AN ABSTRACT OF THE THESIS OF

Judith A. Gray for the degree of Master of Science in Industrial Engineering and Economics presented on July 2, 1997. Title: An Economic Analysis of Pavement Damage caused by Studded Tires in Oregon

Redacted for Privacy

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This report frames the debate over studded tires in terms of economic principles of marginal cost pricing and efficient resource allocation. In the absence of a user tax, the pavement damage caused by studded tires results in inefficient pricing because social costs associated with the damage are excluded from the price paid by consumers. This leads to over use of studded tires.

No attempt was made to quantify the safety effects of studded tire use. A review of research literature was provided to qualitatively support the premise that there is no social benefit from studded tires in Oregon. Quantitative cost analysis was limited to pavement rutting on the state highway system that is sufficient to reduce the useful life of the pavement.

The cost estimation was conducted in two stages: first, the wear rates for asphalt and Portland cement concrete (PCC) pavement surfaces were estimated, expressed as inches of rut depth per 100,000 studded tire passes. Linear regression analysis was conducted using rut depth, traffic, and studded tire data from a sample of Oregon highways. A range of wear rates was estimated, reflecting the numerous factors that influence rutting susceptibility of pavements. The mid-points of wear rates for asphalt and PCC were 0.0386" and 0.0093", respectively.

Second, the wear rate estimates were used to approximate rutting for the state highway system and to predict resurfacing expenses attributable to studded tire traffic. The results indicate that the cost of studded tire damage on Oregon state highways in 1995 was approximately $10 million. This averages to $8 per tire per year.

The implications of the cost are then discussed in terms of the allocation effects of underpricing due to an untaxed externality. The external costs pavement damage caused by studded tires result in inefficient pricing because external costs associated with the damage are excluded from the price paid by consumers. This leads to excess use of studded tires. A studded tires tax sufficient to cover attributable maintenance costs would be in the neighborhood of 30% of the purchase price and would result in a sharp decline in the quantity of studded tires in use.

An Economic Analysis of Pavement Damage caused by Studded Tires in Oregon

by

Judith A. Gray

A THESIS

submitted to

Oregon State University

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the requirements for the
degree of

Master of Science

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Judith A. Gray

Acknowledgment

The completion of this thesis marks the culmination of a long process of work, worry, and quite a lot of fun. I am indebted to many individuals and institutions whose help made it possible. First of all, I thank Renee Harber for the moral support and also the remarkable patience that seems to come naturally to you. You are my relief from both work and worry, and I'm grateful that you are in my life. Simply put, you make good things better.

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An Economic Analysis of Pavement Damage caused by Studded Tires in Oregon

1.0 Introduction

The purpose of this report is to frame the debate over studded tires in terms of economic principles of marginal cost pricing and efficient resource allocation. In the absence of a user tax, the pavement damage caused by studded tires results in inefficient pricing because external costs associated with the damage are excluded from the price paid by consumers. This leads to over use of studded tires.

Defenders claim that the safety benefits of studded tires justify the added expense of maintaining highways. A review of research literature is provided to demonstrate the considerable doubt surrounding claims of a net safety benefit from studded tire use. No attempt is made to quantify the safety effects of studded tire use. Instead the literature review is presented to qualitatively support the premise that there is no external social benefit from studded tires in Oregon. In the absence of a public benefit, any added expenditures arising from studded tire use would be rightly borne by the studded tire users.

Various data sources and estimation procedures are then applied to estimate the cost of pavement damage attributable to studded tires. The cost estimation takes two stages: first, the wear rates for asphalt and Portland cement concrete (PCC) pavement surfaces are estimated as functions of studded tire traffic, using rut depth, traffic, and studded tire data from a sample of Oregon highways. Second, the wear rate estimates are used to approximate rutting for the state highway system and to predict mitigation expenses for damage that is considered sufficient to reduce the useful life of the pavement surface. It is estimated that each studded tire causes pavement damage of approximately $8 per year.

The implications of the cost are then discussed in terms of the allocation effects of underpricing due to an untaxed externality, and policy options for dealing with studded tires. The premise of no net safety benefit is addressed, with consideration of the effect of relaxing this assumption; the limited scope of the cost estimate is addressed as well.

1.1 Background

Studded snow tires have long been associated with pavement damage. Following their introduction in North America in the early 1960's, highway engineers in the US and Canada cautioned that the use of studded tires was causing premature degradation of pavement surfaces. Contrary to commonly held belief, most pavement damage is caused by passenger vehicles, rather than by heavy trucks. Studded tires, which are used almost exclusively by passenger vehicles, are the primary source (Barter, 1996).

The abrasive action of the studs against pavement causes ruts to develop in the wheel paths. Wheel path rutting has been associated with numerous safety hazards, such as adverse steering effects and an increased potential for hydroplaning in wet weather. In order to reverse the safety hazards resulting from studded tire damage, several state highway agencies have increased highway maintenance expenditures.

An early study by the Oregon Department of Transportation (ODOT) estimated that the annual cost of repairing studded tire damage was in the range of $1.5-2.5 million (1974). Accordingly, the amount of maintenance costs attributed to studded tires in subsequent publications of ODOT's *Cost Responsibility Study (CRS)* has been in that range through the 1992 edition, which put the cost at $2.5 million (ODOT, 1993).

Prompted by concerns that this number was overly conservative, ODOT revised its estimate of studded tire related maintenance expenditures and in 1994 increased the estimate to

$11 million (ODOT, 1995). A separate study estimated that the total cost of studded tire damage in Oregon is around $42 million annually (Malik, 1995). In recent years, concern about studded tire damage has provoked calls for various legislative actions, including the imposition of a studded tire tax, or a complete prohibition[1]. No such measure has yet to become law, although the 1995 Oregon legislature restricted the material for tire studs to a lightweight material designed to reduce rutting. The lightweight stud restriction took effect in November of 1996.

1.2 Scope

Both the wear rate and cost analysis in this study are limited to rutting caused by studded tires on asphalt and Portland cement concrete (PCC) surfaces on the Oregon state highway system.

Studded tires also wear away paint stripes on roads and surface grooving added to pavements to improve friction, which are considered proven safety enhancements. Costs associated with these losses are not included.

Damage to bridges is excluded due to lack of reliable data on the cost and extent of damage. Generally, bridges can be expected to have lower wear rates, since they are constructed of higher quality materials. Damage on city and county streets is also excluded due to lack of available data. Finally, no attempt is made to quantitatively evaluate safety and comfort effects of studded tires.

All traffic, studded tire use, and rut depth data are from 1995. The only exceptions are the growth rates used to calculate cumulative studded tire traffic.

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[1] For example, see House Bills 2213, 3163, and 3149 and Senate Bill 307 from the 1997 Oregon Legislature.

2.0 Safety effects of studded tires

The purpose of this chapter is to demonstrate through a review of literature the dubious nature of any safety benefits that can be attributed to studded tires. An understanding of the safety impacts of studded tires is relevant to a cost analysis because claims of improved safety are frequently used to justify the added expenses that highway agencies attribute to repairing studded tire damage on pavements.

Studded tires were introduced in North America in 1963 and quickly gained popularity with drivers due to a perception of improved traction and braking performance under winter driving conditions. By 1972, studded tire use had reached or exceeded 30% in over a dozen states. Alaska, Montana and Vermont were at 60% or above (NCHRP 32).

In Oregon, studded tire use was legalized in 1967 and by the 1973-74 winter the rate of use reached 9.2%. The use of studded tires in Oregon was accompanied by "an alarming amount" of pavement damage. An early ODOT report recommended a focused effort to develop or improve alternative traction devices, followed by complete ban of studded tires (ODOT, 1974).

No ban has since been implemented. Currently, studded tires are permitted in Oregon from November 1 through the end of April, and the use of studded tires appears to be increasing. A recent survey indicates that nearly 16% of vehicles were equipped with studded tires in 1995. Roughly half of those vehicles had studded tires on both axles, effectively pushing the rate of studded tire traffic to over 23% (Malik, 1997).

The use of studded tires varies considerably by geographic region, reflecting the widely divergent climatological conditions throughout the state. In order to capture some of the regional differences, studded tire use rates were determined for each of ODOT's five regions (shown in Figure 2.1). A regional breakdown of studded tire use is given in Table 2.1.

Table 2.1 Studded tire use in Oregon in 1995*

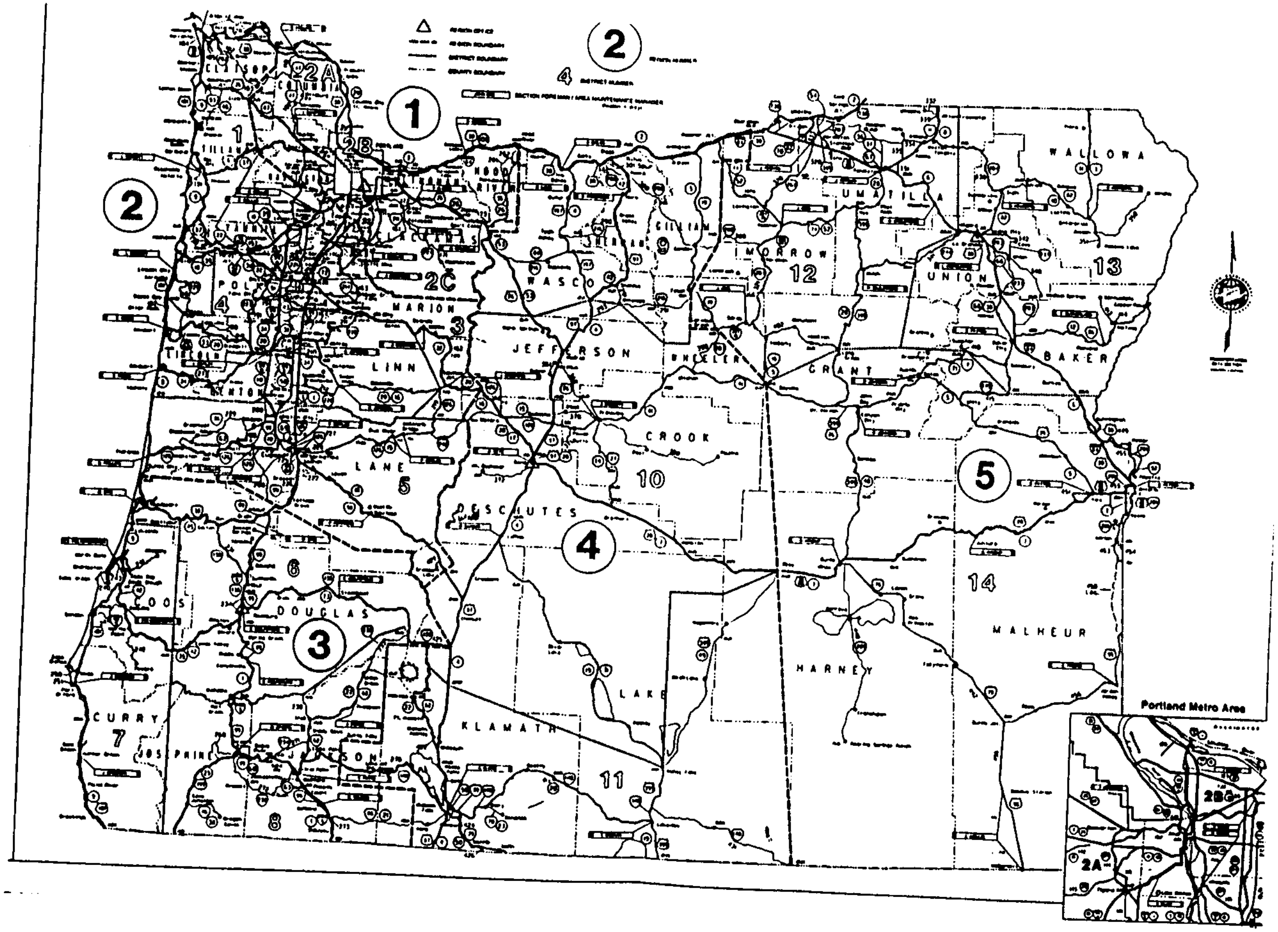
	Nominal vehicle	Nominal axle
Region 1	16.7%	24.3%
Region 2	12.4%	18.0%
Region 3	5.1%	7.8%
Region 4	32.2%	51.4%
Region 5	26.7%	41.1%
Statewide	15.6%	23.2%

* Reflects the percent of vehicles using studded tires at some time during 1995

Pavement damage from studded tires has been especially severe on the high volume interstate system, particularly in the center and left lanes, which are traveled most heavily by passenger car traffic. This reflects the fact that studded tires are used almost exclusively by passenger vehicles.

Immediately following the introduction of studded tires, several state highway agencies embarked on research concerning their effectiveness and the causes and impacts of related pavement damage. Very little research has been conducted in the US since the 1970's, although renewed interest has resulted in some recent research by Oregon and Alaska transportation departments. Sweden, Norway and Finland have recently undertaken a joint $30 million multi-year research project on studded tires and other winter driving issues.

Figure 2.1 Map of ODOT's 5 Regions



2.1 Direct safety effects for studded tire users

The primary benefit of studded tires is improved braking performance on icy surfaces (Lu, 1994). Several studies have demonstrated that studded tires reduce the braking distance on ice, when compared to non-studded snow tires and all-season tires (Lu, 1995; Speer, 1971; Minnesota, 1971). However, the braking improvement is eliminated by a slight increase in driving speed (Lu, 1994; Iowa, 79; NCHRP 32, 1975). Some evidence has demonstrated that drivers tend to drive at increased speeds with studded tires (NCHRP 183, 1978; ODOT, 1974; Kallberg, 1996). Such evidence is consistent with a 1975 study which concluded that drivers respond to safety devices by driving less cautiously, effectively offsetting the benefits of the safety devices (Peltzman). As such, the braking enhancements provided by studded tires constitute a convenience enjoyed by the studded tire user, rather than a safety benefit.

Braking performance is actually hindered on wet or dry pavements, which tend to represent the majority of surface conditions during winter seasons in the US (Schwartz, 1967; Christman, 1974; Lu, 1994). Oregon reported icy conditions existed for only 2.5% of day-miles (the reported road condition multiplied by the number of road miles for which the condition existed) during the years 1966-1972.

Many drivers cite improved traction as a major benefit, but this is a convenience more than a safety benefit, and, like braking, traction performance of studded tires suffers on dry or wet pavement surfaces (Lu, 1994; Minnesota, 1971). The Connecticut State Police discontinued using tire studs after one year, after determining that they were "very dangerous" at high speeds (Christman, 1974).

2.2 Externalities from studded tire use

The biggest problem associated with studded tires is accelerated pavement wear. Unlike direct performance effects for studded tire users, pavement damage impacts all motorists. To the extent that surface damage on pavements causes drivers to suffer a loss of comfort or safety, it constitutes a negative externality imposed by studded tire users onto the general driving public.

Wheel track rutting by studded tire traffic is associated with numerous safety hazards. Wet weather hazards are among those most commonly cited. Water collects in the ruts, increasing the potential for hydroplaning. Also, wheels passing through the ruts splash the water onto windshields of other vehicles, reducing visibility. In freezing temperatures, the collected water can freeze (black ice) and cause slipping. An abundance of motorist complaints and anecdotal information exists regarding these problems, but there is very little quantified evidence on the subject of decreased road safety due to ruts, probably because so many factors can contribute to the occurrence of accidents (Barter, 1996; Lu, 1994).

A national study from 1973 ranked the most common safety hazards from studded tires. At the top of the list are hydroplaning, maintenance hazards, and reduced visibility. The list is shown in Table 2.2 (Burke, 1973). Other problems associated with studded tires include the loss of paint markings and wearing away of surface grooving which is provided for skid protection (Minnesota, 1971; Christman, 1974). Vehicles suffer increased degradation due to increased roughness of pavement surfaces (Burke, 1973). And in Japan, studded tires were prohibited due to concerns about dust pollution (Konagai, 1993).

It is important to note that not all externalities are negative. In freezing temperatures, studded tires can cause roughening of icy road surfaces, which improves traction for all motorists. (Barter, 1996).

Table 2.2 Safety effects of pavement rutting caused by studded tires

Rank*	Safety hazard
1	hydroplaning and wet skid
2	pavement maintenance hazards
3	reduced visibility due to splash and spray
4	improper lateral placement of vehicles to avoid ruts
5	adverse steering effects due to ruts
6	driver fatigue resulting from noise and vibration
7	ejected studs thrown from high-speed vehicles
8	vehicle component degradation

*ranking from Burke, 1973

2.3 Net safety effects from studded tire use

There is continuing disagreement regarding the overall safety effects of studded tires. Considerable evidence from early North American research indicates no net benefit from studded tires, especially with consideration of associated pavement damage. As previously mentioned, highway officials in Oregon recommended a ban on studded tires in 1974. During the 1970's researchers in several other states, including Iowa, Connecticut, and Pennsylvania determined that studded tires produced a net safety hazard and recommended that they be banned (Iowa, 1979; Christman, 1978; Mellot, 1974). In 1974, a Federal Highway Administration memo urged all states to consider banning or limiting the use of studded tires (see Figure 2.2).

Contrary to these US findings, results of recent research undertaken by the Scandinavian countries indicate that a ban on studded tires would not result in an increase in fatal traffic accidents, but that non-fatal accidents would increase by 30% (Johnson, 1996). In Finland, where 95% of drivers use studded tires, researchers determined that if only 50% of cars were equipped with studded tires and everything else remained unchanged, the number of injury accidents would increase by 17% (Kallberg, 1996). Another study comparing different levels of studded tire use and road salting determined that the very high studded tire use in Finland is the socioeconomic optimum, despite the drawbacks. High accident costs were noted as playing a significant role in this outcome (Leppanen, 1996).

The North American and Scandinavian researchers reach different conclusions regarding overall safety effects of studded tires. However, climate is clearly an important factor in the overall effectiveness of studded tires. The Scandinavian countries are considerably colder than Oregon. For much of the region, average temperatures approach or fall below freezing during most of the year (Pearce, 1990). Also, maintenance procedures differ in Scandinavia - in part due to the fact that most drivers use studded tires (Lundy, 1992). Therefore, the research findings from Scandinavia cannot be directly applied to Oregon conditions.

In summary, the evidence on safety effects of studded tires is mixed. Studded tires reduce braking and traction performance suffer on bare pavements, which is the predominant condition on Oregon roads. Some benefits are enjoyed by studded tire users, since braking performance is enhanced on icy roads. But frequently the added safety margin from braking improvements is lost due to faster driving. The ability to drive at higher speeds may be considered an added convenience to drivers, but is clearly a private benefit, rather than a public safety improvement. Improved traction performance from studded tires is also an added convenience, rather than a safety improvement.

The external effects of studded tires arise primarily from pavement damage. Wheel track rutting is associated with numerous safety hazards, particularly in wet weather. Other problems associated with studded tires include the loss of paint markings and the wearing away of surface grooving which is provided for skid protection.

Figure 2.2 FHWA memo on studded tire policy

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U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
WASHINGTON, D.C. 20590

OFFICE OF THE ADMINISTRATOR

IN REPLY REFER TO:
HNG-23

The studded tire issue has been a very controversial matter for several years. Claims and counterclaims are made by both proponents and opponents of the studs. Because of the concern by highway agencies responsible for highway operations and maintenance, we recently made a review of available studies relating to the use of studded tires. The conclusion reached by this review is that the adverse effects on the safety of our highways outweigh any present and foreseeable future benefits. I consider it appropriate for the Federal Highway Administration to make its position known and have issued the following policy statement.

> "Available information indicates that there is no net safety benefit to be derived from the use of present studded tires. This fact, coupled with the excessive wear and physical damage to the roadway surfaces, provides a sound basis for precluding the continued permissive use of a convenience feature which is effective for relatively short periods of time. This warrants State and local consideration of efforts to ban or limit the use of studded tires."

A copy of a summary of reported effects is enclosed for your information and use. As additional information comes to our attention, we will make it available to you for your consideration and use.

Sincerely yours,

Norbert T. Tiemann
Federal Highway Administrator

Enclosure

3.0 Studded tire wear rate estimation

This chapter describes the model, methodology, data requirements and results of a regression analysis to estimate the wear rate of studded tires on pavement surfaces from a sample of highway locations in Oregon.

For the purpose of this research, the *rate* at which studded tire traffic inflicts damage is of more interest than the total rut depth. By expressing rut depth as a function of studded tire traffic, we can make predictions of future rutting under expected future traffic conditions. Additionally, the studded tire damage can be isolated to a given period of time.

Many factors affect the wear rate, including: traffic conditions such as speed and acceleration of vehicles; pavement design and materials; and, properties of the studded tires such as the stud material and the number of studs (Keyser, 1970; Barter, 1996). Table 3.1 lists some of the factors that affect wear rate.

Table 3.1 Factors affecting studded tire wear rate*

Factor	Characteristic
Pavement	Geometry (turns, intersections) Mix type Material hardness Age
Traffic	Speed Acceleration Deceleration Stopping, starting
Vehicle	Axle weight Stud material and type Number of studs
Environment	Humidity, temperature

*adapted from Keyser, 1970

3.1 Wear Rate model

The rutting caused by studded tires is expressed as a function of cumulative studded tire passes over the surface using the following model:

$$R = SP^{life} * a$$

where,

a = wear rate,

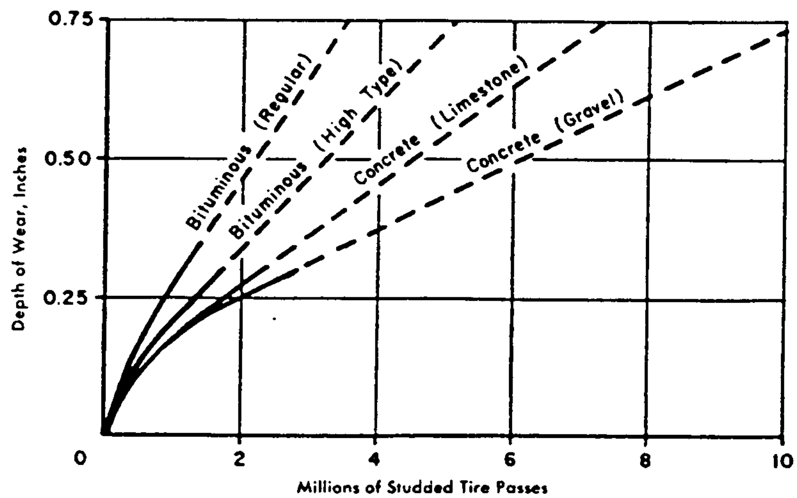
SP^{life} = total studded tire passes occurring during the life of the pavement,

R = rut depth estimate.

Two simplifying assumptions are indicated by the model. First, the wear rate, a, is assumed constant, and not a function of time or past studded tire passes. An early study of studded tire rutting has indicated that pavement surfaces have a higher initial wear rate which stabilizes after 100,000 studded tire passes (see Figure 3.1) (Minnesota, 1971). However, almost all studies have estimated wear as a constant with respect to time and cumulative traffic, probably because of the high variability and the numerous factors affecting wear in different pavements.

The other assumption is implied by the exclusion of an intercept term and other regressors, suggesting that all rutting is caused by studded tire passes only. Studies have shown that on both asphalt and PCC, conventional tires produce virtually no measurable wear (Krukar, 1973; Speer, 1971). However, axle weight of heavy trucks causes rutting on asphalt surfaces, though not on PCC surfaces. This raises some concern about attributing all rutting on asphalt to studded tires. In particular, rutting in the right lane, which tends to be the predominant travel lane for trucks, is likely to be partially caused by truck traffic. This issue is discussed in Section 3.3.2.

Figure 3.1 Graph of wear rate findings from Minnesota (1971)



3.2 Methodology

Total rut depth represents damage sustained over the entire life of the pavement surface. A data set of rut depth measurements was collected from several sections of the Oregon state highway system, including two types of asphalt and Portland cement surfaces.

For each highway section in the rut measurement data set, an estimate was derived for the cumulative studded tire traffic. An estimate for the number of studded tire passes in 1995 was calculated by adjusting total traffic volume data using factors for the relative level of traffic during the studded tire season; the percent of traffic made up of passenger vehicles; and the portion of vehicles using studded tires. Then, historic growth factors for traffic and studded tire use were applied to calculate the studded tire traffic since the construction date of the pavement. This procedure is described below. The sources and methods used to obtain these data are described in Section 3.3.

For each highway segment the following steps were taken:

Step 1. Estimate 1995 Passenger Vehicle Traffic (PVT^{95})

$$PVT^{95} = ADT^{95} * 365 * PV_j$$

where

ADT^{95} = Average Daily Traffic for 1995,

PV_j = percent of traffic comprised of passenger vehicles on highway j,

Note that multiple values for ADT apply to each highway section. ADT tends to change at each exit and entrance point along the highway. All of the highway sections in the data set are long enough to include multiple access points.

Step 2. Estimate passenger vehicle traffic (PVT_m) for each month of the studded tire season

Let months from November through April be designated 1 through 6.

$$PVT_m{}^{95} = PVT^{95} * T_m\,\%$$

and $T_m\%$ is the percent of annual traffic taking place in month m

Step 3. Estimate the studded tire passes for 1995 by applying monthly studded tire factors (St_m) to the PVT_m; sum to find the annual studded tire traffic:

$$SP_m{}^{95} = PVT_m{}^{95} * ST_m$$

and $SP^{95} = \Sigma\, SP_m{}^{95}$ for m = 1 through 6

Step 4. Estimate effective growth in studded tire traffic for the past years of the pavement's life.

Studded tire traffic increases due to both growth in traffic and growth in studded tire use. Average traffic and studded tire growth rates are used to determine an *effective growth* rate of studded tire traffic. Traffic growth rates were determined for each highway, while the studded tire rate represents statewide growth. This rate captures increases in both traffic and studded tire use to express the growth in studded tire passes as follows:

$$EG = [(1 + TG_j) * (1 + SG)] - 1,$$

where EG = Effective statewide growth rate of studded tire traffic,

TG_j = Annual average traffic growth on highway j, and

SG = Statewide annual average growth in studded tire use[2]

Step 5. Apply the Effective Growth rate and 1995 studded tire passes (SP^{95}) to calculate the lifetime studded tire passes (SP^{life}) as follows:

$$SP_{life} = \frac{SP_{95}}{EG} * \left[1 - \frac{1}{(1 - EG)^n} \right]$$

where, SP^{life} = lifetime studded tire passes, and

if age < 29, n = age of segment in 1995

else n = 28

Age is limited to 28 years to limit studded tire growth to the number of years that studded tire use has been legal in Oregon.

3.3 Data requirements

A data set of rut depth measurements was generated by ODOT for use in concurrent research on studded tire pavement rutting. Data on studded tire use were taken from a telephone survey

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2 Example:
Suppose in 1995, annual traffic is 100,000, and effective studded tire use is at 20%, yielding SP^{95} = 20,000. Suppose further that traffic is expected to grow 10% (to 110,000) and studded tire use is expected to increase 5% (to 21%). For SP^{96} we get 21% * 110,000 = 23,100. Or we could simply calculate: (1 + 10%) * (1 + 5%) - 1 = (1.1 * 1.05) - 1 = 15.5% growth in studded tire traffic. Thus, $SP^{96} = SP^{95}$ (1 + 15.5%) = 20,000 * 1.155 = 23,100.

conducted for a concurrent ODOT research project (Malik, 1997). Traffic data were provided by ODOT's Traffic Data Section and *1995 Traffic Volume Tables* (ODOT, 1996a). Each data source is described below.

3.3.1 Rut Measurements

Highly accurate measurements of rut depth can be taken manually by placing a straight-edge across the wheel track and measuring the distance from its edge to the bottom of the rut. However, the cost in terms of labor time, traffic obstruction and safety hazards prohibit manual generation of very large data sets, especially since the most severe rutting tends to occur on the most highly traveled roads. In order to get the desired volume of rut measurements, ODOT used the South Dakota Profilometer van. The Profilometer van uses acoustic signals to measure wheel path ruts while traveling in traffic at speeds up to 55 mph, allowing enormous amounts of data to be collected without the high safety and time costs associated with manual measurements. Due to the high speed, Profilometer measurements are not as accurate as measurements taken manually.

A sample of Profilometer measurements was calibrated with a set of manual measurements from the same highway locations. ODOT then used the calibration results to adjust a larger set of Profilometer measurements, producing a data set of rut depth values for approximately 200 miles of Oregon highways (Malik, 1997). The adjusted measurements constitute the *main data set*. The manual measurements are also used in the wear rate analysis. These are referred to as the *test data set*. The highway sections represented in the main and test data sets are listed in Table 3.2.

Most of the rut measurements were taken on the interstate system in Regions 1 and 2, which tend to be characterized by substantial rutting due to high volume traffic. Locations with high rutting were selected to facilitate rut measurements (Malik, 1997). Two types of asphalt are included in the study: F-mix, which is an *open-graded mix,* favored for good drainage properties in wet weather, and B-mix, which is a conventional dense-graded asphalt mix. Portland cement surfaces are also included in the data sets.

Table 3.2 Highway sections used for wear rate estimation

Surface	Main Data Set (Profilometer)	Test Data Set (manual)
Asphalt (F-Mix)	I5 South, MP 234-247	I5 South, MP 245
	I5 South, MP 294-299	I5 South, MP 243
	I84 East, MP 22-31	US 97 South, MP 133.5
	I84 West, MP 22-31	US 97 South MP, 140.4
Asphalt (B-Mix)	I5 North, MP 234-244	I5 North MP, 242.75
	I5 North, MP 244-249	US 22 East, MP 3
	I84 East, MP 17-22	I84 East, MP 20
	I84 West, MP 17-22	
PCC	I5 North, MP 259-280	I5 North, MP 262
	I5 South, MP 259-294	I5 North, MP 278
	I205 North, MP 0-25	I5 South, MP 287.5
	I205 South, MP 0-25	I205 North, MP 12

3.3.2 Traffic characteristics

The basic building block for calculating studded tire traffic is the traffic count, or Average Daily Traffic (ADT). These were provided by ODOT's Transportation Data Section. The ADT data were specified for each direction on each highway, and reflect the changing traffic level at each access point.

Other characteristics for traffic were taken from ODOT's *Traffic Volume Tables,* which are published annually. A sample page from the 1995 edition is shown in Figure 3.2. In 1995,

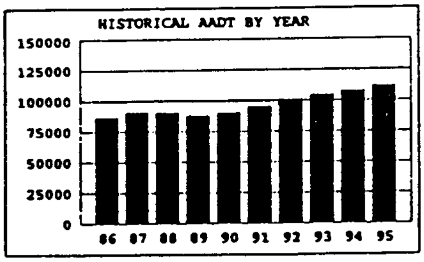
Figure 3.2 Sample of data from ODOT's *Traffic Volume Tables*

Location: I5, PACIFIC HIGHWAY, NO. 1
on Interstate Bridge north of Portland

Recorder: INTERSTATE BRIDGE, 26-004
Installed: January, 1953

HISTORICAL TRAFFIC DATA

Year	Average Daily Traffic	Percent of ADT: Max Day	Max Hour	10TH Hour	20TH Hour	30TH Hour
1986	87017	***	****	****	****	****
1987	90929	123	9.7	9.2	9.1	9.0
1988	90470	***	****	****	****	****
1989	88155	135	10.4	9.7	9.5	9.4
1990	90367	127	9.6	9.2	9.0	8.9
1991	95218	130	9.8	9.2	8.9	8.8
1992	100860	132	9.4	9.2	9.1	9.0
1993	104873	128	9.2	8.9	8.8	8.7
1994	107566	128	9.4	8.9	8.7	8.6
1995	111737	124	9.1	8.7	8.5	8.5



1995 TRAFFIC DATA

	Average Weekday Traffic	Percent of ADT	Average Daily Traffic	Percent of ADT
January	109677	98	104203	93
February	107930	97	103801	93
March	116159	104	111348	100
April	118076	106	113058	101
May	115597	103	112638	101
June	121999	109	116402	104
July	120265	108	116091	104
August	123957	111	119336	107
September	118274	106	113947	102
October	117087	105	112748	101
November	114564	103	109358	98
December	113199	101	107916	97

Classification Breakdown	Percent of ADT
Passenger Cars	62.3
Other 2 axle 4 tire vehicles	29.2
Single Unit 2 axle 6 tire	1.9
Single Unit 3 axle	0.7
Single Unit 4 axle or more	0.1
Single Trailer Truck 4 axle or less	0.3
Single Trailer Truck 5 axle	3.1
Single Trailer Truck 6 axle or more	0.3
Mult-Trailer Truck 5 axle or less	0.6
Mult-Trailer Truck 6 axle	0.3
Mult-Trailer Truck 7 axle or more	0.5
Other	0.0
Buses	0.3
Motorcycles & Scooters	0.4

ODOT had 116 permanent counters located at various points of the state highway system. For each permanent counter location, data are available on the percent of traffic comprised of passenger vehicles and the relative volume of traffic each month. These factors were taken from the 1995 *Traffic Volume Tables* for highway sections in the data sets. Where multiple counters are present along a highway, some judgment was used to extrapolate the most appropriate factor based on traffic volume. Passenger vehicle and monthly traffic factors are shown in Tables 3.3 and 3.4.

The *Traffic Volume Tables* also give traffic growth rates for the preceding ten years at each permanent counter location. For highway sections older than ten years, the statewide traffic growth rate was used, as provided in each annual edition of the *Traffic Volume Tables*. Growth factors are listed in Table 3.5. The derivation of the factors for passenger vehicles and monthly volume are provided in Appendix A.

Table 3.3 Passenger vehicle factors for wear rate estimation

Highway	Location	Passenger vehicles
Interstate 5		
	MP 233-251	80%
	MP 259-282	85.8%
	MP 283-287	90%
	MP 289-298	93%
	MP 300	94.5%
Interstate 84	ALL	75.5%
Interstate 205	ALL	91.3%
US Hwy 22	ALL	93.2%
US Hwy 97		
	MP 130	88.8%
	MP 140	89.6%

Table 3.4 Monthly traffic levels for wear rate estimation

	Interstate 5	Interstate 84	Interstate 205	US Hwy 22	US Hwy 97
January	7.42%	6.01%	6.71%	7.26%	6.99%
February	6.83%	5.80%	6.31%	6.72%	6.52%
March	8.16%	7.74%	7.95%	7.93%	7.94%
April	8.56%	8.03%	8.29%	8.00%	8.15%
November	8.03%	7.58%	7.81%	7.60%	7.70%
December	8.02%	6.46%	7.24%	7.68%	7.46%

Table 3.5 Traffic growth rates wear rate estimation

Highway	1986-95	1976-85	1966-75
Interstate 5	3.96%	2.62%	4.78%
Interstate 84	5.78%	2.62%	4.78%
Interstate 205	6%	2.62%	4.78%
US Hwy 22	4.61%	2.62%	4.78%
US Hwy 97	4.05%	2.62%	4.78%

The distribution of traffic between lanes has an important impact on the pattern of visible studded tire damage. Most severe studded tire rutting shows up on center or left lanes, which are used predominantly by passenger vehicles. Only very general information is available regarding the distribution of traffic in each lane. According to ODOT's Traffic Planning Section, on 4-lane highways, 60% of traffic tends to travel in the right lane, with the remaining 40% in the left lane. On 6-lane highways, the left, center, and right lane distribution tends to approximate 14%, 56%, and 30%, respectively. These patterns are highly generalized; it should be apparent from observation that as traffic becomes more dense, traffic distribution tends to even out across the lanes.

The above lane distribution figures describe total traffic volume. No data were found regarding the lane distribution of truck traffic for Oregon roads, which should be considerably different from the general traffic flow, since trucks tend to travel predominantly in the right lanes. Coupled with the highly generalized nature of the traffic distribution data, this posed a problem for isolating the studded tire traffic in a particular lane of a highway. This problem was resolved for this study by summing the rut depth of each lane for every highway location, and regressing the combined depth against the estimate for total directional studded tire traffic. Because the model assumes a constant wear rate, we should expect that the regression equation for the summation of the lanes is a linear combination of the regression equations for the individual lanes[3].

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[3] We generally expect that, for wear rate, *a*, and studded tire passes, SP,

if Left lane: $Rut^{LEFT} = a * SP^{LEFT}$

Right lane: $Rut^{RIGHT} = a * SP^{RIGHT}$

then Sum of lanes: $Rut^{LEFT} + Rut^{RIGHT} = a * (SP^{LEFT} + SP^{RIGHT})$

or, $Rut^{SUM} = a * SP^{SUM}$

A shortcoming of this approach arises for asphalt surfaces. As was mentioned earlier, the right lanes of asphalt pavements can be expected to bear some rutting that is caused by heavy trucks. The summation of lanes includes heavy truck rutting into the rut depth data. This problem can be minimized by the exercise of caution during the measurement process, since the distance between studded tire ruts in a lane match the wheel base width of a passenger vehicle. Naturally, the wheel base is much wider for heavy trucks.

The Profilometer measurements were taken to correspond to the wheel base width of passenger vehicles (Malik, 1997). Nevertheless, the possibility of including some truck rutting should be noted, as it would have a positive (increasing) influence on the wear rate estimation. Despite this drawback to summing the data from each lane, in the absence of better data regarding lane distribution of traffic, it was determined to be the best method.

3.3.3 Studded tire use

In 1995, ODOT contracted to the Oregon Survey Research Laboratory (OSRL) at the University of Oregon to conduct a telephone survey to ascertain the level of studded tire use in Oregon (Malik, 1997). The surveyors contacted 3,107 households which collectively owned 6,329 vehicles. A summary of the survey results is provided in Appendix B.

The highest rate is in Region 4, where over 32% of vehicles were equipped with studded tires at some time during the 1994-95 winter. In Region 3 has the lowest rate; just over 5% of vehicles were equipped with studded tires. These *nominal* rates indicate the number of vehicles using studded tires. Statewide, roughly half of all studded tire users use studded tires on just one axle, and the other half use them on both axles. In Region 4, nearly 60% of studded tire vehicles use them on both axles. This *nominal axle* use rate is used in Chapter 5 to estimate the total number of studded tires used (refer to Table 2.1).

For the purpose of calculating studded tire traffic, monthly factors were derived from the survey results for each region to reflect the changing levels of studded tire use. These are listed in Table 3.6. In two cases, it was determined that the highway conditions are better represented by county use rates rather than regional rates. This was the case for Interstate-84 (Hood River County) and US Highway 97 (Deschutes County). The rationale for this decision is described below.

The portion of I-84 represented in the data sets travels through the Columbia River Gorge, between Multnomah and Hood River Counties, which are both included in Region 1. Hood River County, which experiences cooler temperatures than the Willamette Valley, has a much higher use of studded tires than Region 1 as a whole. It was determined for this study that the studded tire use from Hood River county is a better representation of studded tire use on I-84. An analogous situation occurred for Deschutes County in Region 4. Regional and County studded tire use rates are also shown in Table 3.6.

Table 3.6 Regional and County monthly studded tire traffic factors in 1995*

	Region 1	Region 2	Region 3	Region 4	Region 5	Hood River	Deschutes
Nov.	8.2%	7.7%	3.5%	24.7%	20.4%	20.0%	27.3%
Dec.	13.3%	10.5%	4.7%	30.0%	25.2%	27.8%	30.8%
Jan.	14.4%	10.7%	4.4%	30.2%	24.5%	28.7%	30.6%
Feb.	14.6%	11.1%	3.9%	29.6%	23.2%	27.8%	30.4%
Mar.	11.3%	9.2%	3.7%	25.5%	18.0%	23.5%	29.1%
Apr.	2.7%	2.0%	1.0%	10.8%	6.5%	8.7%	14.0%
Weighted Ave.	10.7%	8.5%	3.5%	25.1%	19.6%	22.7%	27.0%
Both Axles	45.4%	45.3%	53.7%	59.7%	54.1%	47.0%	69.0%
ST Factor	15.6%	12.4%	5.4%	40.1%	30.2%	33.4%	45.6%

* Reflects the percentage of traffic using studded tires

Very little historical data exists regarding studded tire use in Oregon. As was noted earlier, the 1995 OSRL survey indicates that studded tire use doubled from the estimate given in 1974. No estimates for the intervening years were identified in the course of this study. However, survey responses regarding the growth in studded tire use indicate that the use of studded tires has increased an average of 8.45% during the last six years, but no information is provided for previous periods. Brunette (1995) indicates that studded tire use from 1974 through 1990 was, on average, steady or even declining, though he cautions that some engineering judgment was used to fill the gaps in data. No explanations for this were identified, but it is consistent with the recent increase in visible rutting in Oregon.

Based on the information available, the use of studded tires in Oregon was assumed to be virtually constant from 1967 through 1986, and then to increase at an average rate of 8.45% annually.[4]

3.4 Regression analysis

Studded tire passes over the life of the pavement were calculated for the highway segments of the main data set. These data represent the sum of studded tire traffic and rut depth in all lanes. The test data set (manual measurements) was also used.

Linear regressions were run on both the main and the test data sets. The data were grouped by surface type: asphalt (F-mix and B-mix) and PCC. The estimates are corrected for autocorrelation that results from the interdependence of traffic volumes on adjacent road sections.

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[4] Additional analysis was conducted using a constant growth rate in studded tire use with no significant difference in wear rate estimates.

Wear rates are estimated for every 100,000 studded tire passes. The results of the regression analyses are shown in Tables 3.7a-c[5]. Along with individual wear rate estimates, averages and mid-points for each surface type are listed. Mid-points are used to represent the *base case* in the remaining analyses. Full regression results are provided in Appendix C.

Eight wear rate estimates were determined for PCC surfaces; thirteen for asphalt surfaces. For each surface type, a range of wear rates was estimated. This should be expected due to the many factors affecting rutting susceptibility of pavements.

As was expected, PCC was found to have a considerably lower wear rate than asphalt. PCC has consistently shown more resistance to rutting than asphalt (MinnDOH, 1971; Christman, 1978; Krukar, 1973).

No clear performance advantage was found between F-mix and B-mix asphalts as indicated by comparison of mid-points; the mid-points were very close for both mixes (0.0387 and 0.0385 respectively). Estimates from the manual measurements on I-5 are also similar, at around 0.040". Due to the close physical proximity of the samples (from MP 242.75 to MP 245) we can expect that general conditions (traffic volume, climate, etc.) are quite similar. However, estimates from the main data set indicate better performance by B-mix surfaces. Other recent studies indicate no consistent advantage of B-mix over F-mix in terms of rutting (Brunette, 1995; Hicks, 1995).

Table 3.8 shows wear rate estimates from other studies. The base case estimates from the present study appear similar to other recent studies from Oregon (Malik, 1994; Brunette, 1995), which both used 1993 data. The 1974 ODOT study found a much higher wear rate, suggesting that a sharp decline in the wear rate of studded tires has taken place in the last two decades. This is probably a reflection of design changes that occurred in the 1970's. During that period, tire stud

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5 R^2 values are not given. In cases of regressions through the origin, the R^2 measures variation around zero, rather around the mean. It has been argued that for regression through the origin, R^2 can lead to over estimation of the adequacy of fit of the model. Standard error is a better tool for evaluating the regression results (Casella, 1983; Hahn, 1977).

manufacturers improved designs in response to calls for a prohibition of studded tire use (Brunette, 1995).

Wear rates can be expected to decline in the future as a result of recent legislation restricting the sale of studs in Oregon to those made of lightweight material. Lightweight studs have been found to reduce wear by 30-50% (Barter, 1996; Gustafson, 1992). A further reduction in wear may be realized from current work by ODOT pavement engineers to develop pavements that are less susceptible to rutting.

Table 3.7a Estimated Wear Rates (per 100,000 studded tire passes) for F-Mix asphalt

Data Set	Location	Wear rate	Std Err	T-stat	95% Conf. Interval		DF
Main	5 South, MP 234-247	0.0438	0.0021	21	0.0432	0.0444	52
Main	5 South, MP 294-299	0.0256	0.0012	21	0.0251	0.0261	22
Main	84 E&W, MP 22-31	0.0326	0.0034	9.6	0.0319	0.0333	85
Manual	I5 South, MP 245	0.0393	0.0009	44	0.0391	0.0395	80
Manual	I5 South, MP 243	0.0406	0.0006	67	0.0405	0.0407	81
Manual	US 97, MP 133.5	0.0517	0.0022	23	0.0512	0.0522	80
Manual	US 97, MP 140.4	0.0397	0.0012	34	0.0394	0.0400	80
	Range	0.0256 : 0.0517					
	Average	0.0390					
	Mid-Point	0.0387					

Table 3.7b Estimated Wear Rates (per 100,000 studded tire passes) for B-Mix asphalt

Data Set	Location	Wear rate	Std Err	T-stat	95% Conf. Interval		DF
Main	5 North, MP 234-244	0.0299	0.0012	25	0.0295	0.0303	46
Main	5 North, MP 244-249	0.0196	0.0013	15	0.0191	0.0201	24
Main	84 E&W, MP 17-22	0.0349	0.003	25	0.0340	0.0358	47
Manual	I5 North, MP 242.75	0.0399	0.005	8	0.0388	0.0410	76
Manual	22, Test set (EB)	0.0573	0.002	35	0.0569	0.0577	80
Manual	84 East, MP 20	0.0358	0.002	23	0.0354	0.0362	80
	Range	0.0196 : 0.0573					
	Average	0.0362					
	Mid-Point	0.0385					

Table 3.7c Estimated Wear Rates (per 100,000 studded tire passes) for PCC

Data Set	Location	Wear rate	Std Err	T-stat	95% Conf. Interval		DF
Main	5 North, MP 259-280	0.0110	0.0002	56	0.0110	0.0110	100
Main	5 South, MP 259-294	0.0076	0.0005	15	0.0075	0.0077	169
Main	205 North, MP 0-25	0.0086	0.0003	33	0.0085	0.0087	118
Main	205 South, MP 0-25	0.0084	0.0002	40	0.0084	0.0084	123
Manual	I5 North, MP 262	0.0100	0.0001	96	0.0100	0.0100	80
Manual	I5 North, MP 278	0.0097	0.0002	61	0.0097	0.0097	80
Manual	I5 South, MP 287.5	0.0077	0.0001	81	0.0077	0.0077	80
Manual	205 MP 12 (NB)	0.0083	0.0002	48	0.0083	0.0083	80
	Range	0.0076 : 0.0110					
	Average	0.0089					
	Mid-Point	0.0093					

Table 3.8 Estimated wear rates from other studies (per 100,000 studded tire passes)

State	Source	Asphalt	PCC
Oregon	ODOT, 1974	0.066"	0.026"
Oregon	Malik, 1994	0.035"	0.008"
Oregon	Brunette, 1995	0.034"	0.009"
Alaska	Barter, 1996	0.013"	
Minnesota	MDOT, 1971	0.030"-0.047"	0.075"-0.091"
Wisconsin	Lyford, 1977	0.015"-0.020"	0.007"-0.010"

4.0 Cost of mitigating effective studded tire pavement damage

This chapter estimates the cost of *effective damage*, which can be defined as damage that is expected to reduce the useful life of a pavement surface. ODOT uses a limiting rut depth threshold of 0.75" to signal the need for resurfacing. Roads with very low traffic volume, or very low studded tire use, may exhibit some rutting, but the studded tire traffic is not expected to be sufficient to require an overlay before age related deterioration warrants maintenance. Annual studded tire traffic and the wear rates estimated in Chapter Three were used to estimate the rut depth generated in 1995.

Design Life is used to indicate the number of years that a pavement is expected to last in the absence of studded tires. Typical design life values for asphalt and PCC surfaces in Oregon are 14 and 25 years, respectively (Hoffman, 1995). The cost of mitigating effective damage was estimated for nine scenarios using a range of wear rates and pavement design life values (see Table 4.1). Design life of 14 and 25 years, for asphalt and PCC respectively, and the mid-points of wear rates determined in Chapter 3 are considered the base case.

Table 4.1 Wear rates and design life values used in cost analyses

	Asphalt		PCC	
	Wear rate	Design life	Wear rate	Design Life
Low	.0226	12	.0076	20
BASE	.0386	14	.0093	25
High	.0545	18	.0110	35

Regional passenger vehicle and seasonal traffic factors were derived from information in the *Traffic Volume Tables.* The 116 permanent counter locations were grouped by county and region and the factors were averaged to represent the regional factors.

4.1 Assumptions

Assumptions and conditions imposed on the analysis include:

- Studded tire use, seasonal traffic level, and the passenger vehicle percentage of traffic are factored in by region. These are listed in Table 4.2.
- Repair costs: The assumed method of repair is asphalt overlay, the most common method of rutting repair. The cost is $52,800/lane mile, which represents material costs as given in Hoffman (1995) plus 50% for agency costs of labor and temporary traffic control (Gower, 1997). On asphalt surfaces, only the damaged lane(s) need to be overlaid. Conversely, if a single lane of a PCC highway reaches the threshold rut, the entire width of the highway, including the shoulders, needs to be repaired. All lanes are assumed to be 12' wide. The shoulders are assumed to be 6' and 10' wide, which is equivalent to adding 1.33 lanes.
- Lane distribution of total traffic[6]: The traffic distribution information from ODOT's Traffic Planning Section was used for general traffic.
- Lane distribution of truck traffic: In order to isolate passenger vehicle traffic from heavy truck traffic, an assumption was made that 95% of trucks travel in the right lane and the remaining trucks travel in the adjacent lane. Lane distribution factors for total traffic and for heavy trucks are given in Table 4.3.
- All vehicles are either trucks or passenger vehicles.

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6 Unlike the wear rate estimation, it is necessary to assign rutting to a particular lane. In the wear rate estimation, an assumption of linear dependence was made. However, the cost calculation is not a continuous function, but rather a discrete event: when the rut depth reaches 0.75", an expense occurs. It was necessary to "make do" with the best available information on lane split of traffic, and to make an additional assumption of the lane split of trucks.

Table 4.2 Regional studded tire and traffic factors

	Passenger Vehicles	Seasonal Factor	Studded Tire Traffic
Region 1	88%	44%	15.6%
Region 2	85%	45%	12.4%
Region 3	84%	43%	5.4%
Region 4	81%	43%	40.1%
Region 5	78%	41%	30.2%

Table 4.3 Lane Split Factors for Total Traffic and Trucks

	Two Lanes		Three Lanes		
	left	right	left	center	right
Total Traffic	40%	60%	16%	54%	30%
Truck Traffic	5%	95%	0%	5%	95%

4.2 Methodology

The cost analysis utilizes a database provided by ODOT's Pavement Management Section. The pavement database divides the state highway system into roughly 2,200 highway segments of various lengths. Each segment is designated by beginning and ending mileposts. Data provided include directional traffic (ADT) and surface type. For each segment, only one ADT value is provided. No distinction is made between F-mix and B-mix asphalts surfaces in the database. The low, mid-point, and high wear rates for both mixes are averaged for the cost analysis.

Unlike the wear rate estimation, the cost analysis requires isolating rutting to each particular lane. Total traffic is determined for each lane of highway. Studded tire traffic is then calculated using the regional factors for seasonal traffic and studded tire use. The derivations of regional factors for passenger vehicles and seasonal traffic volumes are shown in Appendix D.

The following steps are taken for each highway section in the pavement database:

Step 1: Split ADT by lane using lane distribution factors for total traffic to determine Lane Average Daily Traffic (LADT):

$$LADT = ADT * L_{x,y}\%$$

where, $LADT_x$ = Average daily traffic for 1995 in lane x,

ADT = Average Daily Traffic for 1995,

$L_{x,y}$ = Lane factor for the x lane (Left, Center, Right) on a y-(two or three) lane highway

Step 2: Adjust lane traffic to isolate passenger vehicle Lane ADT (PvLADT) using the assumed lane distribution of truck traffic.

$$PvLADT_x = LADT_x - T_x (1 - PV_k),$$

where, PV_k = fraction of passenger vehicle traffic in Region k, and

T_x = fraction of truck traffic in lane x.

Step 3: Apply regional factors for seasonal volume and studded tire use to calculate 1995 studded tire traffic:

$$SP_x = PvLADT_x * 365 * S_k\% * ST_k\%$$

Step 4: Apply the appropriate wear rate, *a*, for each surface to calculate the rut depth attributable to 1995 traffic:

$$R_x = SP_x * a$$

R_x = the estimated average rut depth along the entire lane, x

Step 5: Calculate the Expected Life (EL), the expected number of years until the pavement will reach the threshold rut depth of 0.75":

$EL_x = 0.75"/R_x$

where, EL_x = the Expected Life of lane x of the pavement section

Step 6: Determine whether studded tire traffic will reduce the pavement life:

If the Expected Life is less than the Design Life (DL) for the surface type, then the studded tire traffic is considered sufficient to reduce the useful life of the pavement.

For asphalt, a cost is calculated if the following criterion is met:

If $EL_x < DL$,

then a cost is charged.

Recall that when any lane of a PCC surface highway requires an overlay, the entire width of the road, as well as the shoulders, must be overlaid. A cost is charged for PCC surfaces when the following conditional criterion is met:

$(EL_L \text{ or } EL_C \text{ or } EL_R) < DL$,

where, EL_L = EL for the left lane,

EL_C = EL for the center lane,

EL_R = EL for the right lane,

Step 7. Cost calculation:

The cost of an asphalt overlay attributed to 1995 ($cost^{95}$) is based on an even distribution of the overlay cost among the years of useful life of the pavement:

For Asphalt,

TotalCost = \$52,800*LnMi

$cost^{95} = TotalCost \div EL_x$

For PCC,

$$TotalCost = \$52,800*LnMi*(Lanes + 1.333)$$

$$cost^{95} = TotalCost \div EL$$

where,

Lanes = the number of lanes, and

1.333 = the lane equivalent of adding both shoulders.

4.3 Effective damage cost estimates

The cost estimates do not necessarily represent expenditures made during 1995, but rather damage incurred during 1995. A summary of the costs for the base wear rate and design life is provided in Table 4.4. Cost estimates for all of the nine scenarios are summarized in Table 4.5, with details provided in Appendix E.

Table 4.4 Summary of cost estimates, Base case*

	PCC	Asphalt	Total
Region 1	$2,121,389	$3,019,116	$5,140,505
Region 2	$741,829	$1,810,814	$2,552,643
Region 3	$0	$0	$0
Region 4	$0	$2,242,845	$2,242,845
Region 5	$0	$129,238	$129,238
Statewide	**$2,863,218**	**$7,202,013**	**$10,065,231**

* Asphalt design life and wear rate: 14 years, 0.0386".
PCC design life and wear rate: 25 years, 0.0093".

The results indicate the cost of effective damage from studded tires, in the base case scenario, was over $10 million in 1995 for the state highway system. Although this is very close to the maintenance expense amount ($11 million) attributed to studded tire damage by ODOT's updated *Cost Responsibility Study* (1995), it is important to remember that the present $10 million estimate reflects studded tire damage inflicted during 1995, whereas ODOT's $11 million dollar figure reflects maintenance expenditures during the year.

Table 4.5 Summary of cost estimates for nine estimation scenarios

Design life	Wear rate	Asphalt	PCC Cost	Total Cost
Short	Low	$1,473,153	$1,558,059	$3,031,211
Base	Low	$1,901,186	$2,256,597	$4,157,783
Long	Low	$2,628,995	$2,339,834	$4,968,829
Short	Base	$6,134,818	$2,761,362	$8,896,180
Base	Base	$7,202,013	$2,863,218	$10,065,231
Long	Base	$8,162,295	$2,863,218	$11,025,514
Short	High	$12,334,399	$3,386,602	$15,721,001
Base	High	$13,891,958	$3,386,602	$17,278,560
Long	High	$14,861,168	$3,386,602	$18,247,770

The nine scenarios result in cost estimates ranging from $3 million to $18 million, depending on the wear rate and the design life values used. Holding the wear rate at the base level, the different design life values result in a range of costs from roughly $9 million to $11 million. The design life, as used in this study, is basically the expected useful life of a pavement surface in the absence of studded tires. A shorter design life lowers the cost estimate because it lowers the relative impact of studded tire damage on the useful life. The actual useful life of a pavement is a influenced by many factors, such as construction and traffic conditions. Furthermore, the determination of a useful life is by no means an exact science. Some differences of opinion exist regarding the level of damage when a pavement absolutely requires repair or reconstruction. The base case values used here are considered "typical" for Oregon (Hoffman, 1995).

A wider range results from varying the wear rate. It is important to recall that the range of wear rate estimates reflects variability in actual wear rates, not confidence limits of the estimate. Therefore, it is unlikely that either the low or the high wear rate can be considered representative for the entire state highway system, and that the very low or very high cost estimates reflect actual pavement damage from 1995.

The low wear rate does provide some indication of the possible cost impact of the lightweight stud mandate, which is expected to reduce the rutting for each tire by 30 to 50% (Barter, 1996). The actual reduction on the highways will have to happen over time, as conventional studded tires purchased in previous years are replaced with new lightweight studded tires. Also, there may always be some faction that will bring conventional studs from neighboring states. A further reduction in wear can probably be expected from new asphalt mix designs currently under study by ODOT pavement engineers. Therefore, the low wear rate estimates may be considered a reasonable representation of pavement damage in future years.

Over 70% of the cost is on asphalt surfaces, which is by far the predominant surface type in Oregon. Over half of the costs occur in Region 1, due to the high volume interstate highways located in Region 1, and the high proportion of PCC surface roads. PCC surface roads are costly to overlay due to the requirement that all lanes be resurfaced if any lane is resurfaced. These characteristics are present in Region 2 to a lesser degree, where 25% of costs occur. Approximately 22% of the costs are attributed to asphalt in Region 4, which has relatively low volumes but high studded tire use. Region 3, with very low studded tire use and traffic volume, accounts for none of the effective damage cost.

5.0 Implications of cost estimates

The effective damage estimates suggest considerable social costs of studded tire use, in the neighborhood of $10 million for the state system. Regional studded tire use factors, applied to Oregon's Department of Motor Vehicle records for registered passenger vehicles indicate that approximately 1.25 million studded tires were in use in Oregon during 1995 (see Table 5.1), or $8 per tire in costs for increased highway maintenance for the year. Given that studded tires generally last three or four seasons, it follows that a typical studded tire may cost the public $24-$32. Put another way, when social costs are considered, the true cost of a studded tire may easily exceed the average purchase price[7] by around 30%.

Table 5.1 Estimated number of studded tires in use in Oregon during 1995

	Passenger vehicles	Nominal Axle Rate*	Studded tire axles	Studded Tires (Axles * 2)
Region 1	1,076,477	24.3%	261,388	522,776
Region 2	824,776	18.0%	148,602	297,203
Region 3	383,955	7.8%	30,097	60,194
Region 4	220,851	51.4%	113,569	227,138
Region 5	156,695	41.1%	64,472	128,943
Statewide			**618,127**	**1,236,255**

*From Table 2.1

5.1 Effects of pricing on the quantity

It is a fundamental economic principle that efficient resource allocation requires that the price of a good be set equal to the marginal cost of providing that good. The existence of externalities results in inefficient pricing because social costs are excluded from the price paid by

[7] A recent inquiry of a local tire retailer found that studded tire prices range from around $40 to $150 per tire.

consumers. Consumers use more of the good than they would if they had to cover the social costs as well as the purchase price.

The responsiveness of consumers to changes in price is called *price elasticity of demand* and is the ratio of the percentage change in the quantity demanded of a good to the percentage change in the price of that good. For instance, if a 5% increase in price results in a 10% decrease in quantity sold, the price elasticity of demand is 2 (absolute values are used for convenience).

Goods tend to exhibit high elasticities if substitutes are readily available. For example, the price elasticity of demand for food is 0.21. On the other hand, the elasticity for transatlantic air travel is 1.30 (Nicholson, 1995).

The price elasticity of demand for tires has been estimated to be 0.86 in the short run, and 1.19 in the long run (Ruffin, 1997). Based on these elasticity estimates, a price increase of 30% (as suggested by the state highway cost estimate) would result in the quantity of tires demanded by consumers falling by more than 35% in the long run. The elasticities particular to studded tires should be expected to be higher, since tire chains and non-studded snow tires are available as substitutes[8].

5.2 Policy options

The current status of studded tire use in Oregon has resulted in high external costs of pavement damage. Policy options to address the problem can be grouped into three general categories:

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[8] It should be noted that elasticities are appropriately used to measure impacts of small changes in price, whereas the cost analysis above indicates a large price increase of 50%. These elasticities cannot be used to suggest with complete confidence that a 50% price increase would result in a 50% decrease in the quantity of studded tires purchased. As such, some caution should be used in interpreting the meaning of the elasticities with very large changes. However, they still provide a useful indication of the responsiveness to price changes.

restrictions on the use of studded tires; the imposition of a user fee; and engineering strategies to reduce damage.

5.2.1 Restricting the use of studded tires

Oregon currently restricts the use of studded tires to the six-months from November through April. A complete ban on studded tires was proposed in the 1997 Oregon legislative session (see SB307), as well as in the 1974 report by ODOT. Several states have imposed a ban on studded tires, including Wisconsin, Minnesota, and Michigan.

A prohibition of studded tires would imply that the optimal level of studded tire use is zero; in other words, the marginal cost (public and private) of studded tires exceeds the marginal benefit (public and private) at every possible level of use. In theory, an efficient tax would serve the same purpose since all costs would be included, and for all consumers the cost would exceed the benefit. However, two important caveats to the theoretical answer exist.

First, most economic analyses of efficient pricing assume that consumers have perfect information, and, if an appropriate tax is charged, can choose to use studded tires if their marginal benefit exceeds the marginal cost. However, considerable debate surrounds claims of safety benefits derived from the use of studded tires. If consumers overestimate safety benefits due to incorrect information, a policy restricting the use of studded tires, and perhaps a complete prohibition, is supported.

Second, the imposion of an optimal tax may not be feasible. The ambiguous nature of calculating safety costs has already been mentioned. Convenience benefits to studded tire users, and comfort losses to motorists due to rougher road surfaces introduce even more ambiguity. Furthermore, even if an appropriate tax could be determined, the imposition of a tax of this relative magnitude is probably politically infeasible.

5.2.2 Studded tire tax

Several legislative bills in the 1997 legislative session proposed a user fee on studded tires. One proposal is for a $5 fee; other proposals leave the fee amount unspecified pending a cost determination by ODOT (see HB 3149, SB 308, and HB 2213). Each of the proposals recommends that the fee be collected by the tire dealer at the point of sale.

As indicated in the cost analysis, a studded tire fee sufficient to cover the added repair costs for pavement damage on the state highway system would increase the cost of studded tires by around 30%. A tax of such high proportion will give consumers an incentive to purchase tires from neighboring states (tax avoidance), especially since the majority of studded tires are used in Region 1, which is close to the Washington state border. Oregon would then receive no tax revenue from these consumers, but would still bear the related costs.

An alternative approach is to attach a user fee to vehicle registration costs and require a permit for the use of studded tires. Enforcement issues may arise with such an approach, but the tax avoidance problem is averted.

More important, if an enforceable tax is set to equal the social cost of studded tires, the high cost can be expected to cause a sharp reduction in the number of studded tires used. Those drivers who continue to use studded tires will do so based on a determination that their private benefit is at least equal to the purchase price and the tax. Such a determination is the essence of efficient pricing for optimal resource allocation.

5.2.3 Engineering strategies to reduce pavement wear

Oregon has recently renewed efforts toward identifying engineering strategies to address the issue of studded tire damage. Recent legislation mandated the use of a lightweight material for all tire studs sold in Oregon. Currently, ODOT pavement engineers are studying new pavement mix designs and higher quality materials for pavements[9]. The use of lightweight studs has been reported to reduce wear rates by 50%, and changes in pavement design and raw material quality may bring about a further reduction in wear rates of up to 30% (Barter, 1996).

5.3 Expanding the scope of the analysis

The cost estimates derived in this study are limited to the public agency expenditures that are expected to be required for repairing wheel track rutting caused by studded tire traffic in 1995. Notable exclusions from the analysis are city and county streets. No thorough cost analysis has been conducted regarding damage on local streets, but a 1994 report estimated that costs for city and county roads constitute an additional 75% (Malik). That would bring the statewide cost to over $17 million for 1995, or $13.60 per tire per year.

Studded tire damage in forms other than rutting is also excluded. These include the wearing away of paint striping and surface grooving, which are proven safety enhancements. Additionally, environmental effects, increased noise, comfort losses, and vehicle degradation due to roughening road surfaces are excluded from the cost calculation.

Although it is difficult to assess the total cost of studded tire damage when all of the effects are considered, they represent externalities from studded tire use and should be considered additional costs of studded tire use.

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9 These factors may reduce the rutting susceptibility of pavements, but it should be noted that this use of resources, and the increased cost of purchasing higher quality materials represent another cost of studded tires.

5.4 Relaxing the *no net effect* premise

The above policy discussion is based on the premise that there is no net safety effect from the use of studded tires. The premise of a neutral safety impact provides a convenient starting point for the analysis, by removing the most subjective aspects from the discussion. However, the validity of the results does not wholly depend on the premise.

Relaxing the premise simply requires changing the magnitude of the social cost determination, where a presumption of a safety benefit will reduce the net social cost and vice versa. In order to determine that the current use of studded tires is optimal, the social benefit would have to equal the effective damage cost, plus cover the local costs, and the environmental, noise, comfort and vehicle degradation costs described in the expanded scope discussion from the preceding section.

6.0 Summary of findings

- A review of research literature reveals considerable doubt surrounding claims of a net safety benefit for studded tire users in Oregon. Although studded tires improve performance on icy surfaces, the improved handling is offset by a slight increase in driving speed. On bare surfaces, which represent the predominant surface condition in Oregon, studded tires do not perform as well as non-studded tires.
- The pavement damage caused by studded tire traffic presents numerous safety hazards to the general driving public, particularly in wet weather, a frequent condition in Oregon.
- Research results from Finland, Sweden, and Norway indicate that studded tire use provides an overall safety benefit. However, the considerably colder climate in these countries raises doubts about the direct implications of their research findings for Oregon.
- A wide range of wear rates were found for various sections of PCC and asphalt pavements. This reflects the many factors that contribute to rutting susceptibility of pavements. PCC is more resistant to rutting than asphalt. There is no obvious advantage of open-graded mixes over dense-graded mixes. Base wear rates used from this study are 0.0093"/100,000 studded tire passes for PCC surfaces; and 0.386"/100,000 studded tire passes for asphalt.
- The cost of pavement damage from studded tire traffic in 1995 is estimated at over $10 million for the state highway system alone. With an estimated 1.2 million studded tires in use during the year, roughly $8 per year in damage can be attributed to each studded tire. This amount pertains to a limited definition of cost and excludes local roads.
- Empirical estimates of the elasticity of demand for tires (in general) suggest that if the $8 per tire per year social cost were charged to studded tire users, the quantity of studded tires in use would fall sharply.

7.0 Conclusions

Oregon's current policy on studded tires has resulted in excess use of studded tires. Studded tire users pay only the purchase price for studded tires. The cost to all motorists in terms of reduced pavement life on the state highway system is around $10 million per year, or $8 per tire per year. A tax of this amount on studded tires would approach and frequently exceed 30% of the purchase price.

Many other costs are not included in the $8 figure cited above. Damage to city and county streets is not included. Further, there is significant qualitative evidence of safety hazards related to studded tire pavement damage, but no quantitative analysis has been conducted. Comfort losses, environmental concerns, and vehicle degradation are also difficult to assess. However, all of these are relevant costs of studded tire use.

Serious consideration should be given to the argument that the safety benefits from studded tires justify the pavement damage caused. The evidence on safety impacts is mixed, and many researchers have concluded a net safety loss from the use of studded tires. The strongest evidence to support the safety claims is from research in Scandinavia, which experiences much colder climates.

If it appears that the safety benefits from studded tires perceived by drivers are a result of misinformation, then a prohibition of studded tires may be the optimal policy. A prohibition may also be the best policy since so many ambiguities arise in the assessment of costs and benefits, and because a tax of the magnitude suggested here may be politically infeasible.

A more purely economic solution would be to impose a tax equal to the external costs. If a tax is collected at the point of purchase by tire dealers, consumers will have an incentive to purchase studded tires in other states. Most studded tire users are in Region 1, which is near the

Washington state border. A tax that is combined with registration fees will avoid the tax avoidance problem, although enforcement may be an issue. An enforceable tax on studded tires equal to the social costs can be expected to cause a sharp decrease in studded tire use.

As long as studded tires are in use, engineering changes can reduce the costs of associated pavement damage. The use of lightweight studs is expected to reduce pavement wear, as are current research efforts seeking improvements in pavement design and materials.

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Appendices

Appendix A

Derivation of highway passenger vehicle factors

& highway monthly traffic factors

Extrapolation of Passenger Vehicle factors for estimating wear rates

Highway	Location	PV% from *1995 Traffic Volume Tables*	PV% used for estimation
Interstate 5	MP 212	74.3%	
	MP 233-251		80%
	MP 259-282		85.8%
	MP 282	85.8%	
	MP 283-287		90%
	MP 289-298		93%
	MP 298	93%	
	MP 300	94.5%	94.5%
Interstate 84	MP 17.71	75.5	
	ALL		75.5%
Interstate 205	MP 1.27	90.6	
	ALL		91.3%
	MP 25.5	92.1	
US Hwy 22	MP 2.82	93.2%	
	ALL		93.2%
US Hwy 97	MP 125	88.8%	
	MP 130		88.8%
	MP 140		89.6%
	MP 142.27	89.6%	

Traffic Growth Rates for 1986-1995

Highway	Permanent Counter No.	Milepost	1995 ADT	Average Annual Growth	Weighted average
Interstate 5	22-016	212.05	31,500	3.58%	
	03-011	282.24	67,400	4.44%	
	26-016	298.24	131,600	3.60%	
	26-026	300.37	121,800	4.17%	**3.96%**
Interstate 84	26-001	17.71	27,700	5.78%	**5.78%**
Interstate 205	03-016	1.27	72,700	5.29%	
	26-024	25.50	103,300	6.50%	**6.00%**
US Hwy 22	24-004	2.82	20,700	4.05%	**4.05%**
US Hwy 97	09-003	142.27	24,800	4.61%	**4.61%**

Monthly traffic factors

Interstate 5

Permanent Counter 03-011

Month	ADT	% of ADT	# of Days	Monthly Traffic	Annual Traffic (AADT * 365)	Monthly Traffic Factor
January	53,000	79	31	1,643,000	24,612,315	6.68%
February	57,000	85	28	1,596,000	24,612,315	6.48%
March	61,500	91	31	1,906,500	24,612,315	7.75%
April	70,500	105	30	2,115,000	24,612,315	8.59%
November	66,000	30	30	1,980,000	24,612,315	8.04%
December	64,000	95	31	1,984,000	24,612,315	8.06%

Permanent Counter 26-016

Month	ADT	% of ADT	# of Days	Monthly Traffic	Annual Traffic (AADT * 365)	Monthly Traffic Factor
January	122,019	93	31	3,782,589	48,027,430	7.88%
February	115,000	87	28	3,220,000	48,027,430	6.70%
March	126,339	96	31	3,916,509	48,027,430	8.15%
April	137,266	104	30	4,117,980	48,027,430	8.57%
November	129,527	98	30	3,885,810	48,027,430	8.09%
December	125,333	95	31	3,885,323	48,027,430	8.09%

Permanent Counter 26-026

Month	ADT	% of ADT	# of Days	Monthly Traffic	Annual Traffic (AADT * 365)	Monthly Traffic Factor
January	110,400	91	31	3,422,400	44,471,235	7.70%
February	115,800	95	28	3,242,400	44,471,235	7.29%
March	123,000	101	31	3,813,000	44,471,235	8.57%
April	126,162	104	30	3,784,860	44,471,235	8.51%
November	118,000	97	30	3,540,000	44,471,235	7.96%
December	113,545	93	31	3,519,895	44,471,235	7.91%

Interstate 84

Permanent counter 26-001

Month	ADT	% of ADT	# of Days	Monthly Traffic	Annual Traffic (AADT * 365)	Monthly Traffic Factor
January	19,621	71	31	608,251	10,118,165	6.01%
February	20,955	76	28	586,740	10,118,165	5.80%
March	25,254	91	31	782,874	10,118,165	7.74%
April	27,081	98	30	812,430	10,118,165	8.03%
November	25,568	92	30	767,040	10,118,165	7.58%
December	21,079	76	31	653,449	10,118,165	6.46%

Monthly traffic factors, cont'd

Interstate 205

Permanent Counter 03-016

Month	ADT	% of ADT	# of Days	Monthly Traffic	Annual Traffic (AADT * 365)	Monthly Traffic Factor
January	65,632	90	31	2,034,592	26,552,290	7.66%
February	65,361	90	28	1,830,108	26,552,290	6.89%
March	71,268	98	31	2,209,308	26,552,290	8.32%
April	72,408	100	30	2,172,240	26,552,290	8.18%
November	70,789	97	30	2,123,670	26,552,290	8.00%
December	70,277	97	31	2,178,587	26,552,290	8.20%

Permanent Counter 26-024

Month	ADT	% of ADT	# of Days	Monthly Traffic	Annual Traffic (AADT * 365)	Monthly Traffic Factor
January	82,974	80	31	2,572,194	37,695,010	6.82%
February	89,534	87	28	2,506,952	37,695,010	6.65%
March	99,319	96	31	3,078,889	37,695,010	8.17%
April	101,400	98	30	3,042,000	37,695,010	8.07%
November	107,000	104	30	3,210,000	37,695,010	8.52%
December	109,000	106	31	3,379,000	37,695,010	8.96%

US Highway 97

Permanent Counter 09-020

Month	ADT	% of ADT	# of Days	Monthly Traffic	Annual Traffic (AADT * 365)	Monthly Traffic Factor
January	14,355	73	31	445,005	7,197,070	6.18%
February	17,910	91	28	501,480	7,197,070	6.97%
March	19,086	97	31	591,666	7,197,070	8.22%
April	20,150	102	30	604,500	7,197,070	8.40%
November	18,900	96	30	567,000	7,197,070	7.88%
December	18,454	94	31	572,074	7,197,070	7.95%

Permanent Counter 09-020

Month	ADT	% of ADT	# of Days	Monthly Traffic	Annual Traffic (AADT * 365)	Monthly Traffic Factor
January	13,756	80	31	426,436	6,141,356	6.94%
February	14,831	86	28	415,268	6,141,356	6.76%
March	15,665	91	31	485,615	6,141,356	7.91%
April	16,669	97	30	500,070	6,141,356	8.14%
November	15,364	89	30	460,920	6,141,356	7.51%
December	14,668	85	31	454,708	6,141,356	7.40%

Monthly traffic factors, cont'd

US Highway 22

Permanent Counter 24-004

Month	ADT	% of ADT	# of Days	Monthly Traffic	Annual Traffic (AADT * 365)	Monthly Traffic Factor
January	17,699	85	31	548,669	7,556,230	7.26%
February	18,144	88	28	508,032	7,556,230	6.72%
March	19,323	93	31	599,013	7,556,230	7.93%
April	20,154	97	30	604,620	7,556,230	8.00%
November	19,140	92	30	574,200	7,556,230	7.60%
December	18,727	90	31	580,537	7,556,230	7.68%

Highway average monthly traffic factors

Interstate 5				
Permanent Counter	03-011	26-016	26-026	Average
January	6.68%	7.88%	7.70%	**7.42%**
February	6.48%	6.70%	7.29%	**6.83%**
March	7.75%	8.15%	8.57%	**8.16%**
April	8.59%	8.57%	8.51%	**8.56%**
November	8.04%	8.09%	7.96%	**8.03%**
December	8.06%	8.09%	7.91%	**8.02%**

Interstate 84	
Permanent Counter	26-001
January	**6.01%**
February	**5.80%**
March	**7.74%**
April	**8.03%**
November	**7.58%**
December	**6.46%**

Interstate 205			
Permanent Counter	03-016	26-024	**Average**
January	7.66%	6.82%	**7.24%**
February	6.89%	6.65%	**6.77%**
March	8.32%	8.17%	**8.24%**
April	8.18%	8.07%	**8.13%**
November	8.00%	8.52%	**8.26%**
December	8.20%	8.96%	**8.58%**

US Hwy 22	
Permanent Counter	**24-004**
January	**7.26%**
February	**6.72%**
March	**7.93%**
April	**8.00%**
November	**7.60%**
December	**7.68%**

US Highway 97			
Permanent Counter	09-020	09-003	**Average**
January	6.18%	6.94%	**6.56%**
February	6.97%	6.76%	**6.86%**
March	8.22%	7.91%	**8.06%**
April	8.40%	8.14%	**8.27%**
November	7.88%	7.51%	**7.69%**
December	7.95%	7.40%	**7.68%**

Appendix B

Summary of studded tire use survey

Summary of studded tire use survey

REGION 1 SUMMARY

				Vehicles w/ studded tires	days	monthly use
Using Studs	269	16.7%	NOV	133	30	8.2%
No Studs	1346	83.3%	DEC	214	30	13.3%
Total vehicles	1615		JAN	232	31	14.4%
			FEB	235	28	14.6%
2 studs	143	53.2%	MAR	183	31	11.3%
4 studs	122	45.4%	APR	43	30	2.7%
				Seasonal average		10.7%
				Effective Studded tire tire traffic		15.6%

REGION 2 SUMMARY

				Vehicles w/ studded tires	days	monthly use
Using Studs	150	12.4%	NOV	93	30	7.7%
No Studs	1061	87.6%	DEC	127	30	10.5%
Total vehicles	1211		JAN	130	31	10.7%
			FEB	134	28	11.1%
2 studs	80	53.3%	MAR	112	31	9.2%
4 studs	68	45.3%	APR	24	30	2.0%
				Seasonal average		8.5%
				Effective Studded tire tire traffic		12.4%

REGION 3 SUMMARY

				Vehicles w/ studded tires	days	monthly use
Using Studs	41	5.1%	NOV	28	30	3.5%
No Studs	770	94.9%	DEC	38	30	4.7%
Total vehicles	811		JAN	36	31	4.4%
			FEB	32	28	3.9%
2 studs	18	43.9%	MAR	30	31	3.7%
4 studs	22	53.7%	APR	8	30	1.0%
				Seasonal average		3.5%
				Effective Studded tire tire traffic		5.4%

REGION 4 SUMMARY

				Vehicles w/ studded tires	days	monthly use
Using Studs	444	32.1%	NOV	342	30	24.7%
No Studs	941	67.9%	DEC	415	30	30.0%
Total vehicles	1385		JAN	418	31	30.2%
			FEB	410	28	29.6%
2 studs	179	40.3%	MAR	353	31	25.5%
4 studs	265	59.7%	APR	149	30	10.8%
				Seasonal average		25.1%
				Effective Studded tire tire traffic		40.1%

REGION 5 SUMMARY

				Vehicles w/ studded tires	days	monthly use
Using Studs	342	26.7%	NOV	261	30	20.4%
No Studs	939	73.3%	DEC	323	30	25.2%
Total vehicles	1281		JAN	314	31	24.5%
			FEB	297	28	23.2%
2 studs	155	45.3%	MAR	230	31	18.0%
4 studs	185	0.54094	APR	83	30	6.5%
				Seasonal average		19.6%
				Effective Studded tire tire traffic		30.2%

Appendix C

Wear rate regression results

F-MIX: I-5 South, MP 234-247

Autoreg Procedure

Dependent Variable = RUT

Ordinary Least Squares Estimates

SSE	0.529796	DFE	53
MSE	0.009996	Root MSE	0.099981
SBC	-92.475	AIC	-94.464
Reg Rsq	0.9737	Total Rsq	0.9737
Durbin-Watson	0.6770	PROB<DW	0.0001

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.045092	0.00102	44.306	0.0001

Estimates of Autocorrelations

```
Lag Covariance Correlation -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

 0  0.009811   1.000000 |                    |********************|
 1  0.006318   0.643973 |                    |*************       |
```

Preliminary MSE = 0.005742

Estimates of the Autoregressive Parameters

Lag	Coefficient	Std Error	t Ratio
1	-0.64397333	0.106093	-6.070

Yule-Walker Estimates

SSE	0.300184	DFE	52
MSE	0.005773	Root MSE	0.075979
SBC	-118.628	AIC	-122.606
Reg Rsq	0.8973	Total Rsq	0.9851
Durbin-Watson	1.9960	PROB<DW	0.4991

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.043824	0.00206	21.312	0.0001

F-MIX: I-5 South, MP 294-299

Autoreg Procedure

Dependent Variable = RUT

Ordinary Least Squares Estimates

SSE	1.097614	DFE	23
MSE	0.047722	Root MSE	0.218454
SBC	-2.75086	AIC	-3.92891
Reg Rsq	0.9748	Total Rsq	0.9748
Durbin-Watson	1.3035	PROB<DW	0.0371

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.025636	0.00086	29.813	0.0001

Estimates of Autocorrelations

Lag	Covariance	Correlation	-1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1
0	0.045734	1.000000	|********************|
1	0.01561	0.341311	|******* |

Preliminary MSE = 0.040406

Estimates of the Autoregressive Parameters

Lag	Coefficient	Std Error	t Ratio
1	-0.34131139	0.200398	-1.703

Yule-Walker Estimates

SSE	0.967964	DFE	22
MSE	0.043998	Root MSE	0.209758
SBC	-2.46573	AIC	-4.82184
Reg Rsq	0.9522	Total Rsq	0.9778
Durbin-Watson	1.7496	PROB<DW	0.2669

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.025615	0.00122	20.930	0.0001

F-MIX: I-84 East & West, MP 22-31

Autoreg Procedure

Dependent Variable = RUT

Ordinary Least Squares Estimates

SSE	2.423734	DFE	86
MSE	0.028183	Root MSE	0.167878
SBC	-60.1509	AIC	-62.6168
Reg Rsq	0.9299	Total Rsq	0.9299
Durbin-Watson	0.2209	PROB<DW	0.0001

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.041661	0.00123	33.777	0.0001

Estimates of Autocorrelations

Lag	Covariance	Correlation	-1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1
0	0.027859	1.000000	| |******************** |
1	0.024192	0.868377	| |***************** |

Preliminary MSE = 0.006851

Estimates of the Autoregressive Parameters

Lag	Coefficient	Std Error	t Ratio
1	-0.86837744	0.053788	-16.144

Yule-Walker Estimates

SSE	0.47903	DFE	85
MSE	0.005636	Root MSE	0.075071
SBC	-195.335	AIC	-200.267
Reg Rsq	0.5178	Total Rsq	0.9861
Durbin-Watson	1.7869	PROB<DW	0.1676

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.032606	0.00341	9.553	0.0001

F-MIX: I-5 South, MP 243

Autoreg Procedure

Dependent Variable = RUT

Ordinary Least Squares Estimates

SSE	0.577287	DFE	82
MSE	0.00704	Root MSE	0.083905
SBC	-172.403	AIC	-174.821
Reg Rsq	0.9819	Total Rsq	0.9819
Durbin-Watson	2.0157	PROB<DW	0.5285

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.040620	0.000609	66.688	0.0001

Estimates of Autocorrelations

Lag	Covariance	Correlation	-1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1
0	0.006955	1.000000	|********************|
1	-0.00014	-0.019752	| |

Preliminary MSE = 0.006953

Estimates of the Autoregressive Parameters

Lag	Coefficient	Std Error	t Ratio
1	0.01975169	0.111089	0.178

Yule-Walker Estimates

SSE	0.577057	DFE	81
MSE	0.007124	Root MSE	0.084405
SBC	-168.017	AIC	-172.854
Reg Rsq	0.9826	Total Rsq	0.9819
Durbin-Watson	1.9765	PROB<DW	0.4573

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.040622	0.000601	67.591	0.0001

F-MIX: I-5 South, MP 245

Autoreg Procedure

Dependent Variable = RUT

Ordinary Least Squares Estimates

SSE	0.288449	DFE	80
MSE	0.003606	Root MSE	0.060047
SBC	-222.39	AIC	-224.784
Reg Rsq	0.9582	Total Rsq	0.9582
Durbin-Watson	1.9759	PROB<DW	0.4567

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.039495	0.000922	42.820	0.0001

Estimates of Autocorrelations

```
Lag Covariance Correlation -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

 0  0.003561   1.000000 |                    |********************|
 1  -0.00006  -0.015600 |                    |                    |
```

Preliminary MSE = 0.00356

Estimates of the Autoregressive Parameters

Lag	Coefficient	Std Error	t Ratio
1	0.01559979	0.112495	0.139

Yule-Walker Estimates

SSE	0.288375	DFE	79
MSE	0.00365	Root MSE	0.060418
SBC	-218.016	AIC	-222.805
Reg Rsq	0.9594	Total Rsq	0.9582
Durbin-Watson	1.9457	PROB<DW	0.4031

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.039491	0.000914	43.208	0.0001

F-Mix: US Highway 97, MP 133.5

Autoreg Procedure

Dependent Variable = RUT

Ordinary Least Squares Estimates

SSE	2.792731	DFE	81
MSE	0.034478	Root MSE	0.185683
SBC	-40.0227	AIC	-42.4294
Reg Rsq	0.9803	Total Rsq	0.9803
Durbin-Watson	0.4378	PROB<DW	0.0001

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.051989	0.000818	63.525	0.0001

Estimates of Autocorrelations

Lag	Covariance	Correlation	-1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1
0	0.034058	1.000000	| |********************|
1	0.026505	0.778234	| |**************** |

Preliminary MSE = 0.013431

Estimates of the Autoregressive Parameters

Lag	Coefficient	Std Error	t Ratio
1	-0.77823350	0.070210	-11.084

Yule-Walker Estimates

SSE	1.091432	DFE	80
MSE	0.013643	Root MSE	0.116803
SBC	-111.727	AIC	-116.54
Reg Rsq	0.8708	Total Rsq	0.9923
Durbin-Watson	2.2557	PROB<DW	0.8796

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.051726	0.00223	23.216	0.0001

F-Mix, US Highway 97, MP 140.4

Autoreg Procedure

Dependent Variable = RUT

Ordinary Least Squares Estimates

SSE	1.385528	DFE	81
MSE	0.017105	Root MSE	0.130787
SBC	-97.4997	AIC	-99.9064
Reg Rsq	0.9902	Total Rsq	0.9902
Durbin-Watson	0.4257	PROB<DW	0.0001

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.039425	0.000435	90.610	0.0001

Estimates of Autocorrelations

```
Lag Covariance Correlation -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

 0  0.016897   1.000000 |                    |********************|
 1  0.013077   0.773928 |                    |****************    |
```

Preliminary MSE = 0.006776

Estimates of the Autoregressive Parameters

Lag	Coefficient	Std Error	t Ratio
1	-0.77392797	0.070802	-10.931

Yule-Walker Estimates

SSE	0.533458	DFE	80
MSE	0.006668	Root MSE	0.081659
SBC	-170.445	AIC	-175.258
Reg Rsq	0.9365	Total Rsq	0.9962
Durbin-Watson	2.5676	PROB<DW	0.9958

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.039651	0.00115	34.347	0.0001

B-Mix: I5 North, MP 234-244

Autoreg Procedure

Dependent Variable = RUT

Ordinary Least Squares Estimates

SSE	1.171008	DFE	50
MSE	0.02342	Root MSE	0.153036
SBC	-43.8084	AIC	-45.7403
Reg Rsq	0.9692	Total Rsq	0.9692
Durbin-Watson	0.9497	PROB<DW	0.0001

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.030054	0.000758	39.642	0.0001

Estimates of Autocorrelations

```
Lag Covariance Correlation -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

 0  0.022961   1.000000 |                    |********************|
 1  0.010411   0.453437 |                    |*********           |
```

Preliminary MSE = 0.01824

Estimates of the Autoregressive Parameters

Lag	Coefficient	Std Error	t Ratio
1	-0.45343749	0.127327	-3.561

Yule-Walker Estimates

SSE	0.895402	DFE	49
MSE	0.018274	Root MSE	0.13518
SBC	-53.3322	AIC	-57.1958
Reg Rsq	0.9259	Total Rsq	0.9764
Durbin-Watson	1.8588	PROB<DW	0.3062

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.029896	0.00121	24.738	0.0001

B-MIX: I5 North, MP 244-249

Autoreg Procedure

Dependent Variable = RUT

Ordinary Least Squares Estimates

SSE	0.518894	DFE	26
MSE	0.019957	Root MSE	0.141271
SBC	-26.7826	AIC	-28.0784
Reg Rsq	0.9378	Total Rsq	0.9378
Durbin-Watson	0.7496	PROB<DW	0.0001

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.019304	0.000975	19.792	0.0001

Estimates of Autocorrelations

Lag	Covariance	Correlation	-1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1
0	0.019218	1.000000	| |********************|
1	0.006087	0.316729	| |****** |

Preliminary MSE = 0.01729

Estimates of the Autoregressive Parameters

Lag	Coefficient	Std Error	t Ratio
1	-0.31672920	0.189703	-1.670

Yule-Walker Estimates

SSE	0.433619	DFE	25
MSE	0.017345	Root MSE	0.131699
SBC	-28.2285	AIC	-30.8201
Reg Rsq	0.9001	Total Rsq	0.9480
Durbin-Watson	1.2014	PROB<DW	0.0143

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.019635	0.00131	15.010	0.0001

B-MIX: I-84 East & West, MP 17-22

Autoreg Procedure

Dependent Variable = RUT

Ordinary Least Squares Estimates

SSE	1.089715	DFE	48
MSE	0.022702	Root MSE	0.150673
SBC	-43.5415	AIC	-45.4333
Reg Rsq	0.9671	Total Rsq	0.9671
Durbin-Watson	1.0847	PROB<DW	0.0003

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.035231	0.000938	37.558	0.0001

Estimates of Autocorrelations

```
Lag Covariance Correlation -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

 0  0.022239    1.000000 |                    |********************|
 1  0.008566    0.385189 |                    |********            |
```

Preliminary MSE = 0.018939

Estimates of the Autoregressive Parameters

Lag	Coefficient	Std Error	t Ratio
1	-0.38518859	0.134610	-2.862

Yule-Walker Estimates

SSE	0.903369	DFE	47
MSE	0.019221	Root MSE	0.138638
SBC	-48.6786	AIC	-52.4622
Reg Rsq	0.9312	Total Rsq	0.9727
Durbin-Watson	1.7207	PROB<DW	0.1618

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.034881	0.00138	25.214	0.0001

B-MIX: I-5 North, MP 242.75

Autoreg Procedure

Dependent Variable = RUT

Ordinary Least Squares Estimates

SSE	5.384096	DFE	81
MSE	0.06647	Root MSE	0.257818
SBC	13.80451	AIC	11.39779
Reg Rsq	0.9515	Total Rsq	0.9515
Durbin-Watson	0.2886	PROB<DW	0.0001

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.040359	0.00101	39.869	0.0001

Estimates of Autocorrelations

```
Lag Covariance Correlation -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1
 0   0.06566    1.000000 |                    |********************|
 1   0.055691   0.848182 |                    |*****************   |
 2   0.051014   0.776946 |                    |****************    |
 3   0.046238   0.704201 |                    |**************      |
 4   0.042438   0.646329 |                    |*************       |
 5   0.0434     0.660987 |                    |*************       |
```

Preliminary MSE = 0.016374

Estimates of the Autoregressive Parameters

Lag	Coefficient	Std Error	t Ratio
1	-0.66083352	0.110568	-5.977
2	-0.18227884	0.132969	-1.371
3	0.04465320	0.134505	0.332
4	0.14860228	0.132969	1.118
5	-0.26624530	0.110568	-2.408

Yule-Walker Estimates

SSE	1.267602	DFE	76
MSE	0.016679	Root MSE	0.129147
SBC	-81.0308	AIC	-95.4711
Reg Rsq	0.4581	Total Rsq	0.9886
Durbin-Watson	2.0078	PROB<DW	0.5210

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.039914	0.00498	8.016	0.0001

B-MIX: US Highway 22, MP 3

Autoreg Procedure

Dependent Variable = RUT

Ordinary Least Squares Estimates

SSE	1.610899	DFE	81
MSE	0.019888	Root MSE	0.141024
SBC	-85.1413	AIC	-87.5481
Reg Rsq	0.9838	Total Rsq	0.9838
Durbin-Watson	0.7760	PROB<DW	0.0001

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.057482	0.00082	70.085	0.0001

Estimates of Autocorrelations

```
Lag Covariance Correlation -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

 0  0.019645   1.000000 |                    |********************|
 1  0.011921   0.606825 |                    |************        |
```

Preliminary MSE = 0.012411

Estimates of the Autoregressive Parameters

Lag	Coefficient	Std Error	t Ratio
1	-0.60682488	0.088865	-6.829

Yule-Walker Estimates

SSE	1.011402	DFE	80
MSE	0.012643	Root MSE	0.112439
SBC	-118.443	AIC	-123.256
Reg Rsq	0.9390	Total Rsq	0.9898
Durbin-Watson	2.3611	PROB<DW	0.9511

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.057308	0.00163	35.098	0.0001

B-MIX: I-84 East, MP 20

Autoreg Procedure

Dependent Variable = RUT

Ordinary Least Squares Estimates

SSE	1.497511	DFE	81
MSE	0.018488	Root MSE	0.13597
SBC	-91.1264	AIC	-93.5331
Reg Rsq	0.9770	Total Rsq	0.9770
Durbin-Watson	0.4412	PROB<DW	0.0001

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.035704	0.000608	58.693	0.0001

Estimates of Autocorrelations

Lag	Covariance	Correlation	-1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1
0	0.018262	1.000000	| |********************|
1	0.013927	0.762612	| |*************** |

Preliminary MSE = 0.007641

Estimates of the Autoregressive Parameters

Lag	Coefficient	Std Error	t Ratio
1	-0.76261198	0.072321	-10.545

Yule-Walker Estimates

SSE	0.597349	DFE	80
MSE	0.007467	Root MSE	0.086411
SBC	-161.211	AIC	-166.025
Reg Rsq	0.8668	Total Rsq	0.9908
Durbin-Watson	2.3572	PROB<DW	0.9497

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.035778	0.00157	22.814	0.0001

PCC: I-5 North, MP 259-280

Autoreg Procedure

Dependent Variable = RUT

Ordinary Least Squares Estimates

SSE	0.634228	DFE	101
MSE	0.006279	Root MSE	0.079243
SBC	-224.104	AIC	-226.729
Reg Rsq	0.9907	Total Rsq	0.9907
Durbin-Watson	0.8430	PROB<DW	0.0001

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.010944	0.000105	103.952	0.0001

Estimates of Autocorrelations

```
Lag Covariance Correlation -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

 0  0.006218   1.000000 |                    |********************|
 1  0.003493   0.561805 |                    |***********         |
```

Preliminary MSE = 0.004255

Estimates of the Autoregressive Parameters

Lag	Coefficient	Std Error	t Ratio
1	-0.56180480	0.082727	-6.791

Yule-Walker Estimates

SSE	0.427369	DFE	100
MSE	0.004274	Root MSE	0.065373
SBC	-259.366	AIC	-264.616
Reg Rsq	0.9689	Total Rsq	0.9938
Durbin-Watson	1.9707	PROB<DW	0.4413

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.010948	0.000196	55.827	0.0001

PCC: I-5 South, MP 259-294

Autoreg Procedure

Dependent Variable = RUT

Ordinary Least Squares Estimates

SSE	12.06857	DFE	170
MSE	0.070992	Root MSE	0.266442
SBC	37.08752	AIC	33.94585
Reg Rsq	0.9150	Total Rsq	0.9150
Durbin-Watson	0.2569	PROB<DW	0.0001

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.008859	0.000207	42.776	0.0001

Estimates of Autocorrelations

```
Lag Covariance Correlation -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

 0  0.070576   1.000000 |                    |********************|
 1  0.057521   0.815010 |                    |****************    |
```

Preliminary MSE = 0.023697

Estimates of the Autoregressive Parameters

Lag	Coefficient	Std Error	t Ratio
1	-0.81501047	0.044573	-18.285

Yule-Walker Estimates

SSE	3.024746	DFE	169
MSE	0.017898	Root MSE	0.133783
SBC	-193.305	AIC	-199.589
Reg Rsq	0.5704	Total Rsq	0.9787
Durbin-Watson	1.8677	PROB<DW	0.1971

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.007548	0.000504	14.981	0.0001

PCC: I-5 North, MP 262

Autoreg Procedure

Dependent Variable = RUT

Ordinary Least Squares Estimates

SSE	0.310497	DFE	81
MSE	0.003833	Root MSE	0.061914
SBC	-220.144	AIC	-222.551
Reg Rsq	0.9924	Total Rsq	0.9924
Durbin-Watson	1.8595	PROB<DW	0.2615

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.009950	0.000097	102.930	0.0001

Estimates of Autocorrelations

Lag	Covariance	Correlation	-1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1
0	0.003787	1.000000	|********************|
1	0.000263	0.069427	|* |

Preliminary MSE = 0.003768

Estimates of the Autoregressive Parameters

Lag	Coefficient	Std Error	t Ratio
1	-0.06942695	0.111534	-0.622

Yule-Walker Estimates

SSE	0.308998	DFE	80
MSE	0.003862	Root MSE	0.062149
SBC	-216.129	AIC	-220.943
Reg Rsq	0.9913	Total Rsq	0.9924
Durbin-Watson	1.9915	PROB<DW	0.4846

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.009950	0.000104	95.504	0.0001

PCC: I-5 North, MP 278

Autoreg Procedure

Dependent Variable = RUT

Ordinary Least Squares Estimates

SSE	0.347151	DFE	81
MSE	0.004286	Root MSE	0.065466
SBC	-210.994	AIC	-213.401
Reg Rsq	0.9922	Total Rsq	0.9922
Durbin-Watson	0.9666	PROB<DW	0.0001

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.009728	0.000096	101.238	0.0001

Estimates of Autocorrelations

Lag	Covariance	Correlation	-1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1
0	0.004234	1.000000		|********************|
1	0.002002	0.472814		|*********	

Preliminary MSE = 0.003287

Estimates of the Autoregressive Parameters

Lag	Coefficient	Std Error	t Ratio
1	-0.47281410	0.098517	-4.799

Yule-Walker Estimates

SSE	0.262615	DFE	80
MSE	0.003283	Root MSE	0.057295
SBC	-229.218	AIC	-234.031
Reg Rsq	0.9793	Total Rsq	0.9941
Durbin-Watson	2.1853	PROB<DW	0.8007

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.009698	0.000158	61.455	0.0001

PCC: I-5 South, MP 287.5

Autoreg Procedure

Dependent Variable = RUT

Ordinary Least Squares Estimates

SSE	0.659273	DFE	81
MSE	0.008139	Root MSE	0.090217
SBC	-158.401	AIC	-160.808
Reg Rsq	0.9924	Total Rsq	0.9924
Durbin-Watson	1.5129	PROB<DW	0.0123

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.007664	0.000075	102.618	0.0001

Estimates of Autocorrelations

Lag	Covariance	Correlation	-1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1
0	0.00804	1.000000	| |********************|
1	0.00185	0.230161	| |***** |

Preliminary MSE = 0.007614

Estimates of the Autoregressive Parameters

Lag	Coefficient	Std Error	t Ratio
1	-0.23016085	0.108802	-2.115

Yule-Walker Estimates

SSE	0.623413	DFE	80
MSE	0.007793	Root MSE	0.088276
SBC	-158.526	AIC	-163.339
Reg Rsq	0.9880	Total Rsq	0.9928
Durbin-Watson	2.0294	PROB<DW	0.5532

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.007665	0.000095	81.036	0.0001

PCC: I-205 North, MP 0-25

Autoreg Procedure

Dependent Variable = RUT

Ordinary Least Squares Estimates

SSE	2.976082	DFE	119
MSE	0.025009	Root MSE	0.158143
SBC	-98.2933	AIC	-101.081
Reg Rsq	0.9713	Total Rsq	0.9713
Durbin-Watson	0.8171	PROB<DW	0.0001

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.008672	0.000137	63.422	0.0001

Estimates of Autocorrelations

```
Lag Covariance Correlation -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

 0  0.024801    1.000000 |                    |********************|
 1  0.014392    0.580302 |                    |************        |
```

Preliminary MSE = 0.016449

Estimates of the Autoregressive Parameters

Lag	Coefficient	Std Error	t Ratio
1	-0.58030182	0.074972	-7.740

Yule-Walker Estimates

SSE	1.950784	DFE	118
MSE	0.016532	Root MSE	0.128577
SBC	-143.78	AIC	-149.355
Reg Rsq	0.9023	Total Rsq	0.9812
Durbin-Watson	2.1044	PROB<DW	0.7176

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.008617	0.000261	33.004	0.0001

PCC: I-205 South, MP 0-25

Autoreg Procedure

Dependent Variable = RUT

Ordinary Least Squares Estimates

SSE	2.662388	DFE	124
MSE	0.021471	Root MSE	0.146529
SBC	-121.573	AIC	-124.402
Reg Rsq	0.9744	Total Rsq	0.9744
Durbin-Watson	1.0073	PROB<DW	0.0001

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.008406	0.000122	68.663	0.0001

Estimates of Autocorrelations

Lag	Covariance	Correlation	-1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1
0	0.021299	1.000000	| |********************|
1	0.010379	0.487284	| |********** |

Preliminary MSE = 0.016242

Estimates of the Autoregressive Parameters

Lag	Coefficient	Std Error	t Ratio
1	-0.48728395	0.078738	-6.189

Yule-Walker Estimates

SSE	2.017506	DFE	123
MSE	0.016402	Root MSE	0.128072
SBC	-151.144	AIC	-156.801
Reg Rsq	0.9298	Total Rsq	0.9806
Durbin-Watson	2.0944	PROB<DW	0.7020

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.008350	0.000207	40.353	0.0001

PCC: I-205 North, MP 12

Autoreg Procedure

Dependent Variable = RUT

Ordinary Least Squares Estimates

SSE	1.011937	DFE	81
MSE	0.012493	Root MSE	0.111772
SBC	-123.265	AIC	-125.672
Reg Rsq	0.9912	Total Rsq	0.9912
Durbin-Watson	0.6598	PROB<DW	0.0001

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.008292	0.000087	95.420	0.0001

Estimates of Autocorrelations

Lag	Covariance	Correlation	-1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1
0	0.012341	1.000000	| |********************|
1	0.007664	0.621033	| |************ |

Preliminary MSE = 0.007581

Estimates of the Autoregressive Parameters

Lag	Coefficient	Std Error	t Ratio
1	-0.62103287	0.087630	-7.087

Yule-Walker Estimates

SSE	0.583316	DFE	80
MSE	0.007291	Root MSE	0.08539
SBC	-163.545	AIC	-168.358
Reg Rsq	0.9669	Total Rsq	0.9949
Durbin-Watson	1.9361	PROB<DW	0.3864

NOTE: No intercept term is used. R-squares are redefined.

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
SPLIFE	1	0.008303	0.000172	48.335	0.0001

Appendix D

Derivation of County and Regional

Passenger Vehicle and Seasonal Traffic Factors

County Passenger Vehicle and Seasonal Traffic Factor calculations

Monthly factors represent average daily traffic for the month relative to annual average daily traffic
Seasonal factors represent the annual traffic volume occuring during the six month studded tire season.

Baker County

Station Number	Ave.	01-001	01-007	01-010	01-011	01-12
HWY		US30	ORE. 203	ORE. 86	I84	ORE. 7
% Pas Veh	66%	0.869	95.1	90.8	56.3	84.9
Jan		80	76	71	71	66
Feb		88	78	74	76	67
Mar		93	80	86	93	74
Apr		102	90	94	96	86
Nov		91	89	76	90	84
Dec		87	82	71	78	66
Seasonal	41%	45%	41%	39%	42%	37%

Benton County

Station Number	Ave.	3	5	7
HWY		Ore. 34	Ore. 223	Ore. 99w
% Pas Veh	87%	89.7	84.9	86.4
Jan		89	87	86
Feb		90	90	92
Mar		92	97	97
Apr		96	98	99
Nov		96	100	98
Dec		88	85	88
Seasonal	46%	46%	46%	47%

Clackamas County

Station Number	Ave.	11	13	14	16
HWY		I5	Ore. 213	Ore. 211	I 205
% Pas Veh	89%	85.8	91.3	90	90.6
Jan		79	84	85	90
Feb		85	88	88	90
Mar		91	95	95	98
Apr		105	100	99	100
Nov		98	96	91	97
Dec		95	95	84	97
Seasonal	46%	46%	47%	45%	48%

Clatsop County

Station Number	Ave.	1	10
HWY		US101	Ore. 202
% Pas Veh	89%	93.6	84.6
Jan		75	85
Feb		84	79
Mar		95	84
Apr		100	85
Nov		85	125
Dec		76	77
Seasonal	44%	43%	45%

Columbia County

Station Number	Ave.	6
HWY		US30
% Pas Veh	89%	89.3
Jan		82
Feb		87
Mar		93
Apr		101
Nov		90
Dec	45%	45%
Seasonal		44.9167

Coos County

Station Number	Ave.	1	4
HWY		US101	US101
% Pas Veh	86%	86.6	85.6
Jan		73	75
Feb		82	86
Mar		89	88
Apr		93	95
Nov		88	90
Dec		82	89
Seasonal	43%	42%	44%

Crook County

Station Number	Ave.	1
HWY		US26
% Pas Veh	90%	89.5
Jan		70
Feb		75
Mar		80
Apr		90
Nov		99
Dec		75
Seasonal	41%	41%

Curry County

Station Number	Ave.	5
HWY		US101
% Pas Veh	93%	93.1
Jan		85
Feb		91
Mar		86
Apr		95
Nov		90
Dec		86
Seasonal	44%	44%

Deschutes County

Station Number	Ave.	3	5	11	14	20
HWY		US97	US20	Cent Dr.	US20-Ore. 126	US97
% Pas Veh	89%	89.6	85.2	96.3	87.3	88.8
Jan		80	71	189	62	73
Feb		86	82	191	69	91
Mar		91	89	186	79	97
Apr		97	96	109	85	102
Nov		89	85	25	75	96
Dec		85	75	195	68	94
Seasonal	49%	44%	42%	75%	37%	46%

Douglas County

Station Number	Ave.	3	4	6	7
HWY		Ore. 38	Ore. 138	Ore. 42	I5
% Pas Veh	71%	68.6	64.8	84.4	67.9
Jan		67	56	85	83
Feb		79	53	95	85
Mar		92	67	99	95
Apr		92	77	102	85
Nov		86	73	91	92
Dec		83	54	86	92
Seasonal	41%	42%	32%	47%	44%

Gilliam County

Station Number	Ave.	4	7	8
HWY		Ore. 206	Ore. 19	I84
% Pas Veh	72%	93	51.8	71.7
Jan		78	99	67
Feb		77	96	72
Mar		86	101	90
Apr		99	104	93
Nov		105	91	98
Dec		86	82	77
Seasonal	44%	44%	48%	41%

Grant County

Station Number	Ave.	3	6	9
HWY		US26	US395	US26
% Pas Veh	79%	82.3	86.2	68.2
Jan		68	73	59
Feb		67	66	61
Mar		77	81	75
Apr		80	87	92
Nov		97	106	88
Dec		68	62	61
Seasonal	38%	38%	40%	36%

Harney County

Station Number	Ave.	1	3
HWY		US395	US20
% Pas Veh	81%	85.6	76.8
Jan		67	62
Feb		68	71
Mar		71	85
Apr		83	92
Nov		97	87
Dec		74	70
Seasonal	39%	38%	39%

Hood River County

Station Number	Ave.	3
HWY		Ore. 35
% Pas Veh	91%	90.5
Jan		95
Feb		83
Mar		86
Apr		78
Nov		61
Dec		79
Seasonal	40%	40%

Jackson County

Station Number	Ave.	1	2	7	11	12	13
HWY		I5	I5	Ore. 66	Ore. 239	Main St.	Ore. 62
% Pas Veh	86%	79	62.6	92.7	95.8	98	93.2
Jan		86	74	69	82	95	76
Feb		89	81	84	87	102	84
Mar		97	90	80	95	104	85
Apr		99	94	99	101	105	93
Nov		94	92	86	90	95	90
Dec		89	94	71	86	96	86
Seasonal	45%	46%	44%	41%	45%	50%	43%

Jackson County, cont'd

Station Number	Ave.	14	18	19	20
HWY		Ore. 99	I5	I5	Ore. 140
% Pas Veh		96	83.7	84.9	76.7
Jan		88	83	87	70
Feb		96	89	93	80
Mar		95	94	96	77
Apr		101	101	102	84
Nov		97	101	99	93
Dec		95	90	96	79
Seasonal		48%	47%	48%	40%

Jefferson County

Station Number	Ave.	2	6
HWY		US97/US26	US26
% Pas Veh	87%	86.4	87.7
Jan		77	76
Feb		85	82
Mar		94	91
Apr		100	95
Nov		89	87
Dec		80	82
Seasonal	43%	44%	43%

Josephine County

Station Number	Ave.	1	3	6
HWY		I5	US199	cnty rd
% Pas Veh	86%	82	84.9	91.2
Jan		78	64	90
Feb		82	76	96
Mar		92	68	97
Apr		96	88	102
Nov		97	85	97
Dec		90	75	91
Seasonal	43%	45%	38%	48%

Klamath County

Station Number	Ave.	6	17	19	20	21
HWY		US97	Ore. 140	US97	Ore. 39	Ore. 62
% Pas Veh	77%	60.1	85.1	63	84.5	91.6
Jan		60	76	66	79	35
Feb		69	75	79	88	43
Mar		79	87	79	93	44
Apr		88	79	91	100	61
Nov		86	88	97	95	54
Dec		79	75	84	86	39
Seasonal	38%	38%	40%	41%	45%	23%

Lake County

Station Number	Ave.	4	8	10
HWY		US395	US395	Ore. 31
% Pas Veh	80%	79.1	82.7	78
Jan		68	69	63
Feb		77	79	68
Mar		90	84	80
Apr		95	93	87
Nov		74	90	124
Dec		54	74	84
Seasonal	40%	38%	41%	42%

Lane County

Station Number	Ave.	3	4	5	8	10	17	23
HWY		Ore. 99	Ore. 36	Ore. 126	I105	Ore. 126	Ore. 58	Terri. Hwy
% Pas Veh	91%	97.1	91.6	88.4	94	84.1	59.5	93.3
Jan		86	83	84	93	69	74	80
Feb		98	86	87	97	72	77	86
Mar		99	93	94	99	82	82	93
Apr		103	94	94	100	91	84	96
Nov		97	96	86	100	83	80	94
Dec		88	87	84	98	71	65	89
Seasonal	44%	48%	45%	44%	49%	39%	39%	45%

Lincoln County

Station Number	Ave.	6
HWY		US20
% Pas Veh	75%	75.2
Jan		80
Feb		88
Mar		97
Apr		95
Nov		88
Dec		72
Seasonal	43%	43%

Linn County

Station Number	Ave.	10	12	13	16
HWY		Ore. 226	Ore. 99e	US20	I5
% Pas Veh	86%	93.6	83.4	91.3	74.3
Jan		88	85	89	73
Feb		91	89	93	79
Mar		98	97	94	98
Apr		100	98	98	96
Nov		93	91	92	100
Dec		93	88	91	92
Seasonal	46%	47%	46%	46%	45%

Malheur County

Station Number	Ave.	6	12	13	14	16
HWY		US20/US26	US95	US20	I84	I84
% Pas Veh	65%	83.6	56	64.4	71.2	49.1
Jan		80	63	57	92	70
Feb		86	72	65	83	76
Mar		93	98	82	94	92
Apr		103	114	88	96	97
Nov		88	92	85	86	100
Dec		84	75	66	85	86
Seasonal	42%	45%	43%	37%	45%	43%

Marion County

Station Number	Ave.	1	4	10	13	14	16	18	20
HWY		Ore. 99e	Ore. 22	Cnty Rd.	Ore. 22	Ore. 22	W_H Hwy	Ctr St.	Ore. 219
% Pas Veh	91%	94.8	93.2	90.6	81.8	95.2	88.7	98	84.7
Jan		86	85	82	62	92	98	95	76
Feb		90	88	85	69	94	99	97	81
Mar		94	93	91	84	97	98	10	91
Apr		100	97	99	88	101	104	104	98
Nov		91	92	89	78	97	97	99	85
Dec		87	90	83	65	101	98	105	81
Seasonal	44%	46%	45%	44%	37%	49%	50%	43%	43%

Morrow County

Station Number	Ave.	7
HWY		ORE. 74
% Pas Veh	90%	89.8
Jan		86
Feb		87
Mar		96
Apr		97
Nov		99
Dec		93
Seasonal	47%	47%

Multnomah County

Station Number	Ave.	1	2	3	4	5	12	13	16
HWY		I84	US26	US26	I5	I405	Hist. Col	I84	I5
% Pas Veh	91%	75.5	96.1	96.1	91.5	93.3	96.4	94.7	93
Jan		71	94	93	93	92	49	91	93
Feb		76	88	91	93	99	64	87	87
Mar		91	100	97	100	100	81	100	96
Apr		98	102	100	101	103	100	102	104
Nov		92	98	95	98	97	56	99	98
Dec		76	97	99	97	92	46	99	95
Seasonal	47%	42%	48%	48%	49%	49%	41%	48%	48%

Multnomah County, cont'd.

Station Number	Ave.	19	24	26	27
HWY		I5	I205	I5	I405
% Pas Veh		89.7	92.1	94.5	88.3
Jan		94	80	91	99
Feb		93	87	95	92
Mar		100	96	101	102
Apr		101	98	104	108
Nov		97	104	97	95
Dec		94	106	93	93
Seasonal		48%	48%	48%	49%

Polk County

Station Number	Ave.	1
Highway		Ore. 18
% Pas Veh	91%	91.4
Jan		67
Feb		76
Mar		88
Apr		87
Nov		112
Dec		96
Seasonal	44%	44%

Sherman County

Station Number	Ave.	1
HWY		ur97
% Pas Veh	69%	69.3
Jan		69
Feb		77
Mar		94
Apr		100
Nov		87
Dec		75
Seasonal	42%	42%

Tillamook County

Station Number	Ave.	1
HWY		US101
% Pas Veh	90%	89.9
Jan		33
Feb		79
Mar		102
Apr		99
Nov		66
Dec		66
Seasonal	37%	37%

Umatilla County

Station Number	Ave.	2	4	7	12	16	21	25
HWY		US730	I84	US395	Ore. 204	Athena	ORE. 11	I82
% Pas Veh	78%	72.1	69.9	82	82.8	83.7	94	70.7
Jan		68	42	73	87	81	82	72
Feb		89	45	74	84	93	88	79
Mar		90	52	80	69	94	97	96
Apr		92	53	89	72	101	104	99
Nov		94	53	107	90	90	93	95
Dec		80	46	65	82	83	92	83
Seasonal	40%	43%	24%	41%	40%	45%	46%	44%

Union County

Station Number	Ave.	5
HWY		ORE. 82
% Pas Veh	85%	84.5
Jan		72
Feb		75
Mar		88
Apr		90
Nov		93
Dec		78
Seasonal	41%	41%

Wasco County

Station Number	Ave.	1	5
HWY		I84	US197
% Pas Veh	83%	75	91.9
Jan		71	79
Feb		75	83
Mar		92	96
Apr		96	102
Nov		100	91
Dec		82	80
Seasonal	44%	43%	44%

Washington County

Station Number	Ave.	1	4
HWY		US 26	ORE. 6
% Pas Veh	80%	74.4	84.9
Jan		68	68
Feb		76	70
Mar		93	86
Apr		94	88
Nov		81	89
Dec		64	65
Seasonal	39%	40%	39%

Yamhill County

Station Number	Ave.	4	5
HWY		ORE. 99w	ORE. 99w
% Pas Veh	89%	93.6	83.4
Jan		90	91
Feb		91	94
Mar		97	98
Apr		99	102
Nov		101	98
Dec		97	90
Seasonal	48%	48%	48%

Regional Passenger Vehicle and Seasonal Traffic Factor calculations

Region	County	Passenger Vehicles	Seasonal Factor
Region 1	Clackamas	89%	46%
	Columbia	89%	45%
	Hood River	91%	44%
	Multnomah	91%	47%
	Washington	80%	39%
Region 2	Benton	87%	46%
	Clatsop	89%	44%
	Lane	91%	44%
	Lincoln	75%	43%
	Linn	86%	46%
	Marion	91%	44%
	Polk	91%	44%
	Tillamook	69%	42%
	Yamhill	89%	48%
Region 3	Coos	86%	43%
	Curry	93%	44%
	Douglas	91%	41%
	Jackson	86%	45%
	Josephine	86%	43%
Region 4	Crook	90%	41%
	Deschutes	89%	49%
	Gilliam	72%	44%
	Jefferson	87%	43%
	Klamath	77%	38%
	Lake	80%	40%
	Sherman	69%	42%
	Wasco	83%	44%
	Wheeler	*	*
Region 5	Baker	66%	41%
	Grant	79%	38%
	Harney	81%	39%
	Malheur	65%	42%
	Morrow	90%	47%
	Umatilla	78%	42%
	Union	85%	41%
	Wallowa	*	*

* no counter station

Appendix E

Cost estimates for pavement damage:

9 scenarios

Mitigation costs for 1995 studded tire damage on Oregon State Highway System

Surface Inputs	Asphalt	PCC
Rut Threshold (inches)	0.75	0.75
Design Life (years)	12	20
Mitigation cost per lane mile,	$52,800	$52,800
Wear Rate: Inches / 100,000 studded tire passes	0.0226	0.0076

Design life	Wear Rate
Short	Low

Regional Inputs	Season%	Pass. Veh. %	Stud %	Cost Estimates: Asphalt	PCC	ALL SURFACES
Region 1	44%	88%	15.6%	$977,162	$1,558,059	$2,535,221
Region 2	45%	85%	12.4%	$319,388	$0	$319,388
Region 3	43%	84%	5.4%	$0	$0	$0
Region 4	43%	81%	40.1%	$176,602	$0	$176,602
Region 5	41%	78%	30.2%	$0	$0	$0
STATEWIDE				$1,473,153	$1,558,059	$3,031,211

* Mitigation strategy: asphalt overlay
Cost taken from *Repair of Rutting Caused by Studded Tires*, ODOT, July '95.
Includes 50% above material cost for traffic control.

Mitigation costs for 1995 studded tire damage on Oregon State Highway System

Surface Inputs	Asphalt	PCC
Rut Threshold (inches)	0.75	0.75
Design Life (years)	14	25
Mitigation cost per lane mile,	$52,800	$52,800
Wear Rate: Inches / 100,000 studded tire passes	0.0226	0.0076

Design life	Wear Rate
Base	Low

Regional Inputs	Season%	Pass. Veh. %	Stud %	Cost Estimates: Asphalt	PCC	ALL SURFACES
Region 1	44%	88%	15.6%	$1,139,946	$1,733,608	$2,873,554
Region 2	45%	85%	12.4%	$481,785	$522,988	$1,004,774
Region 3	43%	84%	5.4%	$0	$0	$0
Region 4	43%	81%	40.1%	$272,375	$0	$272,375
Region 5	41%	78%	30.2%	$7,080	$0	$7,080
STATEWIDE				$1,901,186	$2,256,597	$4,157,783

* Mitigation strategy: asphalt overlay
Cost taken from *Repair of Rutting Caused by Studded Tires*, ODOT, July '95.
Includes 50% above material cost for traffic control.

Mitigation costs for 1995 studded tire damage on Oregon State Highway System

Surface Inputs	Asphalt	PCC
Rut Threshold (inches)	0.75	0.75
Design Life (years)	16	30
Mitigation cost per lane mile,	$52,800	$52,800
Wear Rate: Inches / 100,000 studded tire passes	0.0226	0.0076

Design life	Wear Rate
Long	Low

Regional Inputs	Season%	Pass. Veh. %	Stud %	Cost Estimates: Asphalt	Cost Estimates: PCC	ALL SURFACES
Region 1	44%	88%	15.6%	$1,347,757	$1,733,608	$3,081,366
Region 2	45%	85%	12.4%	$541,532	$606,226	$1,147,758
Region 3	43%	84%	5.4%	$0	$0	$0
Region 4	43%	81%	40.1%	$722,410	$0	$722,410
Region 5	41%	78%	30.2%	$17,295	$0	$17,295
STATEWIDE				$2,628,995	$2,339,834	$4,968,829

* Mitigation strategy: asphalt overlay
Cost taken from *Repair of Rutting Caused by Studded Tires*, ODOT, July '95.
Includes 50% above material cost for traffic control.

Mitigation costs for 1995 studded tire damage on Oregon State Highway System

Surface Inputs	Asphalt	PCC
Rut Threshold (inches)	0.75	0.75
Design Life (years)	12	20
Mitigation cost per lane mile,	$52,800	$52,800
Wear Rate: Inches / 100,000 studded tire passes	0.0386	0.0093

Design life	Wear Rate
Short	Base

Regional Inputs	Season%	Pass. Veh. %	Stud %	Cost Estimates: Asphalt	Cost Estimates: PCC	ALL SURFACES
Region 1	44%	88%	15.6%	$2,817,844	$2,121,389	$4,939,233
Region 2	45%	85%	12.4%	$1,458,831	$639,973	$2,098,803
Region 3	43%	84%	5.4%	$0	$0	$0
Region 4	43%	81%	40.1%	$1,762,170	$0	$1,762,170
Region 5	41%	78%	30.2%	$95,973	$0	$95,973
STATEWIDE				$6,134,818	$2,761,362	$8,896,180

* Mitigation strategy: asphalt overlay
Cost taken from *Repair of Rutting Caused by Studded Tires*, ODOT, July '95.
Includes 50% above material cost for traffic control.

Mitigation costs for 1995 studded tire damage on Oregon State Highway System

Surface Inputs	Asphalt	PCC
Rut Threshold (inches)	0.75	0.75
Design Life (years)	14	25
Mitigation cost per lane mile,	$52,800	$52,800
Wear Rate: Inches / 100,000 studded tire passes	0.0386	0.0093

Design life	Wear Rate
Base	Base

Regional Inputs	Season%	Pass. Veh. %	Stud %	Cost Estimates: Asphalt	Cost Estimates: PCC	ALL SURFACES
Region 1	44%	88%	15.6%	$3,019,116	$2,121,389	$5,140,505
Region 2	45%	85%	12.4%	$1,810,814	$741,829	$2,552,643
Region 3	43%	84%	5.4%	$0	$0	$0
Region 4	43%	81%	40.1%	$2,242,845	$0	$2,242,845
Region 5	41%	78%	30.2%	$129,238	$0	$129,238
STATEWIDE				$7,202,013	$2,863,218	$10,065,231

* Mitigation strategy: asphalt overlay
Cost taken from *Repair of Rutting Caused by Studded Tires,* ODOT, July '95.
Includes 50% above material cost for traffic control.

Mitigation costs for 1995 studded tire damage on Oregon State Highway System

Surface Inputs	Asphalt	PCC
Rut Threshold (inches)	0.75	0.75
Design Life (years)	16	30
Mitigation cost per lane mile,	$52,800	$52,800
Wear Rate: Inches / 100,000 studded tire passes	0.0386	0.0093

Design life	Wear Rate
Long	Base

Regional Inputs	Season%	Pass. Veh. %	Stud %	Cost Estimates: Asphalt	Cost Estimates: PCC	ALL SURFACES
Region 1	44%	88%	15.6%	$3,322,708	$2,121,389	$5,444,097
Region 2	45%	85%	12.4%	$1,973,943	$741,829	$2,715,772
Region 3	43%	84%	5.4%	$0	$0	$0
Region 4	43%	81%	40.1%	$2,715,304	$0	$2,715,304
Region 5	41%	78%	30.2%	$150,340	$0	$150,340
STATEWIDE				$8,162,295	$2,863,218	$11,025,514

* Mitigation strategy: asphalt overlay
Cost taken from *Repair of Rutting Caused by Studded Tires,* ODOT, July '95.
Includes 50% above material cost for traffic control.

Mitigation costs for 1995 studded tire damage on Oregon State Highway System

Surface Inputs	Asphalt	PCC
Rut Threshold (inches)	0.75	0.75
Design Life (years)	12	20
Mitigation cost per lane mile,	$52,800	$52,800
Wear Rate: Inches / 100,000 studded tire passes	0.0545	0.011

Design life	Wear Rate
Short	High

Regional Inputs	Season%	Pass. Veh. %	Stud %	Cost Estimates: Asphalt	PCC	ALL SURFACES
Region 1	44%	88%	15.6%	$4,832,658	$2,509,170	$7,341,828
Region 2	45%	85%	12.4%	$2,918,365	$877,433	$3,795,797
Region 3	43%	84%	5.4%	$0	$0	$0
Region 4	43%	81%	40.1%	$4,306,004	$0	$4,306,004
Region 5	41%	78%	30.2%	$277,372	$0	$277,372
STATEWIDE				$12,334,399	$3,386,602	$15,721,001

* Mitigation strategy: asphalt overlay
Cost taken from *Repair of Rutting Caused by Studded Tires*, ODOT, July '95.
Includes 50% above material cost for traffic control.

Mitigation costs for 1995 studded tire damage on Oregon State Highway System

Surface Inputs	Asphalt	PCC
Rut Threshold (inches)	0.75	0.75
Design Life (years)	14	25
Mitigation cost per lane mile,	$52,800	$52,800
Wear Rate: Inches / 100,000 studded tire passes	0.0545	0.011

Design life	Wear Rate
Base	High

Regional Inputs	Season%	Pass. Veh. %	Stud %	Cost Estimates: Asphalt	PCC	ALL SURFACES
Region 1	44%	88%	15.6%	$5,552,821	$2,509,170	$8,061,991
Region 2	45%	85%	12.4%	$3,292,930	$877,433	$4,170,363
Region 3	43%	84%	5.4%	$0	$0	$0
Region 4	43%	81%	40.1%	$4,625,490	$0	$4,625,490
Region 5	41%	78%	30.2%	$420,717	$0	$420,717
STATEWIDE				$13,891,958	$3,386,602	$17,278,560

* Mitigation strategy: asphalt overlay
Cost taken from *Repair of Rutting Caused by Studded Tires*, ODOT, July '95.
Includes 50% above material cost for traffic control.

Mitigation costs for 1995 studded tire damage on Oregon State Highway System

Surface Inputs	Asphalt	PCC
Rut Threshold (inches)	0.75	0.75
Design Life (years)	16	30
Mitigation cost per lane mile,	$52,800	$52,800
Wear Rate: Inches / 100,000 studded tire passes	0.0545	0.011

Design life	Wear Rate
Long	High

Regional Inputs	Season%	Pass. Veh. %	Stud %	Cost Estimates: Asphalt	PCC		ALL SURFACES
Region 1	44%	88%	15.6%	$5,843,736	$2,509,170		$8,352,906
Region 2	45%	85%	12.4%	$3,612,451	$877,433		$4,489,883
Region 3	43%	84%	5.4%	$10,488	$0		$10,488
Region 4	43%	81%	40.1%	$4,808,701	$0		$4,808,701
Region 5	41%	78%	30.2%	$585,792	$0		$585,792
STATEWIDE				$14,861,168	$3,386,602		$18,247,770

* Mitigation strategy: asphalt overlay
Cost taken from *Repair of Rutting Caused by Studded Tires,* ODOT, July '95.
Includes 50% above material cost for traffic control.