Use and Effects of Studded Tires on Oregon Pavements

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The use and effects of studded tires in Oregon are investigated, updating a 1974 report. Studded-tire use was surveyed, rut measurements collected, studded-tire traffic estimated, and pavement wear and damage analyzed. Studded-tire use in Oregon varies geographically. Half of the vehicles equipped with studs use them on all wheels, representing a significant change from 1974 practices. More than 23 percent of vehicles used studded tires in 1994. Studded-tire pavement wear coefficients were calculated and found to be half those reported previously. The coefficients for rigid and flexible pavements are 0.20 mm (0.008 in.) and 0.86 mm (0.034 in.), respectively, per 100,000 studded tire passes. Studded-tire wear will shorten pavement life on high-volume routes in Oregon. Asphalt pavements experiencing average daily traffic (ADT) volumes of 35,000 and 20 percent studded-tire use will reach the threshold rut in 7 years. Portland cement concrete (PCC) pavements experiencing 120,000 ADT and 20 percent studded-tire use will develop the threshold rut depth of 19 mm in 8 years. These estimates substantially reduce Oregon design life expectations for asphalt and PCC pavements. The estimated Oregon studded-tire damage for 1994 is $37 million for the state highway network, with similar damage for municipal and county roads. Alternatives are discussed to reduce the damage caused by studded tires, including a ban on studs, shortened use period, lightweight studs, user fees, and public education initiatives.

Studded tires were introduced in the United States in the early 1960s (*1*). Since that time, the public has come to associate improved traction and driving safety in winter with the use of studded tires. Numerous references have also indicated that studded-tire use increases the rate of pavement wear for both asphalt and portland cement concrete (PCC) surfaces.

The use of studded tires and the extent of pavement rutting attributable to them have been topics of spirited debate in the northern snow states, specifically whether user benefits are worth highway agency costs to repair damage caused by studded tires. For example the Alaska Department of Transportation and Public Facilities (DOT&PF) estimates highway damage from studded-tire use in Alaska to be $5 million annually (D. Esch, unpublished data). The Oregon Department of Transportation (ODOT) recently published a preliminary report (*2*) that estimates studded-tire damage for 1993 to be $24 million on the state highway system and $18 million on city and county roads, for a total of $42 million in damage statewide. This new ODOT estimate increased by an order of magnitude previous estimates of pavement damage from studded tires. Clearly, there is renewed interest in Oregon to accurately determine the rate of pavement wear from studded tires and whether perceived safety benefits outweigh annual highway damage.

BACKGROUND

Studded tires were first authorized in Oregon in 1967 (*3*). Within a few years, excessive pavement wear became apparent. This led to a 2-year study to determine studded-tire use and pavement wear rates within the state. The study also investigated whether the advantages afforded by studded tires justified the annual damage costs of pavement wear.

Oregon was not alone in its concern for studded-tire pavement damage. During the late 1960s and early 1970s, many northern states (Alaska, Connecticut, Iowa, Michigan, Minnesota, Nebraska, Pennsylvania, and Utah) were involved in similar studies (*4–8*), as part of a national concern about pavement wear attributed to studded tires. As a result, some states (including Illinois and Minnesota) prohibited the use of studded tires.

ODOT research efforts culminated in the publication of an internal document (*3*) in 1974 that reported that the use of studded tires varied by region (see Figure 1). In 1974, the statewide average of studded-tire use was 9.2 percent. The report also documented that almost all vehicles equipped with studded tires used them on only one axle, typically the drive axle.

Pavement wear rates were established, based on rut measurements at 16 sites. The 1974 wear rate for PCC pavements was reported to be 0.66 mm (0.026 in.) per 100,000 studded-tire passes and 1.67 mm (0.066 in.) per 100,000 studded-tire passes for asphalt pavements. Based on the pavement wear studies, the report estimated that more than 1,600 lane km would require maintenance earlier than they would without studded-tire use and that 150 lane km would require resurfacing annually due to studded-tire wear. The estimated annual cost for increased pavement wear was $1.1 million in 1974. ODOT recommended a prohibition on studded tires based on these costs and the inability to define sufficient safety benefits attributed to studded tires. However, no action was taken by the Oregon legislature to ban studded tires.

Since 1974, no extensive studies have been performed regarding studded-tire wear in Oregon. In 1994, the Oregon legislature (*2*) required that ODOT investigate current studded-tire use and pavement wear rates to determine whether the annual damage model and associated costs had changed since the 1974 study.

A separate related study was undertaken at Oregon State University. The purpose of this study (*9*) was to update the 1974 ODOT report regarding the distribution and use of studded tires in Oregon and to determine pavement wear rates, based on current traffic and rutting information. This information will enhance the existing studded-tire wear model and more accurately describe current annual pavement damage and costs attributed to studded tires.

OREGON STUDDED TIRE USE SURVEYS

Oregon studded-tire use surveys began during the winter of 1993–1994 and continued into the winter of 1994–1995. Studded-tire surveys were performed at 39 locations distributed throughout the state.

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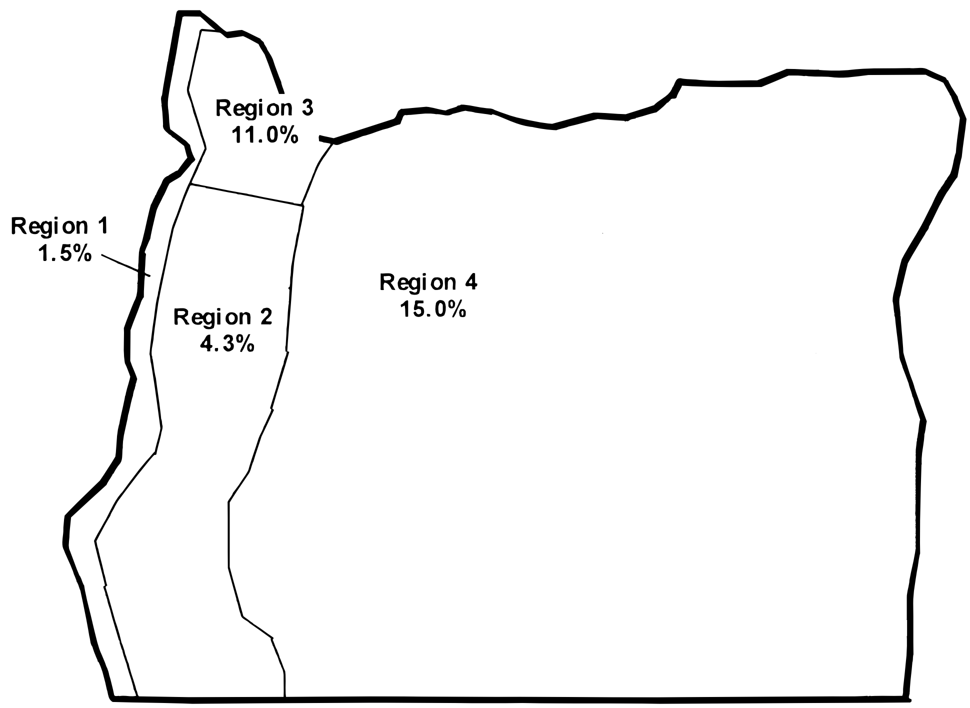

FIGURE 1 Historic Oregon studded tire use rate, reported in 1974 (*3*).

Initially, studded-tire use surveys were obtained from moving traffic at high-volume intersections. Determining stud use in moving traffic, where sound is used to discriminate the use of studs, has inherent problems. These problems include the inability to determine whether a vehicle is equipped with studs on all wheels, inaccuracies in the tallies due to high traffic volumes, and high noise levels generated at the sampling sites. Past moving-traffic studies in Oregon have underestimated studded-tire use compared with parked-vehicle counts on the same day (*3*). Because the principal use of studs is on passenger cars for the reasons listed above, the principal method used to obtain studded-tire use involved counting parked vehicles, primarily at shopping malls. The parked vehicle technique provides a very accurate portrayal of studded-tire use and enables the surveyor to determine whether a vehicle is equipped with studs on all wheels.

The percentage of studded-tire use was calculated by taking a simple ratio of the number of vehicles equipped with studs versus the total number of vehicles surveyed. This information was further refined by calculating an effective studded tire use rate, which compensates for the number of vehicles with studs on all four wheels. For example, a vehicle equipped with studs on all four wheels counts as two studded-tire passes per wheelpath, whereas a vehicle equipped with studs on one axle counts as a single studded-tire pass. Table 1 provides a sample calculation.

To compare past studded-tire use with current use, an effective studded-tire use rate was calculated for the same four geographic regions used in the 1974 report. It should be noted that these four geographic regions do not coincide with those currently used by ODOT.

The results of the 1994 studded-tire surveys are compared with the 1974 results in Table 2. Studded-tire use has increased substantially in all areas of the state. A significant change has occurred in studded-tire practices since 1974, when only in rare instances were vehicles equipped with studs on all wheels. In 1994, almost half of the vehicles equipped with studs have them on all four wheels. This has the effect of greatly increasing the effective percentage of studded-tire use. Increases have occurred in all areas of the state but not as dramatically as on the Oregon coast. Statewide, factoring in the number of vehicles with studs on all four wheels, the use is almost three times that reported in 1974.

Table 3 shows the studded-tire use trend since 1973. Note the data are not continuous; a notable 10-year gap exists between 1973 and 1983. Based on the available information, it appears that studded-tire use was relatively consistent up to 1992. After 1992, a dramatic increase in studded-tire use occurred. It is uncertain whether this increase in studded-tire use was gradual or whether the sampling methodology used previously was insufficient to characterize the true use rate. In either case, the use of studded tires is becoming increasingly popular and should cause Oregon residents concern because of pavement damage caused by studs.

TABLE 1 Methods of Reporting Studded Tire Use, Accounting for the Number of Vehicles with Studs on All Wheels, Sample Calculations

No. of Vehicles Surveyed	No. of Vehicles with Studded Tires	No. of Studded Tire Vehicles With Studs on All Wheels	Studded Tire Use Rate (%)	Effective Studded Tire Use Rate (%)
100	16	8 of the 16	16/100 = 16%	(16 + 8)/100 = 24%

TABLE 2 Comparison of 1974 Studded Tire Use with 1994–1995 Studded Tire Use

State Area	Studded Tire Use (1974)	Studded Tire Use (1994-95)	Effective Studded Tire Use (1994-95)
Area 1 Oregon Coastal Region	1.5%	8.9%	12.8%
Area 2 Central Willamette Valley	4.3%	10.3%	15.4%
Area 3 Tricounty, Portland Area	11.0%	15.6%	21.9%
Area 4 Central and Eastern Oregon	15.0%	37.6%	59.4%
Traffic Weighted Statewide Average	9.2%	15.9%	23.8%

RUT DEPTH DATA

All the rut depth information for the project was obtained from manual rut measuring techniques. The manual measurements involved the use of a 1.2-m-long (4-ft-long) aluminum channel straight edge, equipped with a single brass or steel dowel. The dowel is machined to allow free vertical movement, perpendicular to the straight edge, and is calibrated to measure the depth of rutting to the nearest 1.6 mm ($\frac{1}{16}$ in.). A maximum rut depth was recorded for each wheel track and a paint dot applied to the pavement for each travel lane. The purpose of the paint dot was to mark the location of maximum rut for each wheelpath, which then could be used as a reference for recording the center-to-center distance between wheel tracks. The center-to-center distance was further used as an aid to identify the vehicle type causing the rutting.

Rut measurement site selection was based on a variety of criteria including pavement type (e.g., flexible or rigid), pavement age, traffic volumes, and number of travel lanes. To obtain better isolation of studded-tire wear, only sites with multiple lanes were used in the study. Rut depths were measured in the lanes most frequented by passenger cars and compared with those obtained in the outermost lane.

The longitudinal distance between measurements was acquired using two basic approaches at each site. One technique involved measuring ruts at 0.16-km (0.1-mi) increments for a specified road segment. Measurements were obtained in both wheelpaths in each lane. Pavement segments with similar rut depth data were averaged for the analysis.

Another rut measurement approach involved manual measurements of pavement rutting at 7.6-m (25-ft) increments, for a total distance of 305 m (1,000 ft). Because both wheelpaths were measured in each lane, a total of 80 measurements were obtained for each lane in the 305-m-long (1,000-ft-long) pavement segment. The 80 measurement points were averaged for each lane as the representative rut depth. Because the traffic distribution, rut depths, and number of studded tire passes are unique for each lane, each lane represents a distinct data point that can be compared with all others in regression analysis. Based on this premise, several data points may be established at any one measurement site. Figure 2 portrays the methodology.

Rut measurements were taken during the fall of 1994 and spring of 1995 using the techniques outlined above. Rut depth measurements were obtained for 27 sites, establishing 18 data points for asphalt pavements and 36 data points for PCC pavement. Rut measurements reported in an ODOT preliminary report (*2*) were also used in this study for additional data points. This provided an additional 26 measurement sites (18 for asphalt and 8 for PCC pavements). In the final analysis, 36 data points were examined for asphalt and 45 data points for PCC pavements.

Rut depths varied with pavement type and age and studded-tire traffic. The deepest rut measured for asphalt pavements was 50 mm (2 in.), found on an 11-year-old pavement on US-26. The deepest rut measured for PCC pavements was 16.8 mm (0.66 in.), found on a 13-year-old section of I-205. Both of these pavements are in the Portland metropolitan area and experience average daily traffic (ADT) volumes in excess of 100,000.

Studded-tire rutting is distinctly different from permanent deformation rutting caused by heavy trucks. Stud ruts are typically found in the center lane or left lanes, where passenger cars predominate. Wheelpath ruts attributed to studded tires are also typically narrowly spaced, that is, the distance between wheel tracks is approximately

TABLE 3 Comparison of Historic Studded Tire Use With Current Use Patterns

Geographic Area*	Dates of Surveys					Effective Use
	1973-74	1983-84	1984-85	1989-90	1994-95	1994-95
1	1.5%	3.9%	1.5%	1.7%	9.4%	13.5%
2	4.3%	2.8%	3.4%	3.0%	10.4%	15.4%
3	11.0%	5.8%	5.5%	2.1%	14.5%	20.5%
4	15.0%	11.6%	14.2%	11.1%	37.6%	59.4%
Traffic Weighted Statewide Average	9.2%	6.7%	6.6%	4.7%	15.9%	23.8%

*See Table 2 for Description of regions

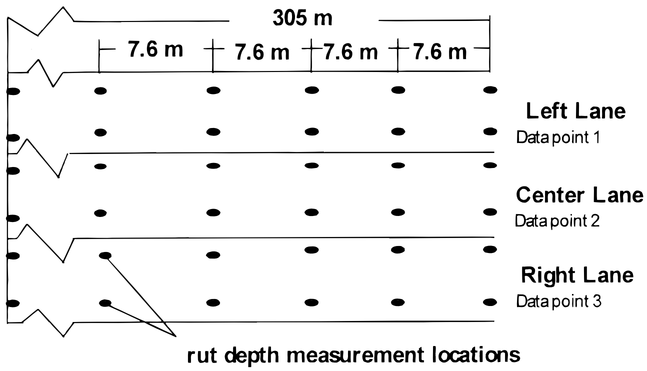

FIGURE 2 Rut depth measurement technique.

1.5 m (60 in.). This contrasts to heavy-vehicle rutting, which is most often found in the right lane where trucks frequently travel. Typical distance in load-related rutting is 1.8 m (70 in.), center to center. Studded-tire ruts are well defined and sharp shouldered whereas those caused by heavy wheel loads are broader and less severe in cross section.

It should be noted that, particularly in asphalt pavements, some rutting is caused by load-related effects. Without careful monitoring, it would be extremely difficult to separate load-related rutting from surface wear due to studded tires. Some researchers report a high initial permanent deformation rate that reaches a lower, stable rate after initial loadings (*4*). For purposes of this study, it is assumed that all the rutting damage is attributed to studded-tire surface wear except where wheel track spacing clearly shows heavy vehicles to be the cause of the rutting. All wear in PCC pavements was assumed to be caused by studded tires.

The distance between wheeltracks was also measured and is shown in Table 4. Note that the distance between wheeltracks varies among sites, with an average of 1.5 m (59 in.). Some of the variation in the distance between ruts is attributable to difficulty in locating the maximum rut depth on relatively new pavements. Nonetheless, the measured distance between ruts closely matches the tracking distance on a variety of intermediate-size passenger cars (*9*). This compares favorably with the average distance of 1.48 m (58 in.) reported in Alaska (*10*).

Of the sites measured, only three locations were found to have a wheel track separation that matches the tracking distance for trucks. All three were found in the right lane and were not used in the average reported in Table 4.

STUDDED TIRE USAGE

Traffic volume data for the study were obtained from the 1992 ODOT Traffic Volume Tables (*11*). This information was further augmented by data obtained from the ODOT Transportation Development Branch (G. Harvey, unpublished data), which provided growth rate and lane percentages for passenger cars for each pavement segment. Data provided by ODOT are based on past traffic counts and experience and are assumed to be accurate.

One can project forward (or backward) to estimate future (or past) traffic using the published traffic data and growth rates for a specific road segment. It is also possible to estimate the total number of studded-tire passes per travel lane using lane percentage, pavement age, seasonal traffic distributions, and historical studded-tire use.

TABLE 4 Distance Between Wheel Track Ruts

				Rut Depth, mm			Distance between Rut, meters		
Highway	Milepost	Pavement Type	Age, years[2]	Left Lane	Center Lane	Right Lane	Left Lane	Center Lane	Right Lane
I-5	243.0	F-mix	4	8.2		7.4	1.47		1.63[1]
I-5	245.5	F-mix	1	3.3		3.9	1.40		1.47
US 97	133.5	F-mix	6	11.7		21.4	1.52		1.45
US 97	140.4	F-mix	3	15.3		18.0	1.55		1.47
I-84	45.5	F-mix	1	2.4		3.5	1.50		1.55
I-5	242.75	B-mix	12	18.4		13.3	1.50		1.55
I-84	46.5	B-mix	9	8.5		13.9	1.63[3]		1.85[3]
I-84	20	B-mix	12	8.4		23.3	1.52		1.75[1]
ORE 22	3	B-mix	19	9.8		18.0	1.57		1.60
I-5	262	PCC	19		11.6	6.2		1.50	1.47
I-5	278	PCC	20		12.8	5.8		1.47	1.50
I-5	287.5	PCC	25		17.3	8.6		1.47	1.52
I-205	12	PCC	13		16.8	13.1		1.50	1.47
						Average	**1.52**	**1.50**	**1.50**

[1] Right lane rutting caused by heavy trucks, so not used in average

[2] Pavement age when ruts were measured

[3] Rutting in both lanes not used because ruts are due to heavy trucks

Pavement Wear Rate Calculations

It is assumed that the measured rut depth for each site is a function of the total number of studded-tire passes experienced by the pavement. It is further assumed that the rut depth represents the accumulated annual rut damage caused by the accumulated annual studded-tire passes for all previous years. For example, rut depth damage for a 1-year-old pavement can be estimated by the following:

$$Rut_1 = a \times TR_1$$

where

Rut_1 = rut depth for the first year after construction,
a = a damage factor or coefficient, assumed to be constant for a specific pavement type, and
TR_1 = total number of studded tire passes for the first year.

After the wear coefficient has been determined, the only variable in the equation is the number of studded-tire passes the pavement experiences.

For a pavement of age n, the total rut depth follows a similar relationship:

$$\sum Rut_n = a \times TR_1 + a \times TR_2 + \ldots a \times TR_{n-1} + a \times TR_n$$

The following procedure was used to determine the total number of studded-tire passes in a given traffic lane.

1. Determine the average annual daily traffic (AADT) from the 1992 ODOT Traffic Volume Tables.
2. Estimate past AADT and future AADT by adjusting for growth using the following relationships:

$$AADT_{x-1} = AADT_x/(1 + AG),$$
$$AADT_{x+1} = AADT_x(1 + AG)$$

where

$AADT$ = data from 1992 ODOT Traffic Volume Tables,
x = 1992 base year, and
AG = annual growth rate, assumed to be constant.

3. Determine the traffic in each direction (ADT_d) by assuming that the traffic is equally split for each direction of travel. This is estimated by simply halving the AADT for each year.

$$ADT_d = AADT/2$$

4. Determine the lane ADT (*LADT*) for passenger cars and pickups by multiplying the percentage of use, based on the ODOT-supplied lane percentage information.

$$LADT = \text{Lane split } \% \times ADT_d$$

5. The annual number studded-tire passes (*ASTP*) is determined by multiplying *LADT* by the percentage of cars and pickups in the traffic stream (from the 1992 ODOT Traffic Volume Tables), the percentage of annual traffic during the months that studded tires are used (seasonal percentage), and the percentage of studded-tire use to determine daily studded-tire passes in each lane. The annual number of studded-tire passes is determined by multiplying by 365 days.

$$ASTP = LADT \times \% \text{ (cars and pickups)} \times \% \text{ seasonal} \times \% \text{ studs} \times 365$$

6. Determine the cumulative number of studded-tire passes for each lane by summing the results of the annual studded-tire passes with the number of iterations based on the age of the pavement.

$$\sum_{i=1}^{n} ASTP$$

where n is the pavement age in years, and *ASTP* is the annual studded-tire passes.

To determine the coefficient of wear, a, for each pavement type, the rut depth information and the total studded-tire passes are plotted and a linear regression line is fitted to the data. The wear rate standard for this project was 100,000 studded tire passes.

Results of Oregon Studded-Tire Pavement Wear Studies

Pavement rutting was plotted against the estimated total of studded-tire passes for 27 of the 36 data points for asphalt pavements and all 45 data points for PCC pavements. Some points were removed from the analysis because the distance between wheelpaths indicated heavy truck rutting or substantial deviation from other data points. Because of the nature of flexible pavements and the inherent variability in asphalt mixes, pavement subgrade, and construction practices, it is not surprising that some data would be unsuitable for analysis. In contrast, the PCC data were very consistent, and all data points were suitable for analysis.

Figure 3 portrays the linear regression results for asphalt. The linear equation explains 87 percent of the variability in the data. The Y intercept, in part, reflects a higher initial wear rate for asphalt mixes. A lower rate of wear is reached within the first few hundred thousand studded-tire passes. Once the higher initial wear value is overcome, the average wear value for asphalt is 0.86 mm (0.034 in.) per 100,000 studded-tire passes.

Figure 4 depicts the linear regression results for PCC pavements and explains 68 percent of the data variability. More scatter exists in the PCC data due in part to the age of some of the sections. It was necessary to extrapolate nearly 30 years of traffic and studded-tire use rates. This undoubtedly affects the quality of the data. The slope of the best fit line was 0.20 mm (0.008 in.) per 100,000 studded-tire passes.

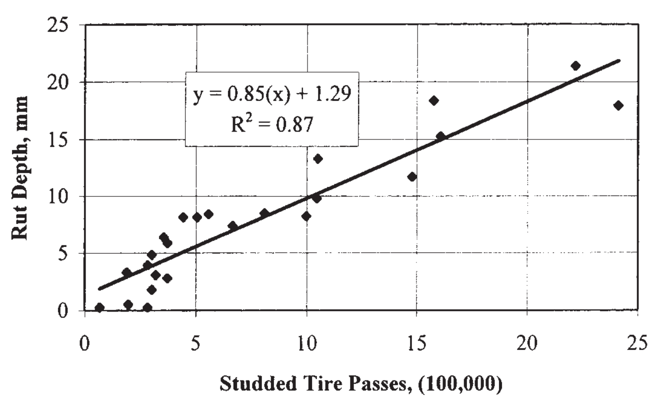

FIGURE 3 Asphalt studded tire wear rate results.

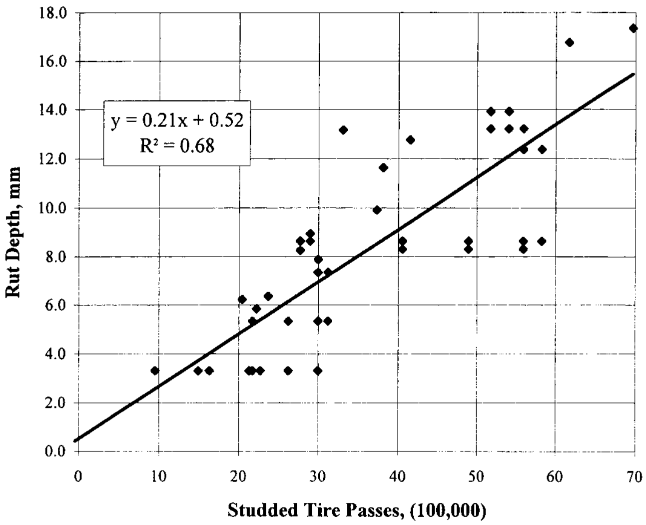

FIGURE 4 PCC studded tire wear rate results.

Table 5 compares the results of past and current studded-tire pavement wear results for Oregon and those reported by Hicks et al. (*12*) for Alaska. It is interesting that the results of the 1974 studded-tire wear studies are roughly twice the values determined in the current study. This finding is consistent with what has been reported by Cantz (*13*) and Cook (*14*), who reported that wear from the controlled protrusion stud was approximately one-half that of the conventional tire stud. The predominate tire stud used in the 1974 study was the conventional stud, whereas the current study is examining pavement wear caused by the controlled protrusion stud.

Oregon values are higher than the asphalt wear rate results reported for Alaska in 1990 (*12*). One possible reason is that the studies performed in Alaska are on lower-speed 55-km/hr (35-mi/hr) facilities, whereas the Oregon pavement sections are located on facilities with speeds in excess of 100 km/hr (65 mi/hr). According to European studies (*15*), increasing speed from 65 to 85 km/hr results in a 30 percent increase in asphalt pavement wear. Other possible reasons for increased wear in Oregon compared with Alaska are Oregon's warmer climate and lighter snow cover. Past studies have indicated pavement wear increases with increasing temperature (*16*). Neither of these factors is singularly responsible for a higher asphalt wear rate, but the combination may lead to higher rates of studded-tire pavement wear in Oregon.

Even though the number of data points for each asphalt mix type is limited, comparisons were made to determine if certain mixes are more resistant to stud wear than others. The results indicate dense-graded mixes (B mixes) are slightly less resistant to studded tire wear than open-graded mixes (F mixes). Using regression, stud wear for B mix and F mix was calculated to be 1.3 mm (0.050 in.) and 0.89 mm (0.035 in.) per 100,000 studded-tire passes, respectively. When viewed in the overall aggregate of asphalt mixes, open-graded mixes appear to offer no statistically significant advantage in stud wear resistance.

TABLE 5 Reported Studded Tire Wear Rates in Oregon and Alaska (in mm) per 100,000 Studded Tire Passes.

Pavement Type	1974 Oregon (4)	1990 Alaska (11)	1995 OSU (3)
Asphalt	1.68	0.84 [1]	0.86
PCC	0.66		0.20

[1] Average of 4 values reported in reference

The studded-tire wear resistance of mixes using modified asphalt was also examined. Unfortunately, only five data points were available for examination, and two of those were considered outliers. The average studded-tire wear resistance was calculated to be 0.41 mm (0.016 in.) per 100,000 studded tire passes, suggesting an improvement in stud wear resistance compared to unmodified asphalt mixes.

Given the limited data, the apparent reduction in pavement wear attributed to modified asphalt is not conclusive. Additional study is warranted, and, if the trend cited above is repeated, modified asphalt mixtures may provide a partial solution to the studded-tire pavement damage problem.

ESTIMATED COSTS OF DAMAGE BY STUDDED TIRES IN OREGON

The ODOT preliminary report estimated the damage caused by studded tires to roads under ODOT jurisdiction (*2*) at $24 million for 1993. A total damage estimate of $42 million was reached when county and municipal damage was included.

The current study updated the damage model to reflect changes in vehicle miles traveled, studded tire use, and pavement wear factors for 1994. Based on the introduction of these factors, a new damage estimate was established for roads under ODOT jurisdiction. The model, provided in Table 6, yields $37 million in damage due to studded-tire wear damage for 1994. A similar magnitude of damage can be assumed for county and municipal road systems. Thus, the total annual damage in Oregon is approximately $70 million. ODOT currently (1993) spends $11 million annually to repair studded-tire damage (*17*).

IMPLICATION OF RESULTS

It can certainly be concluded that the use of studded tires in Oregon is increasing at an alarming rate. Even if the current stud use rates remain constant, Oregon's population growth will likely lead to increased pavement damage from studded tires.

Implications of Studded-Tire Pavement Wear Rates

Pavement surface wear from the use of studded tires has not been formally considered in mix design criteria in North America or in Oregon. However, because the development of a 19-mm (3⁄4-in.) rut triggers rehabilitation in Oregon, it is likely that surface rutting from studs has played some role in establishing pavement design life expectancy in Oregon. For example, life expectancy estimates for Oregon asphalt and PCC pavements is 14 years and 25 years, respectively, reflecting relatively low historical studded-tire use rates (shown in Table 3). With stud use rates now more than doubled, the development of pavement rutting will substantially increase compared with past Oregon experience and cause a decrease in pavement life.

To test the hypothesis that a 19-mm (3⁄4-in.) rut will be reached in a shorter time than in the past, several scenarios were examined. This analysis was performed using the pavement wear rates estab-

TABLE 6 1994 Studded Tire Damage Estimate for Roads Under ODOT Jurisdiction

Current Oregon Geographic Regions	Pavement Type	1992 Gross VKT (billions)	Estimated 1994 Gross VKT (billions)	No. Of Studded Tire Passes (millions)	Damage mm/lane/km
1	Concrete	2.70	2.77	152	193
1	Asphalt	6.44	6.61	363	1960
2	Concrete	1.12	1.56	43	54
2	Asphalt	4.97	5.10	189	1020
3	Concrete	1.26	1.29	22	28
3	Asphalt	5.16	5.30	91	490
4	Concrete	0.04	0.04	6	8
4	Asphalt	2.89	2.96	450	2430
5	Concrete	0.39	0.40	22	28
5	Asphalt	2.00	2.05	113	610
			Total	Concrete	311
			Total	Asphalt	6511

Annual Damage

Mitigating Strategy	Replacement Cost per Lane Mile	Threshold Rut	Pavement Type	Cost
75 mm AC Overlay	$50,000	19mm	Concrete	$1,308,116
Grind & 75 mm AC Overlay	$65,000	19mm	Asphalt	$35,549,576
			Grand Total	$36,857,692

lished by this study and assuming a constant 20 percent (rather than the actual statewide value of 23 percent) studded tire use rate. To simulate situations found in Oregon, traffic growth, percentage of cars, seasonal percentages, lane percentages, and other typical conditions were factored into the analysis. The pavement structures considered included a four-lane asphalt facility and a six-lane PCC pavement. Traffic volumes were varied to determine trends in studded tire surface wear and the time required to reach the 19-mm (3⁄4-in.) rut depth threshold.

The results are indicated in Figure 5 and Figure 6. Note that a traffic level of 15,000 ADT yields no reduction in the asphalt pavement life, and requires about 15 years to reach a 19-mm (3⁄4-in.) rut. However, at traffic levels of 20,000 ADT or higher, studded-tire surface wear substantially shortens the time to reach the threshold rut, reducing pavement life expectancy. At traffic levels equivalent to 35,000 ADT, the time to reach the limiting rut is about 7 years, or one-half the design life expectation for asphalt.

The results for PCC pavements are portrayed in Figure 6 and illustrate a similar pattern. Based on the scenarios generated, a 24-year life is consistent with traffic volumes less than 40,000 ADT. At traffic levels of 120,000 ADT, such as that experienced in the Portland area, the estimated time to reach the threshold rut is less than 10 years.

Based on the results above, if studded-tire use remains constant, it can be concluded that studded tire surface wear will substantially reduce the time before pavement rehabilitation is triggered for Oregon pavements.

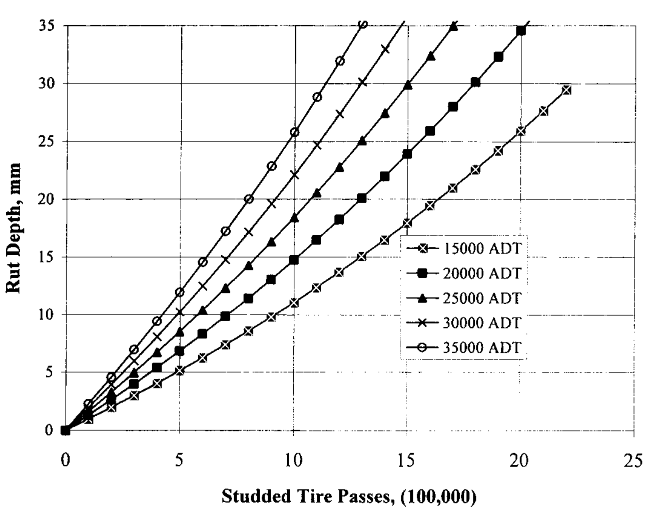

FIGURE 5 Asphalt studded tire rut depth as influenced by ADT.

Cost Implications

A strategy often used by agencies to estimate the cost of damage is to apply only those costs the department commits to spending annually to repair the damage, not the costs of the actual damage. Often the amount committed to repair damage is fixed and does not change even though conditions shift and change the rate at which damage occurs. This strategy is never completely satisfactory but works when the fixed annual expenses approximate the damages incurred for a given year. However, when damage is significantly greater than the fixed costs allocated for repair, a widening gap develops between damage and repair. The net result is a deterioration of conditions over time.

ODOT uses the fixed-cost approach and commits $11 million annually to repair stud damage. Now that studded-tire use has increased substantially, annual pavement damage is accruing at a greater rate than the available repair funds. This should cause con-

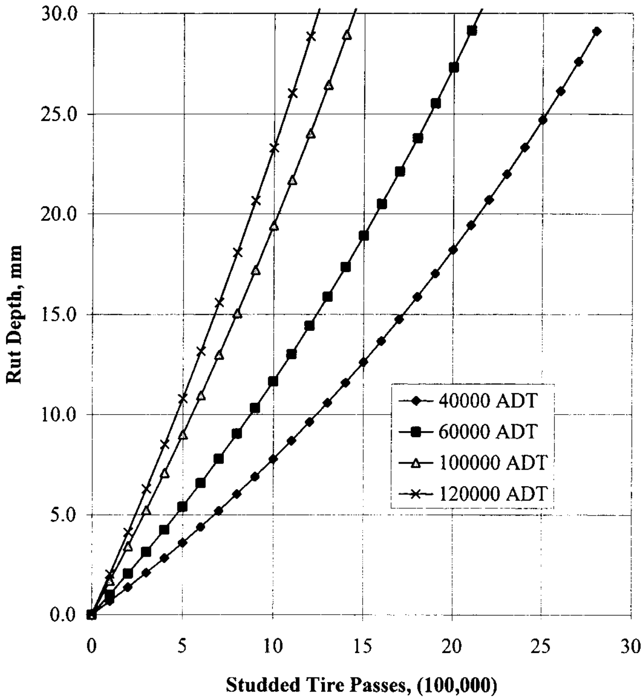

FIGURE 6 PCC studded tire rut depth as influenced by ADT.

cern for ODOT as well as the driving public. Clearly, something must be done to preserve the level of service Oregon drivers have come to expect from the Oregon state highway system.

ALTERNATIVES TO STUDDED TIRES AND AGENCY MANAGEMENT OPTIONS

Several options appear to be available to the state of Oregon to decrease studded tire damage and use. Most of the options will need legislative support to implement. Options include the following:

- Ban the use of studded tires.
- Shorten the length of time studded tires are permitted.
- Require that lightweight studs be used instead of studs used currently.
- Establish a user fee for those who desire to use studded tires.
- Provide pavements more resistant to studded tires.
- Educate the public about the damage caused by studded tires and the situations in which studded tires are effective. (For Oregon weather conditions, it is suggested that studs are effective only a few days out of the entire year.)
- A combination of two, three, four, or more of the options above.

One option to reduce pavement damage is to simply reduce the time studded tires are permitted. The current use period dates back to the late 1960s when legislation permitting studded tires was enacted. For this approach to be effective in reducing stud damage, a substantial reduction in the permitted use period should be examined. A one-third reduction in the permitted time of use should be considered as the minimum; this has the potential of reducing stud wear by one-third.

A lightweight stud provision should also be considered. Based on European studies, lightweight studs reduce pavement wear by one-half, compared with studs currently used (*16*). Lightweight studs are not the complete answer but may provide some relief in reduced damage in several years. The disadvantage of a lightweight stud is that legislation would not likely go into effect for 2 to 3 years because suppliers will request—and likely receive—time to deplete their current stud inventory. It will also take several years before existing studded tires wear out. The overall effect results in delaying the benefits from lightweight studs for an estimated 5 years after enacting legislation.

After lightweight studs are completely deployed, the reduced pavement damage afforded by their use may be satisfactory for lower-volume facilities. But for high-volume corridors, it will only be a matter of time before stud rutting will again become a problem. The lightweight stud option is one being considered by the states of Alaska and Washington. Even though lightweight studs are an important step in reducing damage, they should not be considered the final answer for high-volume facilities.

Initiating action to improve the studded-tire wear resistance of Oregon pavement structures is worthy of consideration. Northern Europe—specifically Norway, Sweden, and Finland—has dealt with studded-tire pavement wear issues for more than 2 decades. These countries, in which studded tire use approaches 95 percent, have been very progressive in ameliorating stud damage. They have developed special testing devices and procedures to reduce stud wear and are willing to share that experience. Alaska DOT&PF is working with the Road Research Institute of Finland to improve the pavement structures (D. Esch, unpublished data). Oregon could adopt a similar strategy. At a minimum, testing in Finland should be undertaken to determine what level of stud resistance current Oregon mix designs are providing.

A studded-tire user fee structure could also be implemented to recover damages to highways from studded tires. The user fee could be established at the time of purchase of studded tires or as an annual fee system. A user fee structure should be considered in the interest of equity because only 16 percent of Oregon drivers use studs and cause all the stud damage. The remaining 84 percent subsidize them by sharing the deteriorating pavement conditions and the costs of repair.

Using Oregon Division of Motor Vehicle records (*18*) and the effective percentage of studded tire use and applying the estimated $42 million in annual studded tire damage for 1993, the basis is provided for establishing a fee structure. Stud users would pay an annual fee of approximately $55 per axle for vehicles equipped with studded tires. For a vehicle equipped with studs on both axles, the annual fee would be $110.

Another fee alternative would assess a studded-tire user fee at the time of sale. The 1993 damage estimate of $42 million, assuming the typical studded tire will last five seasons, results in $140 proportionate damage for the life of the tires, not including inflation. The fees are not trivial, but neither is the pavement damage caused by studded tires. One must also keep in mind that the damage estimate for 1994 is approximately twice that estimated for 1993 simply because studded tire use has increased.

The combination of lightweight studs, a reduction in the time permitted for stud use, and a user fee structure to recoup pavement damage may be the best course of action. In any case, information provided from this research effort yields reliable wear factors and studded tire use percentages for making sound decisions. Unfortunately, past studded-tire legislation efforts have been on the basis of politics instead of rationality.

SUMMARY

It is clear that studded-tire users are convinced studs improve driver safety since past legislative efforts to reduce stud damage have been unsuccessful. Unfortunately, no known objective studies in North America have indicated safety benefits monetarily equivalent to the pavement damage associated with stud use. For most Oregon driving conditions, in which the pavement is either wet or dry and at temperatures above freezing, the use of studded tires appears to offer very limited safety advantages compared with modern radial traction tires. When considering the annual pavement damage and decreased pavement life identified in this study, road user delays while repairing stud damage, and increased splash and spray and hydroplaning conditions experienced all year, the safety benefits afforded by studs would have to be significantly greater than what is currently known to justify their continued use. Based on these conclusions, it is apparent that additional study is needed to better define the safety benefits provided by studded tires.

REFERENCES

1. *NCHRP Synthesis of Highway Practice 32: Effects of Studded Tires*. TRB, National Research Council, Washington D.C., 1975, 46 pp.
2. Malik, M. *Preliminary Estimates for 1993 Studded Tire Pavement Damage*. Oregon Department of Transportation, Salem, Sept. 1994.
3. *The Use and Effects of Studded Tires in Oregon*. Oregon Department of Transportation, Salem, Dec. 1974.
4. C. K. Preus. Studded Tire Effects on Pavements and Traffic Safety in Minnesota. In *Highway Research Record 418*, HRB, National Research Council, Washington, D.C., 1972, pp. 44–54.
5. *Pavement Wear and Studded Tire Use in Iowa*. Final Report, Project HR-148. Iowa Department of Transportation, Ames, 1979.
6. Copple, F. *Studded Tires: Their Effects on Highways and Vehicle Safety in Michigan*. Michigan Department of Transportation, Lansing, November 1971.
7. Shumway, R. D. Memorandum: Studded Tires. File No. 24-3051. State of Alaska, Juneau, April, 1971.
8. Peterson, D., and D. Blake. *A Synthesis of Studded Tires*. Utah State Highway Department, Ogden, Jan. 1973.
9. Brunette, B. E. *The Use and Effects of Studded Tires on Oregon Pavements*. M.S. thesis. Oregon State University, Corvallis, 1995.
10. Esch, D. Memorandum: B. Wessel Response to House Bill 301, Studded Tires. File No. 3555. Alaska Department of Transportation and Public Facilities, April 1994.
11. *1992 Traffic Volume Tables*. Transportation Development Branch, Oregon Department of Transportation, Salem, Dec. 1993.
12. Hicks, R. G., T. V. Scholtz, and D. C. Esch. *Wheel Track Rutting Due to Studded Tires*. Report No. AK-RD-90-14. Alaska Department of Transportation and Public Facilities, Fairbanks, Dec. 1990.
13. Cantz, R. New Tire-Stud Developments. In *Highway Research Record 418*, HRB, National Research Council, Washington D.C., 1972, pp. 11–25.
14. Cook, J. Memorandum to Nebraska State Legislature Re: LB 50, LB 106, and LB 206. Nebraska Department of Transportation, Jan. 1983.
15. Gustafsen, K. *Tests With Lightweight Tyre Studs in the VTI's Pavement Testing Machine* (English Summary). VTI Report 377. Swedish National Road Administration, Stockholm, 1992.
16. Neimi, A. *Factors Contributing to Pavement Wear*. Research Report 485. Technical Research Centre of Finland, June 1985.
17. *Update of the 1992 Motor Vehicle Cost Responsibility Study—May 1995*. Transportation Development Branch, Auto/Truck Section, Oregon Department of Transportation, Salem, May 1995.
18. Malik, M. Memorandum: Draft Information on Studded Tire Use. Oregon Department of Transportation, Salem, Feb. 1995.

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