traction sand.

The following conclusions where established, as the effect of studded tires on traffic safety was studied:

- The consensus of the literature review is that studded tires do improve traffic safety in winter driving conditions.
- Studies done in the early 1970s in North America showed increased safety from studded tires but pavement repair costs motivated bans in Minnesota and Ontario. Substantial improvements in tire and stud design and pavement design make the results of those studies inapplicable today.
- For studies and economic analyses performed more recently, accident costs are usually the overwhelming factor in the sum of economic effects. Pavement wear caused by studs is very expensive as well. However, when studded tires are prohibited the savings in pavement repair may be entirely offset by the increased costs of anti-icing of the road surfaces. This was true on Hokkaido where the cost of surface applications was greater than the cost of pavement repair. In the Nordic Countries, lightweight studs are now the norm and pavement wear has been reduced by almost half with no change in accident risk.

A large number of studies exist on the effect of studded tires on pavement wear. These studies mainly conducted in the Nordic Countries conclude the following:

- Pavement wear is affected by factors relating to traffic, road geometry, pavement characteristics, environment and quality of construction. Some of these factors have larger effect than others, and the magnitude of the effect may be site specific.

- All literature reviewed reported that the rutting is directly related to the traffic volume, the percentage of vehicles using studs, stud types and vehicle speed. Increasing traffic volumes, proportion of vehicles using studs and vehicle speed increase the amount of rutting.
- Pavement materials and mixture types are reported to be one of the main factors affecting road wear by studded tires. Aggregate is stated to be the most important pavement factor. The abrasion resistance and the content of the coarse aggregates are the significant aggregate characteristics. The next most important pavement factor after aggregate is the mix design. The SMA mixtures are reported to be more wear resistant than dense graded asphalt mixtures. The asphalt cement has significantly smaller effect on pavement wear than the aggregate and mix design, which has made it difficult to determine the specific effect of asphalt cement on rutting resistance. It has reported, that in some cases, especially with poor aggregates, the use of polymer-modified asphalts reduce pavement wear. PCC pavements are found to have greater wear resistance than asphalt concrete pavements. However, they are not commonly used in cold regions, such as Alaska, for frost related reasons.
- Rutting increases with decreasing temperatures below 0°C and with a wet pavement surface when compared to a dry surface. The wet surface affects rutting more than cold temperatures. The most important factor to reduce the pavement wear is to enforce the usage of studded tires only when needed, during the winter months when pavements may be icy or have slick compacted snow.
- The wear by studded tires is reported to be higher where the vehicles are accelerating or decelerating. These areas include curves, uphills, downhills and intersections. The lane width affects the rut depth due to the channeling of the traffic. The narrower the lane, the deeper the rut.
- Since water accelerates the wear by studded tires, drainage is an important factor in the cross section design.
- The quality of construction is very important in keeping the ruts from the roads. Well designed pavement with good materials can rut in the field, if it is manufactured or compacted in wrong temperature or with improper equipment.

Gathered data of studded tire usage in Anchorage revealed the following:

- Stud usage rates in Anchorage have remained about the same from February 1990 to February 2003.
- Usage rates for passenger cars, SUV’s, trucks and vans are 59, 43, 40 and 60%, respectively.
- Based on the data from December 2002 to April 2003, the highest rate for studded tire usage was for January.
- Lightweight studs have been available for Anchorage since 1995.
- Twenty-night percent (29%) of studded tires have lightweight studs.
- Almost every vehicle with studs has them on all four tires.

An economic analysis was conducted for the data from the literature review and the usage studies. The following conclusions were made:

- The economic impacts felt by vehicle owners, the state government, and others are distinctly different. Vehicle owners bear the direct cost of studded tires by paying additional $5 tax for conventional studded tires and a higher purchase and operation cost for all studded tires. Tires with lightweight studs have the same base tax as non-studded tires. However, vehicle owners are also the primary beneficiaries of cost savings from avoided crashes. Other drivers who do not use studs also benefit from avoided crashes. The state government bears the costs of road maintenance, but benefits from the tire tax revenues and cost savings from avoided crashes.

- The economic analysis conducted was based on available current information and the stated assumptions. With the used figures, the use of studded tires has an overall positive impact on Alaskan economy. Tire tax money moves from the hands of vehicle owners to the state government. The state government spends the money in another part of the Alaska economy. Therefore, the money moves from one part of the economy to another and the overall net economic impact on Alaska from the tire tax is small. The savings from avoided crashes are the most substantial impacts and benefit the broadest range of groups including the state government, vehicle owners, passengers, and insurance companies (and their policy holders). The quality of life benefits of avoided crashes benefit mostly passengers and drivers of vehicles.

9.2. Recommendations for Implementation

On the basis of this study, the following recommendations are given for Alaska:

- continue to study, test and apply wear-resistant asphalt mixtures, which have been proven to reduce the amount of rutting by studded tires.
- consider mandating the use of lightweight studs in the studded tires, which have been proven to reduce the amount of rutting by studded tires.
- develop a comprehensive winter road maintenance policy that would consider traffic safety, pavement wear and the health and environmental effect of winter traction sand and anti-icing agents.
- continue the enforcement of the seasonal restrictions on studded tire usage.
- consider reducing the winter speed limits on high trafficked urban highways.
- consider the pavement wear by studded tires in the geometric design of its roads and streets.

9.3. Recommendations for Future Research

Research is needed to

- determine the extent to which rutting contributes to summertime accidents.
- determine how much improved pavement materials and mix designs would reduce pavement wear in Alaska.
- determine how much would reduced winter speeds in urban areas reduce accidents and pavement wear.
- enforce criteria for acceptable rut depth triggering maintenance operations taking into considerations reduced accident rate.
- determine how much road wear is currently attributed “solely” to studded tire use, and how much road wear is attributed to heavy vehicle loads and non-studded tires.
- directly compare site-specifically in Alaska’s urban areas the human health trade-off of increased respiratory risk of studded tire dust versus the human health risk associated with a studded tire ban or decreased studded tire use. Additional research is necessary to speciate roadway dust samples and evaluate chemicals of concern to human health.

- determine the winter traction of studded tires, friction tires and all-season tires with tire life (e.g. km/tire)
- determine actual economic costs of owning and using studded tires more accurately using data from collected tire tax revenue.

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