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STUDDED TIRE PERFORMANCE AND SAFETY

by

Jian John Lu, Ph.D., P.E.

December 1994

FINAL REPORT

Report No. INE/TRC 94.07
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16. Abstract

Studded tires have been used in the U.S. to improve vehicle traction performance for more than 30 years. A major concern has been pavement damage caused by studded tires. This report summarizes a study conducted by the University of Alaska Fairbanks and sponsored by the Alaska Department of Transportation and Public Facilities to evaluate studded tire performance and safety. Past studies conducted in the U.S., Canada, Japan, and Northern European countries were reviewed to evaluate the following aspects: traction performance (friction performance, stopping distance, starting traction, and cornering and hill climbing ability), safety performance, pavement surface damage, and other impacts (driver behavior, fuel consumption, environment, and health effects). It was concluded from the study that studded tires showed some traction advantages over non-studded tires on icy surfaces. On snow surfaces, there was no significant traction difference between studded and non-studded tires. Studded tires showed poorer traction performance on dry or wet pavement surfaces than non-studded tires. No major accident analysis studies related to studded tire safety characteristics have been identified; one reason may be that too many contributing factors are involved in any given accident; thus it is difficult to statistically quantify the impacts of studded tires on traffic incidents. However, some studies concluded that studded tires did not present significantly better safety performance than non-studded tires, and a ban of studded tires would not result in significantly increased vehicle accidents. The major disadvantage of studded tires is accelerated pavement wear. Past studies have shown that pavement wear caused by studded tires was much more serious than that of non-studded tires. Decreasing the percentage of studded tire use can increase the service life of pavement surfaces.

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Transportation Research Center
University of Alaska Fairbanks

A Report on Research Sponsored by
Alaska Department of Transportation and Public Facilities

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DISCLAIMER

ABSTRACT

Studded tires have been used in U.S. to improve vehicle traction performance for more than 30 years. A major concern has been pavement damage caused by studded tires. This report summarizes a study conducted by the University of Alaska Fairbanks and sponsored by Alaska Department of Transportation and Public Facilities to evaluate studded tire performance and safety. Past studies conducted in the U.S., Canada, Japan, and Northern European countries were reviewed to evaluate the following aspects: traction performance (friction performance, stopping distance, starting traction, and cornering and hill climbing ability), safety performance, pavement surface damage, and other impacts (driver behavior, fuel consumption, environment, and health effects). It was concluded from the study that studded tires showed some traction advantages over non-studded tires on icy surfaces. On snow surfaces, there was no significant traction difference between studded tires and non-studded tires. Studded tires showed poorer traction performance on dry or wet pavement surfaces than non-studded tires. No major accident analysis studies related to studded tire safety characteristics have been identified; one reason may be that too many contributing factors are involved in any given accident; thus it is difficult to statistically quantify the impacts of studded tires on traffic incidents. However, some studies concluded that studded tires did not present significantly better safety performance than non-studded tires, and a ban of studded tires would not result in significantly increased vehicle accidents. The major disadvantage of studded tires is the accelerated pavement wear. Past studies have shown that pavement wear caused by studded tires was much more serious than that of non-studded tires. Decreasing the percentage of studded tire use can increase the service life of pavement surfaces.

SUMMARY

This study reviewed and summarized the major performance of studded tires in terms of traction performance, safety performance, pavement wear, and other impacts. Detailed summaries and conclusions are presented in Chapter 6 of this report.

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1. INTRODUCTION

Studded tires were introduced in North America in the mid-1960's. Since then, motorists have rapidly accepted studded tire use to improve vehicle safety performance during winter seasons. Compared to tire chains, studded tires are more durable, maneuverable, comfortable, and convenient, since they do not require troublesome fastening and unfastening. Adoption and continued use of studded tires, however, has been a source of much controversy in the highway community. Advocates of studded tires argue for their continued use, claiming that they improve safety under winter driving conditions because of the improved vehicle traction performance on icy or snowy surfaces. Opponents maintain that they accelerate highway pavement wear substantially, thereby adding to pavement maintenance costs. According to the summary report written by Christman and Sime [1], the advantages and disadvantages of studded tires can be listed as follows.

Advantages:

1). More safety during ice-and snow-covered road conditions

2). Convenience of full time availability of aforementioned advantages

3). Low cost of studs to consumers

Disadvantages:

1). Less safety during dry or wet road conditions

2). Accelerated wear of roadways

3). High cost to all taxpayers for repairing accelerated wear of roadways

4). Obliteration of pavement lane markings

5). Overconfidence in drivers

As indicated in a NCHRP synthesis report, the use of studded tires creates a false sense of security for many drivers, and small margins of studded tire safety benefits on ice and snow covered roads are nullified by overconfident drivers who often increase their speed by 5 mph or more during these periods [2]. In fact, during winter season, the majority of the roadway surfaces are dry or wet. For example, based on the data provided by Connecticut and Alaska in 1975 and 1973, respectively, 0.5% of Connecticut winter road conditions were icy, 3% were snow covered [1], and 22.6% of Alaska winter road conditions were snow covered, and 12.4% were icy [3]. With these road surface conditions, studded tires may not present a significant winter safety advantage over non-studded tires due to their less safe performance on dry or wet pavement surface.

Since the introduction of studded tires, regulations regarding their use in the United Sates have varied. The use of studded tires is controversial, and, accordingly, each state has its own regulations. Based on the results of the literature review, state regulations regarding use of studded tires are shown in Table 1.1 [4]. Of all states reported in this table, an estimated 22 % of state agencies prohibit the use of studded tires, 68 % restrict the use of studded tires to a specific time period, and 10 % allow unrestricted use of studded tires. Similar results for Canada, the European countries, and Japan are given in Table 1.2.

The positive and negative effects of studded tires have been discussed frequently in past years. In the United States, compared to 1960's, fewer research studies in this area have been reported in last two decades. In recent years, studies have been reported from Japan and Northern European countries. The purpose of this study, summarized in this report, was to investigate the results obtained from research of the past two decades, and to conduct a literature review related to studded tire performance from existing literature, data bases, and other related resources. Areas discussed in the report include studded tire traction performance, studded tire safety performance, pavement wear due to studded tires, and other impacts, including driver behavior, fuel consumption, and environment.

Table 1.1. State Regulations Regarding Use of Studded Tires [4].

State	Regulation	Conditions
Alabama	Prohibited	
Alaska	Allowed	Sept. 15 - May 1
Arizona	Allowed	Nov. 15 - Apr. 15
Arkansas	Allowed	Nov. 15 - Apr. 15
California	Allowed	Nov.1 - Apr. 1
Colorado	Allowed	
Connecticut	Allowed	Nov. 15 - Apr. 30
Delaware	Allowed	Oct. 15 - Apr. 15
District of Columbia	Allowed	Oct. 15 - Apr. 15
Florida	Prohibited	
Georgia	Prohibited	
Hawaii	Prohibited	
Idaho	Allowed	Oct. 15 - Apr. 15
Illinois	Prohibited	
Indiana	Allowed	Oct. 1 - May 1
Iowa	Allowed	Nov. 1 - Apr. 1
Kansas	Allowed	Nov. 1 - Apr. 15
Kentucky	Allowed	
Louisiana	Prohibited	
Maine	Allowed	Oct. 1 - May 1
Maryland	Allowed (in certain counties)	Nov. 1 - Mar. 31
Massachusetts	Allowed	Nov. 2 - Apr. 30
Michigan	Prohibited	
Minnesota	Prohibited (30 days non-residents only)	
Mississippi	Prohibited	
Missouri	Allowed	Oct. 1 - Apr. 1
Montana	Allowed	Oct. 1 - May 31
Nebraska	Allowed	Nov. 1 - Mar. 15
Nevada	Allowed	Oct. 1 - Apr. 30
New Hampshire	Prohibited	
New Jersey	Allowed	Nov. 15 - Apr. 1
New Mexico	Allowed	
New York	Allowed	Oct. 16 - Apr. 30
North Carolina	Allowed	
North Dakota	Allowed	Oct. 15 - Apr. 15
Ohio	Allowed	Nov. 1 - Apr. 15
Oklahoma	Allowed	Nov. 1 - Apr. 1
Oregon	Allowed	Nov. 1 - Apr. 30
Pennsylvania	Allowed	Nov. 1 - Apr. 1
Rhode Island	Allowed	Nov. 15 - Apr. 1
South Carolina	Allowed	
South Dakota	Allowed	Oct. 1 - Apr. 30
Tennessee	Allowed	Oct. 1 - Apr. 15
Texas	Allowed	
Utah	Allowed	Oct. 15 - Apr. 15
Vermont	Allowed	
Virginia	Allowed	Oct. 15 - Apr. 15
Washington	Allowed	Nov. 1 - Mar. 31
West Virginia	Allowed	Nov. 1 - Apr. 15
Wisconsin	Prohibited	
Wyoming	Allowed	

Table 1.2. Regulations on Use of Studded Tires.

<table>
<tr><th colspan="2">Country</th><th>Regulation</th><th>Reference</th></tr>
<tr><td rowspan="10">Canada</td><td>Ontario</td><td>Prohibited</td><td rowspan="13">Ref. 5</td></tr>
<tr><td>Quebec</td><td rowspan="2">Oct. 15 - April 15</td></tr>
<tr><td>Nova Scotia</td></tr>
<tr><td>Newfoundland</td><td>Nov. 1 - April 30</td></tr>
<tr><td>New Brunswick</td><td>Oct. 16 - April 14</td></tr>
<tr><td>Prince Edward Island</td><td>Oct. 1 - May 31</td></tr>
<tr><td>British Columbia</td><td rowspan="2">Oct. 1 - April 30</td></tr>
<tr><td>Manitoba</td></tr>
<tr><td>Saskatchewan</td><td>No Restriction</td></tr>
<tr><td rowspan="3">Scandinavia</td><td>Germany</td><td>Prohibited</td></tr>
<tr><td>Sweden</td><td>Oct. 31 - Easter</td></tr>
<tr><td>Finland</td><td>Nov. 1 - March 31</td></tr>
<tr><td colspan="2">Japan</td><td>Prohibited</td><td>Ref. 6</td></tr>
</table>

2. STUDDED TIRE TRACTION PERFORMANCE

Tire traction performance is mainly controlled by the characteristics of the friction between tire and pavement surface. The special surface characteristics of studded tires result in different friction performance. The main difference between a studded tire and a non-studded tire is the studs embedded in the tread. The studs may result in increased friction factors when a vehicle equipped with them travels on an icy or snowy surface. The direct physical phenomena of tire friction characteristics can be converted to stopping distance, starting traction, maximum climbing slope, and maximum cornering speed. Most traction performance tests of studded tires, carried out by agencies in North America and North Europe in the 1960's and early 1970's [7 - 12], were limited to stopping distance evaluations. Statistically, these studies suggested that studded tires resulted in a reduced stopping distance on icy or snowy surfaces, but an increased stopping distance on dry or wet surfaces, compared to standard highway and snow tires. New types of tires have been developed during this time period. The newly developed tires may show better traction performance than older types of highway and snow tires. The following sections summarize tire traction studies from available literature and data.

a. Friction Performance

Two major studies of studded tire friction characteristics were conducted and reported in the last two decades. One was conducted by the Pennsylvania Transportation Institute (PTI) in 1982 [13], and the other one was performed by Swedish Road and Traffic Research Institute (VTI) in 1990 [14].

PTI Study

In this study, a selected set of test procedures measured the braking, driving traction, and controllability of vehicles fitted with tires and tire-associated traction aids intended to increase available friction on icy and snowy surfaces. The traction or driving aids included snow tires, studded tires, four-wheel drive, and anti-lock brakes. The following tests were run.

Test 1 (Locked-Wheel Braking):

Locked-wheel braking friction at a speed of 20 mph.

Test 2 (Traction):

Spinning driving traction at a vehicle speed of 5 mph with the traction force measured at a slip ratio greater than 1.

Test 3 (Controllability):

Spinning driving traction with the test vehicle not moving and tire slip speed greater than 10 mph.

Test results from the experimental program are summarized in Table 2.1, which gives typical friction values for all these tests. Conclusions are summarized as follows.

Test 1:

On icy surfaces, studded tires had slightly better friction performance (larger friction factor) than other driving aids. On snowy surfaces, studded tires had the same friction performance as snow tires, but performed better than other driving aids. On wet surfaces, basically, all driving aids had the same friction performance.

Test 2:

On icy surfaces, four-wheel drive performed best. The studded tires were worse than four-wheel drive, but better than other driving aids. A snowy surface produced similar results, except that studded and snow tires had the same performance. On wet surfaces, four-wheel drive had the best performance, and all others were the same.

Test 3:

On icy, snowy, and wet surfaces, four-wheel drive and anti-lock brakes had significantly better performance.

VTI Study

In August, 1988, the Swedish Government asked Swedish National Road Administration and the Road Safety Office to investigate the possibilities of reducing road wear by means of modified regulations concerning studded tires or other actions. One of the study objectives was to investigate the changes since a similar study in 1975, if any, in stud friction and friction differences between modern studded and non-studded winter tires and

Table 2.1. Vehicle Friction Factors for Various Driving Aids [13].

Driving Aids	Locked-Wheel Braking			Traction			Controllability		
	Ice	Snow	Wet	Ice	Snow	Wet	Ice	Snow	Wet
Highway Tires (No Traction Aid)	.08	.15	.4	.024	.03	.19	.08	.15	.4
Snow Tires (On Rear Only)	.08	.175	.4	.024	.055	.19	.08	.175	.4
Studded Tires (On Rear Only)	.09	.175	.4	.032	.055	.19	.09	.175	.4
Four-Wheel Drive	.08	.15	.4	.064	.12	.37	.16	.3	.8
Anti-Lock Brakes (4-Wheel System)	.08	.15	.4	.024	.03	.19	.16	.3	.8
Anti-Lock Brakes (2-Wheel System)	.08	.15	.4	.024	.03	.19	.12	.23	.6

summer tires. During the test procedure, the braking force was increased gradually until the wheel was fully locked. The friction was measured as a function of the longitudinal slip, and the peak friction and optimum slip, as well as the locked wheel friction were evaluated. Results of the tests comparing the friction properties of studded and non-studded tires on smooth ice and ice roughened by studded tires are summarized in Table 2.2. Overall, studded tires showed better friction performance. In some cases, however, the studded tires gave no improvement in friction. This occurred at braking with optimum slip and at maximum cornering friction on very clean, smooth ice in the temperature range -3 to -7^{o} C. The study also found that the influence of speed on friction on ice was small for the summer tires, the non-studded and the studded tires.

b. Stopping Distance

Stopping distance has been considered one of the best indications of tire traction performance. Two studies are summarized here, one study conducted by the Alaska Department of Highway (AKDOH) in 1975 [12], the other study by the University of Alaska Fairbanks (UAF) in 1994 [15].

AKDOH Study

The purpose of this study was to compare garnet tires with studded tires and snow tread tires. All three types were tested on snow-adhered ice and glare ice in order to compare stopping distances. An area of Finger Lake located between Palmer and Wasilla, Alaska, was used as a test site. Stopping distance tests were performed from 35 mph with locked wheels and driver direction control. By combining all factors, including drivers and vehicles, the mean stopping distances are summarized in Table 2.3. From this table, it can be concluded that on ice with a thin film of snow present, the garnet tires appeared equal to radial snow tires, and the studded tires exhibited a 5% stopping distance advantage. Glare ice stopping distance tests indicated garnets had a 4% advantage over radial snow tires, and studded tires had an 8% advantage over radial snow tires. However, not all these differences were significant.

Table 2.2. Vehicle Friction Factors of Studded and Non-Studded Tires on Icy Surfaces [14].

Tire Type	Temperature: 0° C					Temperature: -1 to -14° C				
	Smooth Ice			Stud Roughened Ice		Smooth Ice			Stud Roughened Ice	
	Optimum Slip	Locked Wheel	Maximum Cornering	Optimum Slip	Locked Wheel	Optimum Slip	Locked Wheel	Maximum Cornering	Optimum Slip	Locked Wheel
Studded Tires	.14 - .21	.12 - .19	.16 - .17	.36 - .44	.24 - .33	.14 - .26	.12 - .19	.21 - .26	.18 - .27	.15 - .20
Non-Studded Tires	.09 - .11	.10 - .12	.12 - .12	.36 - .38	.20 - .23	.09 - .25	.10 - .14	.21 - .25	.14 - .27	.10 - .13

Table 2.3. Stopping Distances (ft.) of Various Tires [12].

	Surface Condition	
Tire Type	Snow	Ice
Radial Snow Tires	174.33	332.33
Garnet Tires	173.59	320.83
Studded Tires	166.56	305.33

UAF Study

This study was conducted in Spring 1994. Three different types were tested: studded tires, all-season tires, and a new type called "Blizzak," developed by Bridgestone Tire Company. In the field, packed snow, icy, and bare pavement surface conditions were used. Test results are shown in Table 2.4.

a. Packed Snow Surface

Field tests were conducted at Fairbanks International Airport, Chena Lake access road, and Old Nenana Highway, in Fairbanks, Alaska. Test results under a packed snow surface condition are presented in Table 2.4 with all test site data averaged. From this table one can see that Blizzaks gave about 15% shorter stopping distances on a full-sized car, but were about 15% longer in stopping distance on a pickup, compared to either the studded or all-season tires. Based on the average of all data from the three Fairbanks sites on hard packed snow and three testing vehicles, as shown in Table 2.4, it was concluded that all tire types gave equal stopping distances.

Table 2.4. 25 mph Stopping Distances (ft.) on Packed Snow, Icy, and Bare Pavement Surfaces [15].

	Front Wheel Drive Car (Lumina w. anti-lock brakes)	2 Wheel Drive F. S Pickup (Chevy w. anti-lock brakes)	Rear Wheel Drive Car (Caprice w. anti-lock brakes)	Average
Packed Snow Surface				
Blizzak Tire	62.2	79.3	50.7	64.1
Studded Tire	64.3	68.6	59.4	64.1
All-Season Tire	64.0	69.0	57.4	63.5
Icy Surface				
Blizzak Tire	104	122	128.5	118.2
Studded Tire	84	116.5	117.7	106.1
All-Season Tire	105.5	152.7	127.0	128.4
Bare Pavement Surface				
Blizzak Tire	N/A	16.3	N/A	16.3
Studded Tire	N/A	17.0	N/A	17.0
All-Season Tire	N/A	16.6	N/A	16.6

b. Icy Surface

The stopping distances on ice were typically two to three times longer than distances on packed snow. Test results were obtained at the Fairbanks International Airport test site. As shown in Table 2.4, stopping distances were shortest for the studded tires, followed by the Blizzaks, and then the all-season tire types. The average 25 mph stopping distances were 106 ft. for the studs, 118 ft. for the Blizzaks and 128 ft. for the all-season tires. Compared to the Blizzaks, studs shortened stopping distances by 15%, while all-season distances increased by 8%.

c. Bare Pavement Surface

Stopping distance tests were conducted at the Old Nenana Highway test site. Only a pickup truck was tested at this site. Two people were asked to drive the testing vehicle; one male, the other female. To statistically determine the differences between tires, driver type was combined, and the final results are shown in Table 2.4. From these results, it was concluded that on a bare pavement surface no significant differences were found between tires in terms of stopping distance. In these tests the Blizzaks and all-season tires showed 5% and 2% shorter stopping distances, respectively, than studded tires.

c. Starting Traction

Starting traction is considered as the traction ability of a vehicle demonstrated from a stopped state to a certain speed. Two major studies were conducted since 1973, by AKDOH (1975) [12] and UAF (1994) [15].

AKDOH Study

The tires (garnet, studded, and snow tires) were tested on glare ice in order to determine starting traction. One end of 300 pound spring scale was attached to an unmovable object, and the rear bumpers of the test vehicles was attached to the other end. The maximum traction force was determined by slowly applying torque to the rear wheels until the tires broke traction. The test results were shown as follows:

Radial Snow Tires:	Unable to move vehicle
Garnet Tires:	40 - 50 pounds

Studded Tires: In excess of 300 pounds

The traction test on glare ice showed that the same advantage was supplied by garnet tires but that it did not approach the effectiveness of the studded tires.

UAF Study

In the UAF study, the starting traction was defined as the time (in seconds) for a vehicle to reach a speed of 25 mph. Three tire types were tested, including studded tires, Blizzak tires, and all-season tires. Surface conditions tested were packed snow, ice, and bare pavement. Field results are summarized in Table 2.5.

a. Packed Snow Surface

Field tests were made at the Fairbanks International Airport, Chena Lake access road, and Old Nenana Highway test sites in Fairbanks, Alaska. According to the results shown in Table 5, except the studded tires, the front wheel drive car had the best traction, followed by the full size pickup, and then rear wheel drive car. For the studded tires, the full size pickup showed the shortest time to reach a speed of 25 mph from zero, and the rear wheel drive car had the longest starting time. To eliminate the effect of vehicle type, starting traction data from different vehicles were averaged. The average starting time to reach 25 mph for the studded tires and Blizzaks were about 9.2 sec. and 9.6 sec., respectively. The all-season tires took about 10.5 sec. to reach 25 mph. Basically, there was no significant difference between the Blizzaks and studded tires.

b. Icy Surface

In this test, only the Fairbanks International Airport test site was used due to weather condition limitations. As might be expected, starting traction tests on ice were very operator and vehicle dependent, as well as tire dependent (see Table 2.5). Front wheel drive cars were superior to rear wheel drives. Blizzaks and studded tires performed about equally on the pickup, and, on that vehicle, both were superior in starting time to all-season tires, by about 40%. On the average, for all vehicles, Blizzak starting times from zero to reach 25 mph were about 18% longer than those for studded tires, but about 13% less than times for the all-season tires.

Table. 2.5. Starting Traction Tests [Time to Reach 25 mph (sec.)] on Packed Snow, Icy, and Bare Pavement Surfaces [15].

	Front Wheel Drive Car (Lumina w. anti-lock brakes)	2 Wheel Drive F. S Pickup (Chevy w. anti-lock brakes)	Rear Wheel Drive Car (Caprice w. anti-lock brakes)	Average
Packed Snow Surface				
Blizzak Tire	8.88	9.50	10.41	9.60
Studded Tire	9.27	8.53	9.57	9.12
All-Season Tire	10.06	10.42	10.99	10.49
Icy Surface				
Blizzak Tire	12.70	13.00	17.53	14.41
Studded Tire	9.94	12.63	13.01	11.86
All-Season Tire	12.94	19.08	18.03	16.68
Bare Pavement Surface				
Blizzak Tire	N/A	3.52	N/A	3.52
Studded Tire	N/A	3.74	N/A	3.74
All-Season Tire	N/A	3.73	N/A	3.73

c. Bare Pavement Surface

Tests were conducted at the Old Nenana Highway test site. The testing vehicle, the pickup truck, was run by a male driver and a female driver, respectively. Test data are shown in Table 2.5 with all drivers combined. As indicated in this table, the Blizzaks gave slightly quicker starts, reducing by about 7% the time needed to reach 25 mph, compared to the studded tires and all-season tires. The studded and all-season tires had the same starting traction performance.

d. Cornering and Hill Climbing Ability Tests

Between 1973 and 1994, no major study about studded tire cornering and hill climbing ability has been identified. In the UAF study conducted in 1994 [15], both cornering and hill climbing ability were investigated.

Cornering test

The main purpose for running cornering tests was to estimate the maximum speed of a vehicle moving along a given curve covered with packed snow or an icy surface. The impact of tire type on this estimate can be evaluated from cornering tests in the UAF study. Maximum cornering speeds for different types of tires were tested in Fairbanks and Anchorage on curves with inside radii of 25 and 50 feet. Longer radius curves were not possible due to the widths of the available test areas. Observed speeds were reported by the vehicle operators, but these figures were not extremely precise due to the dual tasks of avoiding skidding while checking speeds. Data on the maximum speeds observed came from three to six test runs for each combination of tires and vehicles. Vehicle acceleration or deceleration data, called G-force, were measured by an instrument called "g Analyst" made by the Valentine Research Inc. The calculated maximum cornering speeds were based on the maximum cornering G-force measurements recorded during testing. Conversions were made by the following equation from the 1990 AASHTO Policy Manual on Geometric Design of Highways and Street:

$$\text{Maximum Cornering Speed (mph)} = \sqrt{\text{Radius(ft)} \times G \times 15} \qquad (2.1)$$

The lateral G-forces on snow typically were between 0.25 and 0.4, while G-forces on ice were between 0.1 and 0.2. At the point of skidding these forces are equivalent to the side friction factors used for highway curve designs. Due to tire spin and errors on the observed speeds, the G-forces and calculated speeds based on Eq. 2.1 were considered more accurate and were used for analysis and reporting of the Fairbanks and Anchorage test results, as summarized in Table 2.6. The data shown in the table were obtained by averaging data from all vehicles and runs for both right and left turns. From Table 2.6, it can be concluded that the Blizzaks out-cornered all other tires on both snow and ice in the Fairbanks trials, and also on snowpack in the Anchorage tests. The only exception occurred during testing on glare ice in Anchorage, where maximum cornering speeds for the studded tires were about 0.9 mph higher in cornering speed than the Blizzak tires. On all other surfaces there were no very significant differences, although the non-studded tire types out-cornered the studs by about 1 mph on average.

Hill climbing ability test

Hill climbing ability of a vehicle was evaluated by maximum G-forces. As shown in Figure 2.1, for the maximum slope that a vehicle can climb, the following equation is obtained:

$$m\, g\, \mu \,\text{Cos}\, \beta_{max} = m\, g\, \text{Sin}\, \beta_{max} \tag{2.2}$$

where

m - mass of the vehicle

g - natural acceleration

μ - coefficient of rolling resistance

β_{max} - degree of maximum slope

The maximum traction or maximum G-force, G_{max}, can be obtained when β is zero, as shown in Figure 2.2. In this case, the following equation is obtained:

$$m\, G_{max}\, g = m\, g\, \mu$$

or

$$\mu = G_{max} \tag{2.3}$$

By combining Eqs. 2.2 and 2.3, the following relationship is obtained:

$$G_{max} = \text{tg}\, \beta_{max} \tag{2.4}$$

Maximum highway grades or hill climbing ability of a vehicle can be calculated from Eq. 2.4 if the maximum G-forces are available.

Table. 2.6. Maximum Cornering Speeds during Cornering [15].

Fairbanks Tests

25 ft. Curve:	Packed Snow	Ice on Pavement
Blizzak Tires	12.1 mph	10.1 mph
Studded Tires	10.9	9.8
All-Season Tires	11.8	10.3

50 ft. Curve	Packed Snow	Ice on Pavement
Blizzak Tires	17.2 mph	14.2 mph
Studded Tires	15.9	13.6
All-Season Tires	17.2	13.7

Anchorage Tests

25 ft. Curve:	Packed Snow	Ice on Pavement
Blizzak Tires	12.0 mph	N/A
Studded Tires	11.2	N/A
All-Season Tires	11.4	N/A

50 ft. Curve:	Packed Snow	Lake Ice - Glazed
Blizzak Tires	14.7 mph	10.2 mph
Studded Tires	14.7	11.1
All-Season Tires	14.8	N/A

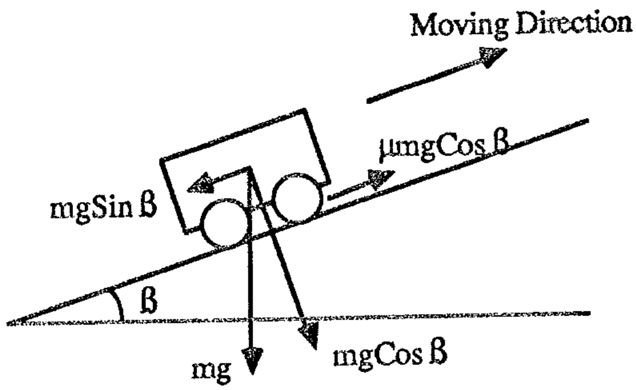

Figure. 2.1. Forces When a Vehicle Reaches Its Maximum Climbing Ability ($\beta = \beta_{max}$).

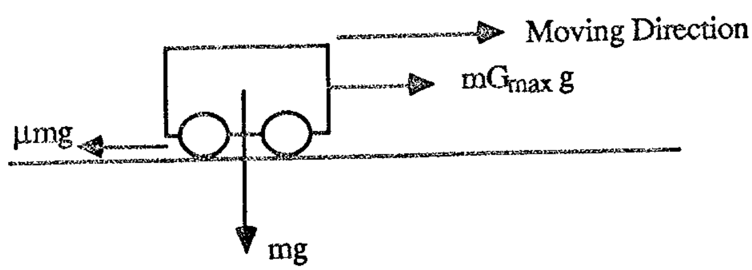

Figure. 2.2. Forces When a Vehicle is on a Level Surface ($\beta = 0$).

Field tests were conducted in Fairbanks and in Anchorage on packed snow and icy surfaces. The maximum G-force data were collected during starting traction tests in Fairbanks and Anchorage. Various vehicles with Blizzaks, studded tires, and all-season tires were tested for three to six repeated runs on given test sites. The average data of maximum G-forces or maximum starting grades were obtained from different vehicles and runs and summarized in Table 2.7. For tests in Fairbanks, by converting the maximum G-forces to hill climbing ability, it was concluded that the Blizzaks and studded tires would climb up to a 16 % grade on packed snow surface and 11 % grade on icy surface. The all-season tires would climb up to a 15 % grade on packed snowy surface and a 10 % grade on icy surface. Maximum highway grades are generally 8 % or less. Test results in Anchorage were almost identical. The hill climbing ability of a vehicle on bare pavement was controlled more by engine power than by tire type, since none of the test vehicles had the power needed to reach wheelspin on bare pavement.

Table. 2.7. Maximum Starting Grades [15].

Fairbanks Results:

	Packed Snow	Ice on Pavement
Blizzak Tires	16%	11%
Studded Tires	16%	12%
All-Season Tires	15%	10%

Anchorage Results:

	Packed Snow	Lake Ice - Glazed
Blizzak Tires	18%	10%
Studded Tires	16%	11%
All-Season Tires	15%	N/A

3. STUDDED TIRE SAFETY PERFORMANCE

a. General

The advantages of studded tires have generally been ascribed to their ability to improve vehicle traction for actions such as stopping, starting, and cornering on smooth icy surfaces. While these factors contribute to safe vehicle performance, their individual effects cannot be considered a measure of general highway traffic safety. The most important single safety benefit of studded tires is their ability to reduce the stopping distance of vehicles when traveling on icy surfaces. Improvement of starting traction on icy surfaces through use of studded tires is rated highly as a benefit by many motorists. But this is generally considered a convenience rather than a safety feature. On bare surfaces, it has been shown that regular tires perform best with regard to preimpact rotation and stopping distance, and studded tires performed worse than both regular and snow tires [1, 13, 15]. In fact, during the winter season, roadway surfaces are covered with snow or ice only a small part of the time. The majority of roadway surfaces are dry or wet. Table 3.1 presents some recorded surface conditions of roadways during winter seasons. The data shown in Table 3.1 are based on available literatures [1, 3, 16]. A study conducted by Takagi and Horita indicated that of all accidents resulting in injury or death during the winter of 1992/93 in Hokkaido, Japan, about 30 % occurred in slippery conditions while icy/snowy surfaces were present about 20 % of the time [17]. During this winter, the percentage of studded tires used in Hakkaido was about 30 %. The reduction of stud use occurred because the studded tire prohibition law was in effect in Japan since the winter of 1991/92.

A 1994 study conducted by Mäkinen in Finland indicated that on slippery and twisting road sections, drivers using non-studded tires drove more slowly than those using studded tires [18]. Based on study surveys and statistical analysis, the tire type did not explain accident involvement. Road slipperiness explained accidents better than the tire type.

In a study performed by Cornell Aeronautical Laboratory, Inc, of Cornell University [19], traffic accident data and questionnaire survey data were collected to analyze the safety effectiveness of studded tires. This study reported that of all vehicles in accidents, 14% were involved due to slippery road surfaces. Twenty-one percent of the accidents were caused by sliding. Of single vehicle accidents, 30% were caused by sliding. Accidents attributed to sliding were less severe than others, as measured by degree of injury and vehicle impact penetration. In accidents attributed to sliding, loss of directional control was the most frequent problem. The study also indicated that the use of studded tires was correlated with vehicle and owner characteristics such as vehicle size, owner age, sex, and annual mileage.

Table 3.1. Average Winter Road Surface Conditions [1, 3, 16].

State/Area	Dry/Wet Pavement %	Snow/Packed Snow %	Icy Pavement %
Alaska	65	22.6	12.4
Connecticut	96.5	3	0.5
Minnesota	75	12	13

b. Safety Problems Due to Studded Tire Associated Pavement Damage

Pavement ruts caused by studded tires have been considered a contributing factor to traffic safety. If ruts in the wheel paths are sufficiently deep, they interrupt the normal transverse run off of water from the pavement. Greater concentration of water in the ruts causes more splash and spray onto adjacent vehicles, increases hydroplaning accidents, and reduces driver visibility. An other disadvantage of studded tires affecting traffic safety is accelerated pavement marking loss caused by the increased wear from studs. Finally, vibration of the vehicle, accompanied by pronounced noise, increase both inside and outside of the vehicle. The vibration is caused by the roughened surface in the wheel ruts.

c. Accident Analysis

No major studies related to studded tire safety performance have been identified in the study. One of the reasons for this may be that the factors contributing to a traffic accident are too complicated to be identified. A NCHRP report published by the Highway Safety Research Institute of the University of Michigan proposed studies to analyze available accident data from the study highway system [20]. The proposed studies would be linked with the accident data to determine if a statistically meaningful relationship existed between studded tire associated pavement wear and traffic crashes. Basically, a multi-variable regression model was proposed. The main independent variables were the number of vehicle miles, the average depth of wear, the standard deviation of wear, the pavement type, and the percent of time that the pavement was wet. The dependent variable was the number of accidents. However, since then, no major reports covering traffic accident analysis related to studded tires have been found in North America. The main difficulties in performing any accident data analysis are the large amount of involved factors and the statistically rare nature of accident event probabilities. In Northern European countries, mostly in Finland, statistical methods have been used to analyze traffic accidents. Many factors were analyzed in these studies, including the use of studded tires. A typical study was conducted by Roine during 1987-1994 [21]. He used disaggregated survival models to study the effects of tires and their wear on road safety. Of particular interest was the potential impact on road safety if drivers were to replace studded tires with friction tires in the winter seasons. The analysis only included car drivers involved in fatal accidents involving two or more vehicles in the period from January 1, 1987 to December 31, 1991. The data base consisted of data on 1347 drivers. Out of 500 variables available, roughly 50 were chosen as most relevant for the analysis. These variables covered the categories of driver characteristics, vehicle characteristics, driver behavior, and route and road conditions. According to the research results, the best factors explaining lifetime and hazards of the drivers were the annual mileage, age of driver, driving speed before accident, use of alcohol, familiarity with the route, weight of the car, use of safety belt, and road conditions. Generally, tires seemed to have minor effects on hazards in this population. So far, the impact of the tire type on traffic safety has not been statistically quantified.

The effect of the studded tire ban on traffic accident rates was also evaluated by Alaska Department of Highway in 1973. The AKDOH study used data obtained from Minnesota and Ontario to investigate whether the studded tire ban regulation significantly increased accident rates. The data obtained from Minnesota and Ontario are summarized in Figures 3.1 and 3.2, respectively. Using the three previous winters when studded tires were legal as a basis of comparison, Figure 3.1 shows that there was no appreciable increase in total traffic accidents on snowy and icy surfaces in Minnesota. For the data obtained from

Ontario, a similar comparison method was used. Figure 3.2 shows that the general trend of yearly increases in the total number of highway accidents continued in 1971, at the same rate as in preceding years when studded tires were legal. Table 3.2 summarizes the total number of collisions obtained from Ontario. The total number of collisions that occurred on ice and packed snow decreased even though the total number of ice-covered roads increased by 87% over the preceding winter. Thus it appears that removal of studded tires in Ontario caused no increase in accident rates. Based on an analysis of the occurring accidents, the absence of studded tires does not appear to significantly affect winter safety.

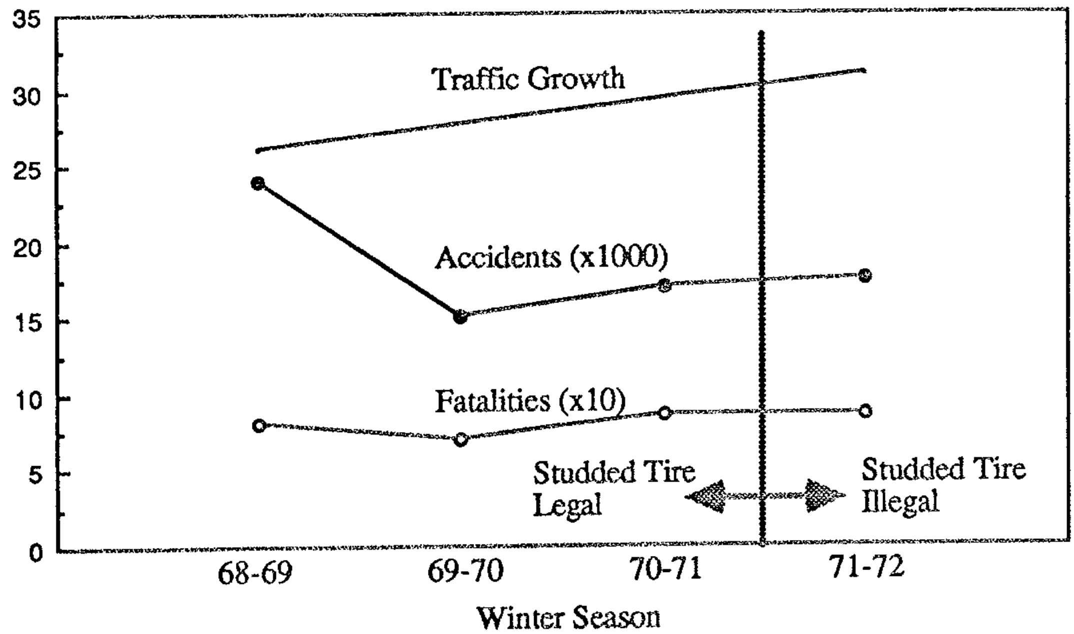

Figure 3.1. Minnesota Accidents on Snow or Icy Roads (November - April) [3].

In Sapporo, Japan, the Hokkaido Institute of Technology conducted a study in 1990 to evaluate winter traffic safety [22]. Studded tire usage, vehicle ownership, and number of winter traffic deaths during 1984 to 1990 were surveyed in this study. Figure 3.3 presents the results. In this figure, the studded tire usage ratio decreased year by year from 95% in 1985 to 55% in 1990. This trend was due to the various measures and campaigns launched by the City of Sapporo. Since 1984, the number of vehicles had been increasing, and in 1990, it exceeded 1984 total by 128%. An increase in vehicle numbers usually means a source of increase in traffic accidents, but the number of deaths during these years stayed at an even 10-11 per winter season. During this period, non-studded tires became more popular, and there was a growing concern for accident prevention, and even though the use of studded tires was prohibited, it was believed that accidents would not increase.

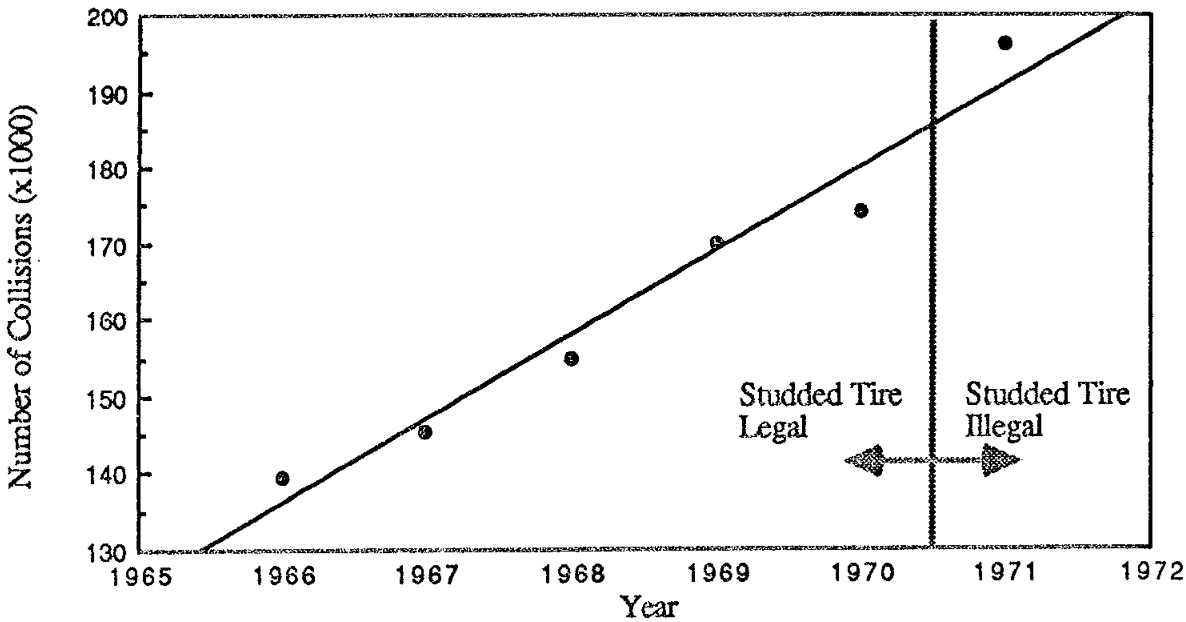

Figure 3.2. Trend in Total Collisions (Ontario, 1966 - 1971) [3].

Table. 3.2. Ontario Winter Accidents 1970/71 and 1971/72 [3].

Road Surface Condition	Property Damage		% Increase	Personal Injury		% Increase
	1970/71	1971/72		1970/71	1971/72	
Ice & Packed Snow	14,245	13,958	-2.0	3,427	3,554	3.7
Snow & Slush	22,348	22,324	-1.0	5,297	5,502	3.9
Other	48,506	62,997	29.8	17,121	21,671	26.6
Total	85,099	99,279	16.7	25,845	30,727	18.9

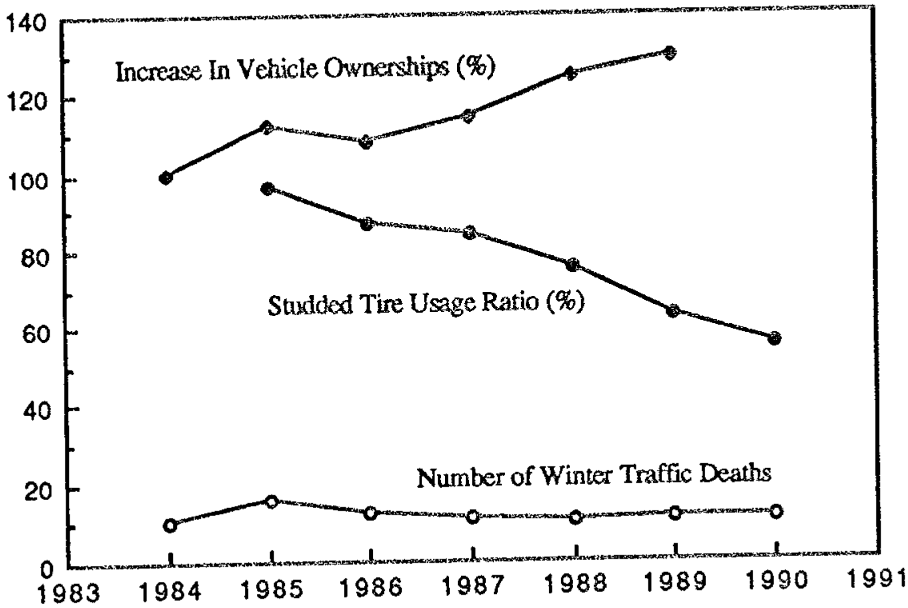

Figure 3.3. The Yearly Shift of Winter Traffic Deaths, Studded Tire Usage, and Vehicle Ownership in Sapporo, Japan [22].

d. Savings due to Ban Regulation

Despite their scarcity in the U. S., some studies about the influence of studded tires on traffic safety have been performed before [3, 23 - 28]. In 1994 the Institute of Transport Economics of Norway [23] performed sensitivity analyses to evaluate the influence of prohibiting studded tires on traffic safety and associated socio-economic savings. The results showed that prohibiting the use of studded tires yielded savings of 280 to 410 million NOK/year (1 US $ = 6.54 NOK). The accidents would, however, increase with 100 to 400 injury accidents/year. The analysis showed that prohibition of studded tires might prove profitable if the potential traffic accident increases were curbed by traffic safety measures.

A similar study was conducted in 1992 by the Swedish Road and Traffic Research Institute [26] to evaluate the influence banning studded tires on vehicle accident cost increases and maintenance cost reduction. In the study, it was concluded that a studded tire ban would result in an increase in costs of accidents on icy and snowy roads. However, a ban on studded tires would reduce vehicle owner cost, including expenses for tires and rims as well as car washing and windshield cleaning, and reduce municipal or public maintenance costs, including less erosion of pavement marking and pavement surfacing. Taking into account the reduction in road wear without adversely affecting road safety to any noticeable extent, the research group proposed alternatives to a ban on studded tires. These alternatives included (1) a smaller number of studs and lower stud weight, (2) continuation of management efforts to raise the pavement standard on heavily trafficked roads, and (3) introduction of performance tests for studded tires.

4. PAVEMENT SURFACE DAMAGE DUE TO STUDDED TIRES

a. General

Pavement damage caused by studded tires has been addressed since their introduction. According to the report by Western Photogrammetry Limited [27], during the 1968 spring "clean up" operations on the Metro street system, supervising engineers of the Metropolitan Corporation of Greater Winnipeg observed unusually severe wear in the wheel paths of pavement surfaces at many of the intersections, particularly in the region of vehicle acceleration and deceleration. They found this severe wear in the wheel paths was caused by studded tires. It was apparent that the Corporation faced a serious problem, studded tire abrasion damage on its street system. Similar effects had been observed in other Canadian provinces, northern parts of the United States, and Scandinavian countries, causing widespread concern.

Two types of stud-induced changes on pavement surface have been addressed: the extent of rutting, and alterations in pavement friction properties. Additionally, accelerated wear of pavement markings has been reported. These changes or damages definitely constitute safety related problems for the traveling public. Research studies on this issue have been reported in past two decades [1, 5, 6, 16, 17, 20, 29 - 36].

b. Wheel Path Analysis

In one study, Kennametal Inc. [29] evaluated pavement wear caused by different types of studded tires and studs. Variables tested in the study were stud number, tire stud protrusion, tire stud flange diameter, different tire constructions, carbide pin shape, and stud weight. This study concluded that while it was impossible to eliminate all pavement wear due to the use of studded tires, new tire stud designs, in combination with improved pavement compositions, might reduce the problem.

Pavement wear in Alaska due to studded tires was estimated in 1973 by the Alaska Department of Highways [3]. This estimation was based on field measurements from southeast, central, and northern regions. The relationship between average wear in inches and studded tire passes per lane is shown in Figure 4.1. The difference between curves may be due to weather and humidity conditions. In colder, drier regions, studded tires may cause less wear, because pavement surface gets harder if the temperature is lower and/or the environment is drier, and its resistance to wear increases. In fact, according to Hicks, Scholz, and Esch [33], many factors contribute to pavement wear. These factors include the vehicles, tires, studs, pavement characteristics (geometry, material, surface condition), environment (humidity, temperature), and traffic (volume, speed, wheel track, contact mode) involved. With other factors constant, studded and non-studded tires do show different impacts on pavement wear. Figure 4.2 presents the difference between studded and non-studded tires as well as pavement type. This figure is taken from a study performed by Minnesota Department of Highway [11]. As shown in Figure 4.2, studded tires caused much more serious pavement wear, compared to non-studded tires.

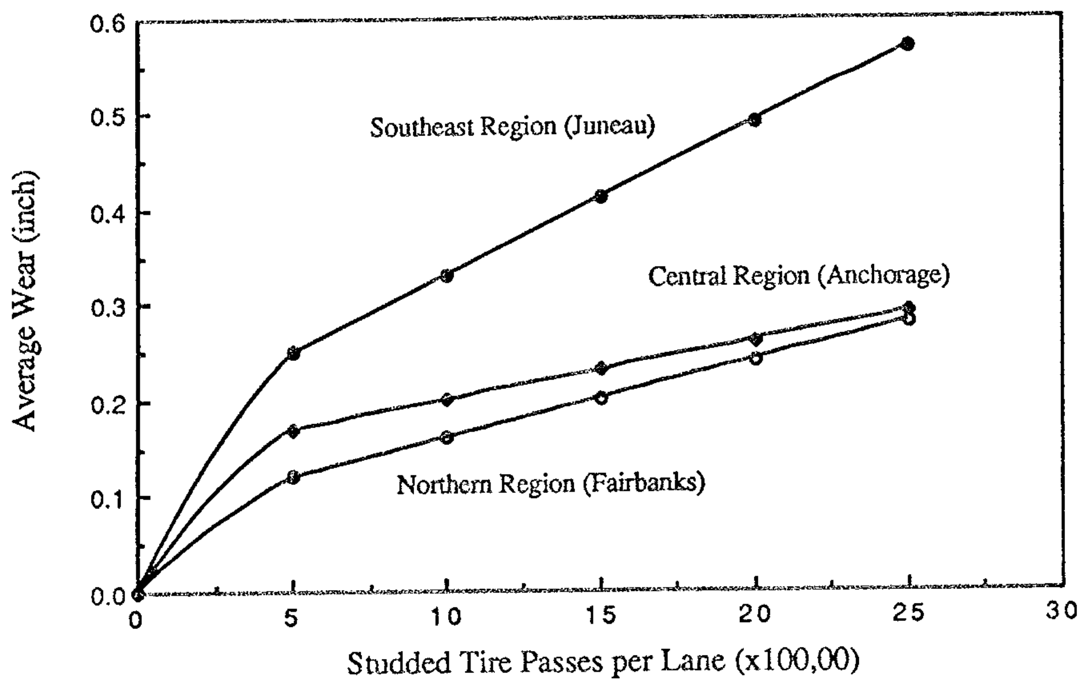

Figure 4.1. Pavement Wear due to Studded Tires in 1973 in Alaska [3].

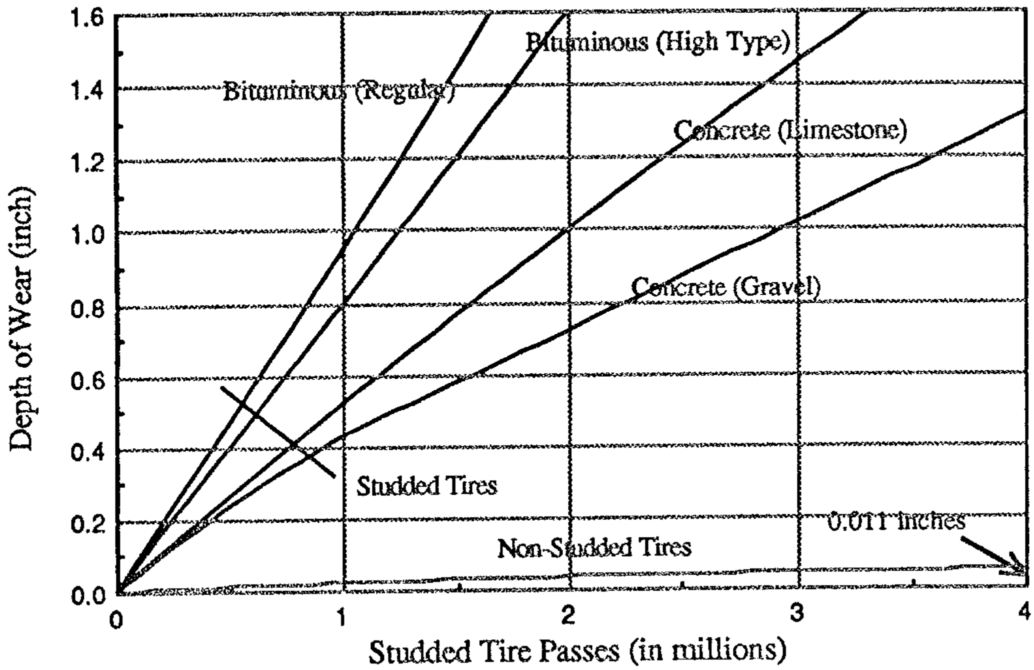

Figure 4.2. Average Wear Rates for Different Pavement Types at Test Track in 1972 [16].

In last ten years, studies about pavement wear have been performed and reported by agencies in the United States, Japan, and Finland. In 1989, the Alaska Department of Transportation and Public Facilities and Oregon State University began a joint research study to review literature as well as conduct a survey about wheel track rutting caused by studded tires [5, 33]. Although most of the information regarding pavement wear was collected from studies conducted before 1973, this study provided a very useful summary about the current use of studded tires throughout North America and North Europe, about results of road wear studies, and about consequences and benefits of using studded tires. In addition, roadway rut depth measurements were made in Juneau, Alaska at four locations. Measurements were taken at fixed points using five dial indicators mounted on a rut measurement bar. The resulting measurements are shown in Table 4.1. As indicated by the study investigators, the ruts were quite consistent at each of the three sites, and they were more shallow than any ruts reported by the other agencies surveyed (except Connecticut). The data collected on and before the bridge produced very similar wear ruts, eliminating the possibility that the measured rutting resulted from subgrade deformation. Measurements were also taken at different times of the year to isolate the pavement wear attributable to stud use during the winter and that of the "no studs allowed" summer seasons. It was reported that rut depths increased much more rapidly during the winter than the summer months. About 10% of the total rutting came from summer stud use.

Table. 4.1. Pavement Wear per Million Studded Tire Passes in Juneau, Alaska [5].

Location	Total Stud Passes by 4/91 (Millions)	Wear per Million Passes	
		Wear Rate (inches)	Wear Area (Square inches)
Juneau - Douglas Bridge On Bridge	5.37	0.148	9.31
Juneau - Douglas Bridge Before Bridge	5.37	0.134	9.92
Douglas Road	3.84	0.122	9.08
Mendenhall Loop	5.84	0.102	7.56

In Finland, a study about the effects of studded tires on road surface wear was reported by the Finnish National Road Administration in 1994 [34]. In the study, the effects of studded and non-studded winter tires on road surface wear were studied on a test track. Two surfaces were prepared for the experiment by spreading snow on a natural hard icy surface and packing it by driving lorries across it. Water was mixed into the snow to speed up the packing process. The two surfaces differed in respect to the amount of water used. Therefore they also exhibited different resistance to wear. The two test surfaces were worn by four test cars so that the left wheel track had about 85% of the wheel passes from studded tires and 15% from non-studded winter tires (stud track). The right wheel track underwent 15% of the wheel passes from studded tires and 85% from non-studded winter tires (the comparison track). Surface wear in the stud track occurred twice as fast as in the comparison track on the harder of the two surfaces. On the softer surface, the speed of wear was about the same in both tracks. The conclusion was that on the harder surface studs loosened small bits of the ice and snow surface, which did not happen on the softer surface.

Pavement wear amount is assumed to correlate with equipping percentage of studded tires. A major study was performed in 1994 by Takagi and Horita of Hokkaido Development

Bureau of Japan to prove such correlation [17]. This study was conducted in Sapporo where no special anti-abrasion or anti-rutting pavement mix was employed. The average wear for each year is shown in Figure 4.3. This figure indicates that the actual measurement of wear correlated closely with the equipping rate of studded tires, and a decrease in equipping rate led directly to a decrease in wear. Konagai, Asano, and Horita [6] reported that the worn amount of asphalt pavement during the 1990-91 winter was 33% less than it was in the 1989-90 winter. This drop was linked to the declining percentage of studded tire use.

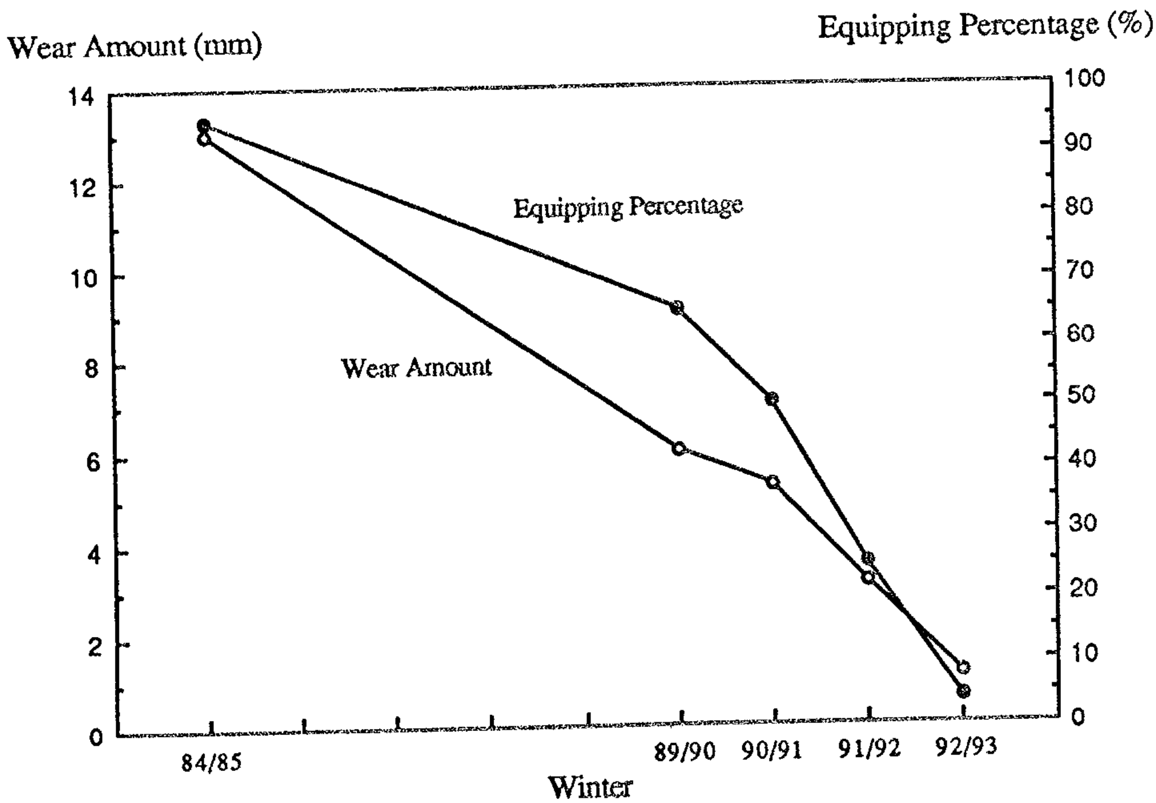

Figure 4.3. Equipping Percentage of Studded Tires and Wear Amount [17].

c. Pavement Marking Wear Analysis

Takagi and Horita's study also summarized and reported on the pavement marking wear caused by studded tires [17]. Using light reflection measurement equipment, the pavement marking diffuse reflection factor was surveyed on National Road 36 in Sapporo of Japan where pavement markings were restored every spring. According to their summary, outside lines, central lines, and lane lines were measured with the reflection measurement equipment. Field results are shown in Figures 4.4.a, 4.4.b, and 4.4.c for the three types of lines, respectively. The outside lines were often covered with snow, and the central lines were often run over by right-turning vehicles. Due to the studded tire ban regulation, the equipping percentage of studded tires decreased dramatically in the winter of 1992/93. The pavement marking diffuse reflection factor of the central and lane lines decreased significantly slower during that winter than in previous years, as shown in Figures 4.4.b and 4.4.c. This study clearly shows that decreasing studded tire use can increase the service life of pavement markings.

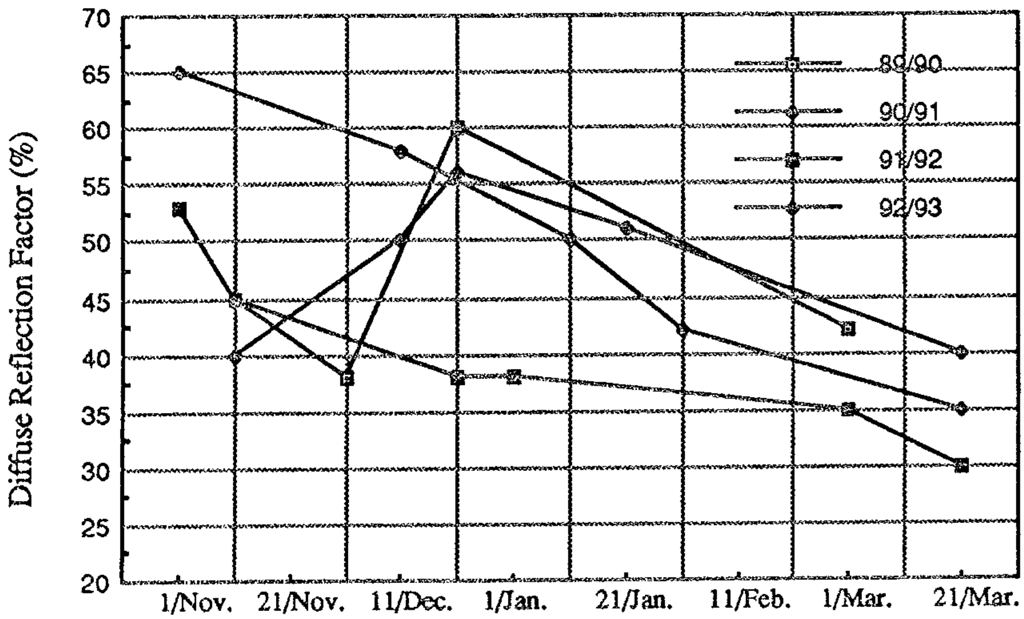

Figure 4.4.a. Pavement Marking Disappearance (Outside Line) [17].

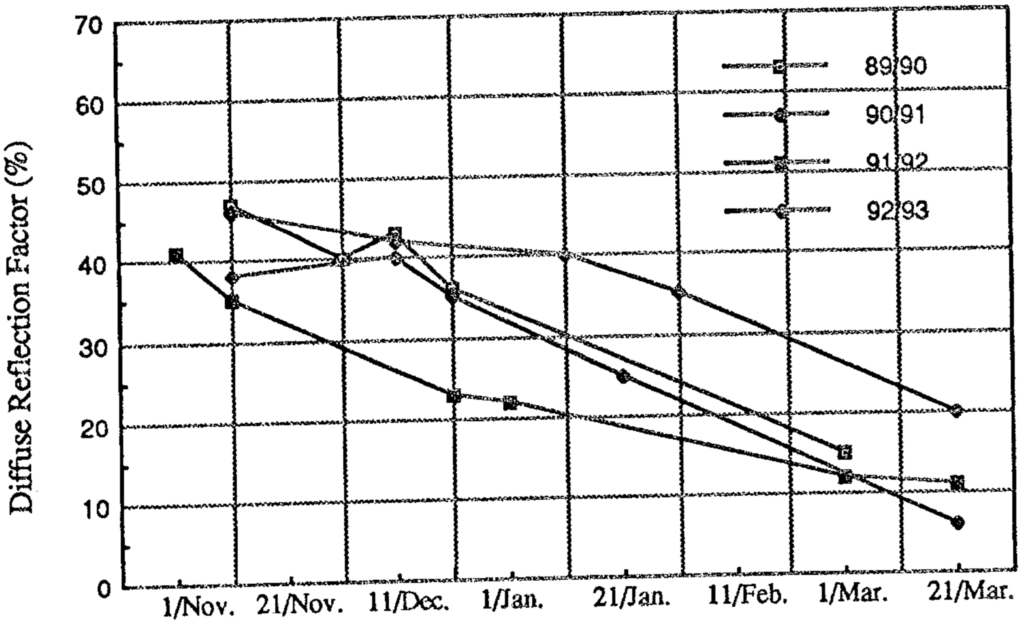

Figure 4.4.b. Pavement Marking Disappearance (Central Line) [17].

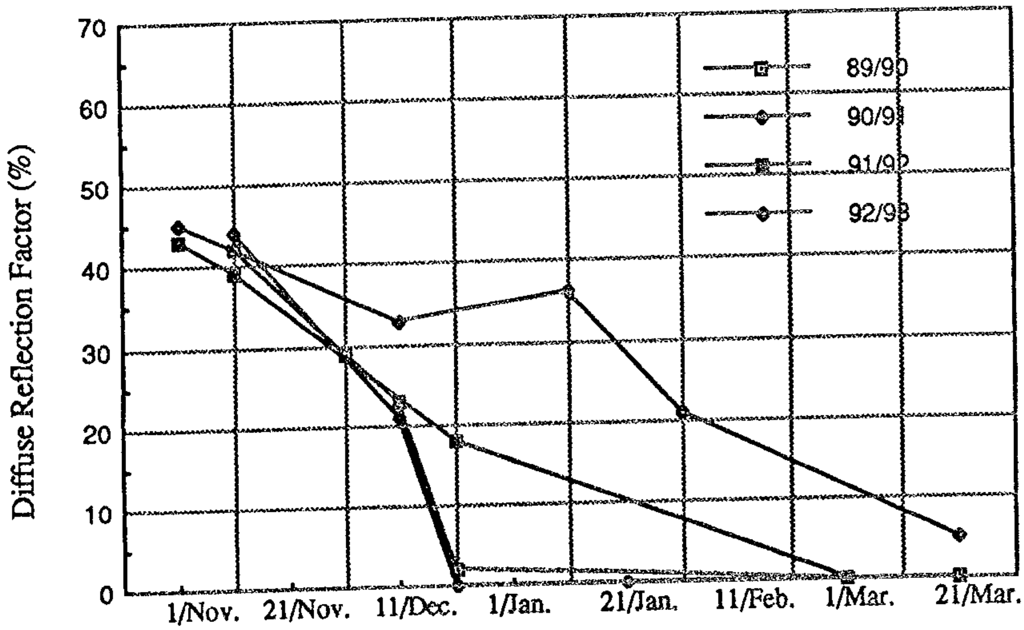

Figure 4.4.c. Pavement Marking Disappearance (Lane Line) [17].

d. Pavement Wear Cost

Each year, money must be spent to repair pavement wheel path damage and pavement marking damage caused by the use of studded tires. As this wear progresses, the ruts deepen to the degree that they cause vehicle steering problems and pavement structure strength loss. As indicated in the Alaska Studded Tire Study, Phase III, conducted in 1973 [3], the depth of wear at which asphalt pavement must be repaired to avoid those problems was 3/4 of an inch, and, to minimize salt water infiltration into concrete bridge decks, a minimum of 1 inch of concrete must be maintained over the reinforcing steel.

Costs of pavement wear due to studded tires have been estimated by state agencies and agencies in other countries. Table 4.2 presents the 1973 damage cost estimation in Alaska for the highway primary and secondary systems only [3]. Wear cost in different cities and areas are listed in this table. For wear cost analyses conducted by other agencies, typical results along with pavement replacement costs, are shown in Table 4.3.

Table 4.2. Alaska Highway Annual Wear Cost (Primary and Secondary System only) [3].

Areas	Wear	Paint Striping
Anchorage	$8,803,270	
Ketchikan	$3,036,881	
Juneau	$2,281,478	
Sitka	$500,000	
Fairbanks	$462,060	
Statewide		$670,700
Total :	$15,754,389	

Table 4.3. Annual Cost Effects of Studded Tires on Pavement Wear.

Agency	Repair Costs	Year	Reference
Alaska	+ 5 Million	1990	[33]
	+ 16 Million	1973	[3]
Connecticut	+ 50 Million	1978	[1]
Oregon	+ 1.1 Million	1993	[5]
Finland	+ 175 - 250 Million MKS	1978	[5]
Swenden	+ 300 - 400 Million SEK	1992	[26]

5. OTHER IMPACTS OF STUDDED TIRES

In past studies, major consideration has been given to the impacts studded tires have on vehicle traction, roadway safety, and pavement wear, as described in previous chapters. In fact, studded tires affect other factors, such as driver behavior, fuel consumption, and environment. Based on collected information, no major study specifically addressing these factors has been performed. However, some reports based on the studies conducted in Japan and Northern European countries discuss the effects peripherally.

a. Driver Behavior

Driver behavior is an important factor in traffic safety. Studded and non-studded tires have different impacts on driver behavior. The Finnish National Road Administration conducted a study to investigate the effects of studded tires on driver behavior [18]. Basically, the study objectives were to evaluate driver behavior when test subjects switched from studded to non-studded tires. The evaluated behavior included recording the number of trips made, use of other transportation modes, timing of trips and choice of driving routes, and driving speed and use of braking in various conditions. According to this report, switching from studded to non-studded tires had no effects on the number of trips made, timing of trips, use of other transportation mode, or driving routes. However, after switching to non-studded tires, drivers seemed to take driving conditions into account by negotiating steeps curves more carefully and using their brakes more softly than before.

Another study conducted in 1993 by the same agency [37] investigated driver behavior while driving in queues and on sharp curves during winter with studded and non-studded tires. This study focused on roads with slippery surface conditions. Speed models used in the study suggested that drivers with studded tires drove at somewhat higher speeds on curves than drivers with non-studded winter tires. However, there were no major differences in the average safety margins between drivers with studded tires and drivers with non-studded tires. The average speed of drivers with studded tires in queues on main roads was a little higher than the speed of drivers with non-studded winter tires.

b. Fuel Consumption

A difference in fuel consumption may exist between use of studded and non-studded tires, which is probably due to the effects of vibration and noise caused by studded tires and braking behavior. A fuel consumption study performed by the Finnish National Road Administration in the winter of 1993/94 [38] evaluated the effects of icy and snowy road surface conditions on fuel consumption. Comparing fuel consumption performance between studded and non-studded tires was one of the the study tasks. The resulting report concluded that fuel consumption with studded tires was 1.2% higher than with non-studded winter tires.

c. Environment

Studded tires primarily impact environment by increasing the density of dust or suspended particulate matter from the road surface scraped by the studs. The pavement particles are dispersed in the area adjacent to the road and pollute any available surface water. The dust produced by studded tire use has become a source of environmental pollution. It is believed that a lower the percentage of studded tires, will lessen the density of suspended particulate matter or dust. Figure 5.1 presents the density of suspended particulate matter during the winters of 1987/88 to 1991/92 in Sapporo, Japan. The percentage of cars equipped with studded tires (equipping percentage) are also shown in this figure. These results are obtained from a study conducted by the Hokkaido Development Bureau of Japan [6]. This figure indicates that as the percentage of cars with studded tires decreased, the density of suspended particulate matter also decreased. Environmental standards of Japan stipulate that the average density of suspended particulate matter must be less than 0.1 mg/m^3 in 24 hours or less than 0.2 mg/m^3 each hour. Figure 5.2 shows the number of days exceeding the amenity standard with the results obtained from the same study. It is clear that reducing the percentage of cars with studded tires would result in a decreased number of days in which the amenity standard was exceeded.

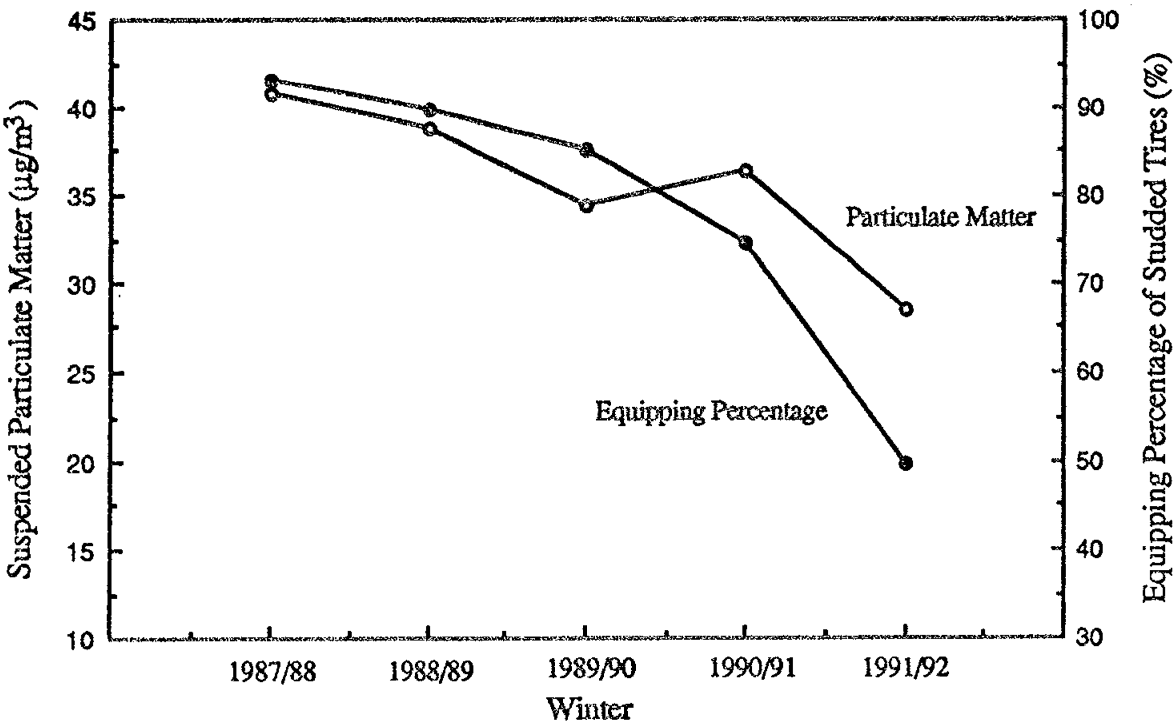

Figure 5.1. Density of Suspended Particulate Matter and Equipping Percentage of Studded Tires at Each Year [6].

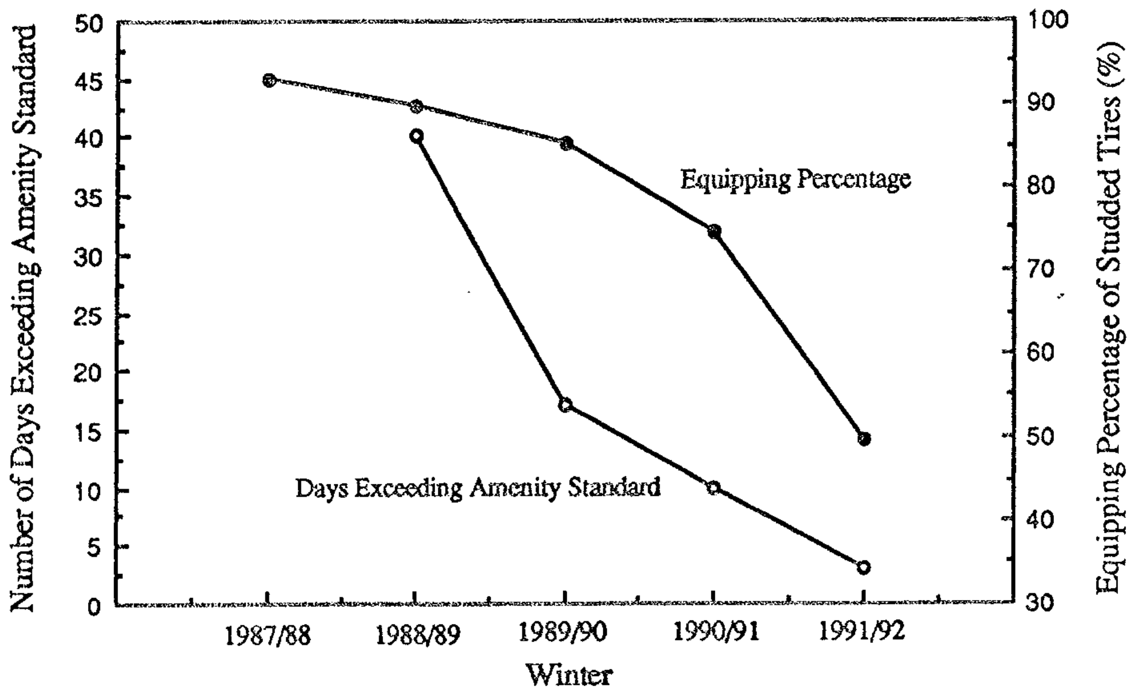

Figure 5.2. Number of Days Exceeding Amenity Standard and Equipping Percentage of Studded Tires at Each Year [6].

d. Health Effects

As stated previously, the use of studded tires results in an increased density of dust or suspended particulate matter from the road surfaces. The increased amount of airborne particulates may influence daily mortality and hospital admissions. As reported in a 1994 study by the School of Public Health of Harvard University [39], associations between daily mortality and various measurements of airborne particulates were observed and proven. According to the study, the results from recent studies of acute effects of particles on daily mortality in U.S. and Canada suggested approximately an 1% increase in daily mortality for a 10 $\mu g/m^3$ increase in daily PM_{10} (particulate matter) and about 2 - 4% increase in hospital admissions (asthma or respiratory admissions) for a 10 $\mu g/m^3$ increase in daily PM_{10}. Other adverse health effects accompanying exposure to particles, such as an increase in asthmatic attacks and bronchodilator use or a decrease in pulmonary function measurements, have also been reported. This study suggested that the regulatory control decisions on sources of particle emissions incorporate the recent epidemiologic evidence on mortality and morbidity effects of airborne particles.

Based on the study conducted by Hokkaido Development Bureau of Japan [6], the law prohibiting the use of studded tires resulted in a 10 $\mu g/m^3$ decrease in average particulate matter as shown in Figure 5.1. If the same decrease in particulate matter were applied to the U.S. and Canada, banning studded tires would result in about 2 - 4 % reduction in hospital admissions, according to the study conducted by the School of Public Health of Harvard University.

6. SUMMARY

This report summarizes a study performed by the University of Alaska Fairbanks, which conducted a literature review on studded tire safety and performance. Most of the summarized results were obtained from studies conducted after 1975. The main areas discussed in the report cover (1) studded tire traction performance, (2) studded tire safety performance, (3) pavement wear due to studded tires, and (4) effects of studded tires on driver behavior, fuel consumption, and environment. Main conclusions are listed as follows.

Very few research studies have been done in the North America in last two decades, but Japan and some Northern European countries have conducted relevant studies. Major tire manufacturers and vehicle insurance companies were contacted, as part of this study, to survey performance information on studded tires. However, no records or data were available from tire manufacturers and vehicle insurance companies.

In the United States, it is estimated that of all 50 states, 22% of state agencies prohibit the use of studded tires, 68% restrict their use, and 10% allow the use of studded tires.

New types of non-studded winter tires have been developed in the last two decades; the Blizzaks are one example. On icy surfaces, studded tires showed some traction advantage over non-studded winter tires. On snowy surfaces, no significant difference between studded and non-studded winter tires were found. Finally, studies have concluded that studded tires show poorer traction performance on dry or wet surfaces than non-studded tires.

Because too many contributing factors are involved in a vehicle accident, no major study has attempted to quantify the impacts of studded tires on vehicle accidents or vehicle safety. Based on results obtained from Japan and Northern Europe, however, it was concluded that banning studded tires would not significantly result in increased vehicle accidents.

Accelerated pavement wear, including appearance of wheel path ruts and pavement marking wear, is the major disadvantage of studded tires. Past studies showed that pavement wear caused by studded tires was much more serious than that caused by non-studded tires.

Studies have proved that the amount of pavement wear was proportional to the percentage of cars with studded tires. A decrease in studded tire use can increase the service life of a pavement surface.

Maintenance cost savings due to the ban of studded tire use have been estimated in several studies. For example, estimates such that the maintenance cost savings for Connecticut State would be more than 50 million US dollars per year. However, increases in accident costs due to banning studded tire use have not been estimated because the impact analysis of studded tires on highway safety is too complicated to quantify.

The effects of studded tires on driver behavior, fuel consumption, environment, and public health are also addressed in this report. The difference between the impacts of studded and non-studded tires on driver behavior was not significant. The average fuel consumption of vehicles with studded tires was about 1.2% higher than those with non-studded tires. Reducing the percentage of vehicles equipped with studded tires would result in a decrease in the density of dust or suspended particulate matter from the road surfaces. Recent studies have reported associations between daily mortality and hospital admissions and various measurements of airborne particulates. A ban on studded tires would decrease the particulate matter, and therefore decrease daily mortality and hospital admissions.

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