REPAIR OF RUTTING CAUSED BY STUDDED TIRES

Literature Review
SPR Project #5273

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16. Abstract

Rutting caused by studded tire wear has become a major issue in Oregon because of the impact on the infrastructure and the increase in driving hazards. It is estimated that the cost to mitigate the damage from studded tire use in 1993 alone is $42 million state-wide. The ruts caused by the studs lead to reduced pavement life which increases the life cycle costs. The safety hazards include an increase in splash and spray and hydroplaning during rainy weather.

The objectives of this report are:

1) To identify alternatives available for studded tire rut repair, and
2) To determine the viability of these alternatives with regard to material costs, availability, constructability and compatibility with Oregon pavement types.

Several alternatives were identified to repair the ruts caused by studded tires. The alternatives include: microsurfacing, stone mastic asphalt (SMA), NOVACHIP®, thin overlays, conventional overlays, roller compacted concrete, ultrathin concrete overlays, fine tooth milling, diamond grinding, hydroblasting with a bonded inlay, and realigning travel lanes.

Microsurfacing and fine tooth milling are feasible alternatives for pavements that will be overlaid or reconstructed within a couple of years. SMA is reported to offer the best resistance to studded tire wear. Field testing of an SMA section is warranted for evaluation.

The ODOT Paving Committee should consider:

Constructing an SMA wearing course to compare the performance with conventional mixes. At a minimum, one section should include PCC using a dense-graded mix as a leveling course and another section should include AC using rotomilling for leveling. Construction of an SMA wearing course will require laboratory testing to establish an appropriate mix design.

The recommendations for further research include:

1) Investigating the preventive techniques Scandinavian countries have initiated. The investigation would entail identifying the aggregate properties that reduce wear caused by studded tires, based on Finland's aggregate specifications; evaluating sources that would meet the properties, and finally, modifying the ODOT aggregate specifications.
2) Identifying pilot projects and investigating surface preparation requirements and/or tack coats for thin overlays.
3) Conducting a more detailed investigation into the advantages and disadvantages of shifting travel lanes in certain areas as a preventive measure.

A work plan will be developed that will cover the previous recommendations.

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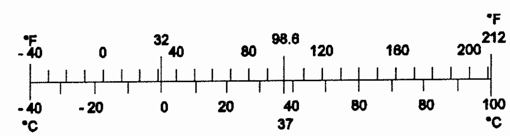
SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	millimeters squared	mm^2
ft^2	square feet	0.093	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometers squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3
NOTE: Volumes greater than 1000 L shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9	Celsius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometers squared	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celsius temperature	1.8 + 32	Fahrenheit	°F



* SI is the symbol for the International System of Measurement

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DISCLAIMER

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1.0 INTRODUCTION

Studded tires were first authorized for use in Oregon in 1967 *(1)*. The standard studded tire season in Oregon is from November 1 through April 30, which may be shortened or lengthened when necessary for the preservation of the highway surface or safety of the traveling public. Studded tire use has come to be associated with improved traction and safety in winter driving conditions. Whether the advantages afforded by studded tires is balanced with the associated annual pavement wear costs is still under debate in several arenas.

The Oregon Department of Transportation (ODOT) first recommended prohibiting studded tire use in 1974*(1)*. Rutting caused by studded tire wear has again become a major issue because of the impact on the infrastructure and the increase in safety hazards. It is estimated that the cost to mitigate the damage from studded tire use in 1993 alone is $42 million statewide *(2)*. The ruts caused by the studs lead to reduced pavement life increasing pavement life cycle costs. For example, the design life expectancy estimates for Oregon asphalt and PCC pavements is 14 years and 25 years, respectively. The life expectancy is based on a limiting wheel path rut depth of 19 mm, at which time the pavement would require rehabilitation. According to some calculations, the time to reach a 19 mm rut for an asphalt pavement subjected to studded tires at 35,000 ADT, is about 7 years. For PCC at 120,000 ADT, the estimated time to reach a 19 mm rut is less than 10 years *(3)*.

The ruts may also cause a safety hazard due to the increase of splash and spray, and hydroplaning during rainy weather. In Alaska, the state is currently being sued for several accidents associated with studded tire ruts *(4)*. The rut depths measured in these lawsuits are similar to those currently reported in Oregon, therefore, Oregon may be faced with similar suits.

The objectives of this report are:

1) To identify alternatives available for studded tire rut repair, and

2) To determine the viability of these alternatives with regard to material costs including life-cycle costs, availability, constructability and compatibility with Oregon pavement types.

2.0 ALTERNATIVES

Several different alternatives were identified for studded tire rut repair. They include: microsurfacing, stone mastic asphalt, thin overlays, NOVACHIP®, conventional overlays, roller compacted concrete, fine tooth milling, diamond grinding, hydroblasting and a bonded inlay, and shifting travel lanes. Limited information was presented in the literature concerning the applied material's resistance to further rutting from studded tires.

2.1 MICROSURFACING *(5,6,7,8,9)*

According to the Washington D.C. based International Slurry Seal Surfacing Association (ISSA), microsurfacing is a polymer-modified cold-mix paving system where the material is placed in micro, or thin lifts. The concept of microsurfacing was first tried in France and refined in Germany in the late 1960s and early 1970s.

This treatment can be used to fill ruts and/or as a thin surface treatment to improve skid resistance. This type of treatment must be placed on a structurally sound pavement. Surface courses are usually applied in thicknesses of 10 to 15 mm. If wheel ruts are between 6 and 13 mm deep and a surface course is desired, two layers of microsurfacing should be used. The first layer is used as a leveling course and the second is used as the surface course. Microsurfacing has been used over both dense-graded asphalt concrete and portland cement concrete pavements. If it is placed over portland cement concrete, a tack coat is required. Under the right weather conditions (at least 24°C, no more than 50% humidity), microsurfacing will usually set within 10 minutes and accept rolling traffic within one hour.

The mixture includes aggregate, asphalt emulsion, water, additives, and mineral fillers. Aggregates constitute about 82 to 90 percent by weight of the mixture. The aggregate should be 100 percent crushed, clean, strong and durable, free of absorbed chemicals, clays and other materials. The crushed aggregate should be angular and not have too many flat or elongated particles. Typical aggregate gradations from two types of microsurfacing mixes are shown in Table 2.1.

Table 2.1 Typical Aggregate Gradation for Microsurfacing

SIEVE SIZE (mm)	% PASSING	
	ISSA II	ISSA III
9.5	100	100
4.75	90-100	70-90
2.36	65-90	45-70
1.18	45-70	28-50
0.60	30-50	19-34
0.30	18-30	12-25
.15	10-21	7-18
0.075	5-15	5-15

The emulsified asphalt is a quick-set polymer modified cationic type CSS-1H emulsion. The polymer material is milled into the emulsion or blended into the asphalt cement prior to the emulsification process. The polymers used in microsurfacing are the same as used for other asphalt mixes. Natural rubber latex is used most often. The residual asphalt content generally varies from 5.5 to 9.5 percent of the dry weight of the aggregate.

Water is the main factor for determining mixture consistency. Depending on the weather conditions and aggregate absorption rate, mixtures can be placed over a limited range of total moisture content, usually 4 to 12 percent of the weight of the dry aggregate.

The amount of additives used to retard the break time ranges from 0 to 2 percent of the weight. Generally, the emulsifier used in emulsion manufacturing is used as an additive because of its compatibility with other mixture components.

Mineral filler serves two major purposes: 1) to minimize aggregate segregation and 2) to speed up or slow down the rate at which the system breaks and sets. Portland cement and hydrated lime have been used as mineral filler. Normally up to 3 percent of portland cement by dry weight of aggregate is specified.

A self-propelled, front feed, continuous loading and mixing machine is used to place microsurfacing. For surface applications, microsurfacing is placed by a full width spreader box equipped with hydraulically powered augers to mix, and spread the mixture. For rut repairs, rut boxes usually come in two sizes, 1.5 and 1.8 m and have two V-shaped chambers with the point of the V toward the rear of the box. Ruts up to 38 mm can be filled with one pass. They are adjusted to leave a slight crown in the surface to compensate for the initial compaction by the traffic. Each wheel path must be individually filled.

Two local agencies in Oregon are constructing microsurfacing projects this season. Washington County/City of Beaverton is planning to construct 250,000 square meters with a bid price of $0.75 per square meter. The City of Corvallis has approximately 26,000 square meters being placed at $1.77 per square meter *(10,11)*. The Washington County microsurfacing is being placed to fill ruts and as a surface treatment, while the City of Corvallis project is being constructed as a surface treatment intended to seal the pavement. Both agencies commented that selection of the material was based on the quick setting properties of microsurfacing.

2.2 ASPHALT OVERLAYS

There are several different types of hot mix asphalt overlays utilized to repair pavements. Some of these offer structural value as well as provide a level wearing course. Stone mastic asphalt (SMA), overlay designs from Austria and Michigan, and NOVACHIP® were considered thin asphalt overlays (<25mm). Conventional overlays utilized include Oregon Class "B" dense-graded mixes and Class "E" and "F" open-graded mixes.

2.2.1 Stone Mastic Asphalt *(12,13,14,15)*

SMA is a hot-mix with a relatively large proportion of stones and an extra large amount of mastic-stabilized asphalt cement. The principle idea is to obtain greater stone on stone contact, when compared to a dense-graded mixture. SMA can be placed in thicknesses of 13 - 20 mm. The mix provides high skid resistance due to its coarse and open texture, which also promotes good drainage of water and lessens spray problems. SMA was developed in West Germany about 25 years ago to decrease the amount of rutting in pavement surface courses. This pavement type is also used in Sweden to decrease surface wear from studded tires. Several states, including Georgia, Michigan, Missouri and Wisconsin, have used SMA on experimental sections. Over 20 such sections have been constructed.

The aggregate gradation for SMA mixtures is more open compared to dense-graded mixtures. The typical aggregate gradation is shown in Table 2.2. SMA aggregates must be as durable as those used in open-graded mixtures. The Europeans typically specify "high quality" aggregates for their SMA.

Table 2.2 Typical Aggregate Gradation for SMA

SIEVE SIZE (mm)	% PASSING
4.75	20-40
2.36	15-35
0.075	10

More than 85 percent of the SMA mixtures produced in Sweden and Germany use fibers to prevent drain down and bleeding of the asphalt. The common fibers are cellulose and a natural mineral filler termed rock wool. Fibers are generally added in amounts from 0.3 to 1.5 percent by weight of the mixture. The amount of fiber needed depends on the properties of the fiber, how susceptible the mixture is to drain down, and the discharge temperature of the mixture. The binder content should be a minimum of 6.3 percent when absorptive cellulose fibers are used and 6 percent for other stabilizers.

Although, conventional paving equipment is used to place this mixture, compaction by a non-vibrating steel-wheeled roller should take place within 150 m of the laydown machine to achieve the required density. The cost of stone mastic asphalt is approximately $2.48 per square meter for a 20 mm lift *(17)*.

By modifying the gradation to essentially a single size coarse aggregate, a free-draining or porous asphalt mix can be developed for overlaying open-graded mixes commonly found in Oregon *(16)*.

2.2.2 Austria's Thin Overlay *(21)*

Thin bituminous layers (20 mm thick) have been used successfully for road maintenance in Austria for several years. One of the principle Austrian applications to date, has been filling ruts in asphalt and concrete surfaces caused by studded tires. Structural capacity is not increased with this type of treatment.

Aggregates used should be as close to cubic as possible, edge holding power must be high, and the Los Angeles coefficient from the Los Angeles Abrasion Test (AASHTO T96) should not exceed 18 to 25, depending on the traffic load. A typical gradation is shown in Table 2.3.

Table 2.3 Typical Gradation for Austria's Thin Overlay

	Percent by Weight
Filler (<0.09 mm)	7-9
Sand (0.09 to 2 mm)	18-28
Chips (>2 mm)	63-75

Only polymer-modified binders were used for the Austrian overlays. To be suitable, the binders must have a broad range between softening and breaking point temperatures, high elasticity and good low temperature characteristics. Typically, the binder content ranges from 6 to 6.5 percent by weight of the aggregate.

Conventional equipment is used to place this overlay. The estimated cost per square meter for Austria's overlay is $4.50. The cost of materials in Austria tend to be more expensive than in Oregon, therefore, the actual cost should be lower.

2.2.3 Michigan's Thin Overlay *(22)*

Contractors in Michigan are using a thin hot-mix asphalt to compete with microsurfacing treatments. The overlay is approximately 20 mm thick and does offer some structural value.

The typical mix for these overlays requires 6.5 to 7.0 percent asphalt concrete. The aggregate gradation is shown in Table 2.4.

Table 2.4 Aggregate Gradation for Ultrathin Overlay

SIEVE SIZE (mm)	% PASSING
12.5	100
4.75	65-90
2.36	55-70
0.60	25-45
0.075	7

Conventional equipment is used to place this type of overlay. The overlay prices were typically in the range of $1.79 to 2.09 per square meter.

2.2.4 NOVACHIP® *(14,18,19)*

A NOVACHIP® friction course consists of a layer of gap-graded hot-mix material placed over a heavy tack coat in thicknesses of 10 to 20 mm. The NOVACHIP® process was developed in France in 1986 to restore skid resistance and surface impermeability. NOVACHIP® can also be used to restore pavement-surface smoothness. This treatment does not increase the structural capacity of the pavement. This treatment was used as a surface rehabilitation project by the Texas Department of Transportation.

The NOVACHIP® process requires that coarse aggregate in the mix be a high-quality, 100% crushed material. The Los Angeles Abrasion Test (AASHTO T96) loss must be less than 35%, and the magnesium-sulfate soundness test loss must not exceed 25%. The fine aggregate must meet the same criteria as the coarse aggregate as well as having a sand-equivalent value (AASHTO T176) of 60 or more *(20)*.

The binder content ranges from 5.3 to 6.0 percent depending on the traffic, climate and peculiarities of the existing pavement. The heavy tack coat is generally a polymer-modified, emulsified asphalt placed at an application rate between 0.7 and 1.0 L/m^2.

NOVACHIP® is placed with a specially designed paving machine that combines the functions of an asphalt distributor and a laydown machine. The paving machine includes: 1) a hopper for the collection of the mix and a coupling for attaching it to the hook of the truck supplying the mixture, 2) a screw or rake conveyor that lifts and feeds the mix into a hopper, 3) a heated compartment to store the mixture, 4) a heated tank for the tack binder, 5) a conveyor to transfer the mixture to the forward part of the smoothing assembly, 6) a spray bar to distribute the tack coat and 7) a heated assembly for screeding the hot mix layer. This machine has to be transported from France at this time.

2.2.5 Conventional Overlays *(26)*

Traditionally, Oregon has used "F" mix (open-graded mixes, maximum size aggregate 25 mm) and "E" mix (open-graded mixes, maximum size aggregate 19 mm) overlays to repair rutted pavements. The depth of the overlay ranges from 25 to 50 mm. Open-graded mixes are normally placed over sound underlying layers.

The aggregate and the binder play the most important role in "F" and "E" mixes. The aggregate must be 100% crushed material with at least 75% by weight of the coarse aggregate having at least two fractured faces, and 90% with one or more fractured faces. Typical aggregate gradations are shown in Table 2.5.

The asphalt binder content for "F" mixes is between 4 and 8 percent and for "E" mixes is between 4 and 9 percent. Asphalt binder grade PBA - 5 is generally used in mild climates and PBA - 6 is used in cold climates. PBA - 6 is specified for all interstate highways and other heavy duty applications, regardless of geographic location.

Table 2.5 Typical Gradation for "F" & "E" Mixes

Sieve Size (mm)	% Passing	
	"F"	"E"
25	99-100	100
19	85-96	99-100
13	60-71	95-100
6	17-31	52-72
2	7-19	5-15
0.075	1-6	1-5

Conventional equipment is used to lay both "F" & "E" mix overlays. The average cost per square meter for an "F" mix is $3.00. The cost for an "E" mix is approximately half of the cost of an "F" mix.

2.3 ROLLER COMPACTED CONCRETE/THIN CONCRETE OVERLAYS *(23,24)*

Roller compacted concrete (RCC) has been used on badly rutted intersections in Calgary. According to the City of Calgary, RCC paving is rapid and economical, performing well with a thin asphalt surface course designed for wearing and rideability. It gained strength quickly, and provided a rigid pavement structure that will not rut. This technique allows roads to be open to traffic within 24 hours. The pavement structure consists of 150 mm of RCC with 15 mm of polymer-modified asphalt concrete. Thin portland cement concrete overlays have been used at several airports in the Mid-West. The thin lift design is 89 mm thick with an average flexural strength of 5.8 MPa.

The RCC consists of 20 mm crushed gravel, Type 10 normal Portland cement, and water. The thin portland cement concrete overlay is a fiber reinforced, fine aggregate mix.

The RCC was placed using an ABG Titan 411 paver with a dual tamping bar screed capable of achieving densities up to 92% of Standard Proctor out of the back of the paver. The remaining compaction was provided by a Dynapac CC50A, 16-ton roller with dual vibrating drums. The thin portland cement concrete overlay was placed with standard concrete pavement equipment.

The thin overlay costs approximately $10.00 per square meter. The cost of the RCC is unknown.

2.4 FINE TOOTH MILLING *(32)*

Fine tooth milling has been used in Wisconsin as a short-term solution for rutting on asphalt concrete surfaces. The work usually consists of milling the driving lane and a 0.8 m section of the shoulder. A minimum cross slope of 0.005m/m is normally maintained.

The machine used for milling should be self-propelled, and capable of accurately and automatically establishing profile grades by referencing. The cutting drum should be at least 70 mm in diameter with a minimum of two wraps of flighting teeth, with carbide cutting tips.

The cost for fine tooth milling is approximately $0.47 per square meter. This price does not include traffic control, disposal of the millings or mobilization costs.

2.5 DIAMOND GRINDING *(25)*

Diamond grinding the concrete pavement to a depth that eliminates ruts has been used for rut repair in Scandinavia. Diamond grinding reduces pavement thickness, so it can only be used if the structural section is adequate.

The machines used are a PRM 3804 and a Cushion Cut PC-500. They have a grinding unit consisting of a rotating shaft, holding about 180 diamond coated circular saw blades, which leave the pavement surface with a fine pattern of longitudinal grooves. This equipment is available in the United States.

The cost for diamond grinding is approximately $6.00 per square meter. This price does not include traffic control or mobilization costs.

2.6 HYDROBLASTING WITH A BONDED INLAY

Another technique that has been suggested is hydroblasting the existing pavement to below rut depth and then placing a microsilica concrete inlay. The cost for this type of treatment is over $32.00 per square meter for a large quantity.

2.7 SHIFTING TRAVEL LANES *(30)*

Another option to resurfacing the roadway would be to shift the travel lanes over. For example, on a six-lane freeway, the fog line and inside stripes could be moved 0.7 m to the left, and the yellow fog line could be moved 0.35 m to the left. The final configuration would consist of a narrower left lane and shoulder. The option also includes prohibiting trucks from using the left lane because of its decreased width. Other options for "re-aligning" the lanes should be considered.

The cost for this option would include removing existing striping and replacing it with new striping shifted to the left. The cost per kilometer would be approximately $2,100.00. The cost for raised pavement markers would be more.

3.0 VIABILITY ON OREGON HIGHWAYS

The viability of the alternatives is determined by the material costs and availability, constructability and compatibility with existing Oregon pavements.

3.1 MICROSURFACING

Microsurfacing is a viable rut repair alternative for dense-graded or PCC pavements. Use on open-graded pavements may be considered, however, the drainage properties would be lost as the void structure would be filled. The quick setting advantage of microsurfacing makes it a candidate for high volume roads where traffic delays would be significant. Major routes which require night paving may be excluded, however, since night paving with microsurfacing is not recommended. The thin application could be applied with minimal additional work, i.e., little shoulder work would be required; the impact to structure clearance would be reduced; and manholes, inlets, and curbs would not need to be adjusted.

Careful selection of microsurfacing projects is necessary as the material does not provide structural support. Most dense-graded pavements in need of treatment require additional pavement thickness to support the traffic loads. Also, the life of microsurfacing subjected to heavy traffic and studded tire wear is unknown as it was not addressed in the literature. Microsurfacing may be most applicable when a quick, short term treatment is required.

3.2 ASPHALT OVERLAYS

Stone mastic asphalt would be appropriate over all types of pavements. Since SMA can be designed as a porous mixture the loss of drainage on open-graded mixes would be minimal. The mix design, however, would need to be developed and tested. SMA can also be placed as a thin mixture to minimize the extra work normally involved with a thicker overlay.

Other thin overlays may be a viable option for Oregon if an appropriate mix design can be developed to maintain the splash and spray resistance of open-graded mixes. Other agencies have successfully placed thin overlays of 20 mm thick.

"F" and "E" mix overlays continue to be a viable alternative for Oregon highways. A disadvantage of an "F" mix overlay is that the thickness is twice that of some of the other options. Because of the thickness, additional work may have to be included with overlay construction. Although an "E" mix is thinner, the overlay is more sensitive to construction practices than an "F" mix because of the thickness of the application. Since an "E" mix is typically less than 25 mm thick, surface preparation techniques and placement temperatures need to be closely monitored.

NOVACHIP® may be a viable alternative in the future. At this time, the cost is prohibitive because of the special equipment required to place this type of overlay.

3.3 ROLLER COMPACTED CONCRETE/THIN CONCRETE OVERLAYS/BONDED INLAYS

Roller compacted concrete, thin concrete overlays and hydroblasting with a bonded inlay should only be considered in very specialized applications. The materials are cost prohibitive and very labor intensive. The delay to motorists for a thin concrete overlay and for hydroblasting and a bonded inlay would be significant.

3.4 DIAMOND GRINDING/FINE TOOTH MILLING

Diamond grinding may be an option on PCC pavements if the structural section is adequate. Grinding is a relatively short term solution, though, more expensive, and takes longer than other options available.

Fine tooth milling may be a feasible, low-cost construction method for short term reduction of ruts on asphaltic pavements. Since the milling reduces the pavement section, the reduced structural capacity would need to be evaluated to determine the expected pavement life based on traffic loads.

3.5 SHIFTING TRAVEL LANES

Shifting the travel lanes of the existing roadway is a suggestion that should be investigated more thoroughly. One disadvantage of this option is decreased safety because of decreased shoulder width, clear zones and possibly vertical clearance. Another possible disadvantage on concrete is that the existing stripe runs along the top of the joint. If the stripe was shifted, the motorist would be driving on top of the joint, resulting in a rough ride and possible pavement degradation.

This option would be most appropriate as a prevention measure on new pavements where the section is designed for systematically moving travel lanes before ruts develop. The resulting structural section would need to be wider to accommodate the lane shifts. The shoulders would also need to be wider to allow full shoulder width after the lane shift.

4.0 COST ANALYSIS

A cost analysis was performed to determine the equivalent uniform annual cost (EUAC) of applying each of the treatments to different pavement types. Several leveling options were considered including diamond grinding, microsurfacing material, and hot mix asphalt concrete for Portland cement concrete (PCC); rotomilling, microsurfacing material, and hot mix asphalt concrete for asphalt concrete (AC) pavements.

The life-cycle cost analyses of the viable alternatives have several assumptions in common. They are:

1) The treatment will be placed on a structurally sound pavement.
2) The evaluation section is a one lane kilometer, 3.6 m wide, high-volume road.
3) The analysis period will be 10 years.
4) The service life of all treatments is based on data available in the literature.
5) Any residual value is a direct proportion of the remaining life.
6) The discount rate will be 4%.

User costs were not included in the analyses. The costs, however, should be considered when comparing the materials, since the traffic delays or user costs vary significantly by alternative.

4.1 SURFACE PREPARATION AND MATERIAL COSTS

4.1.1 Preparation Costs

Preparation or leveling costs were included in determining the EUAC for each treatment type. The costs for the four preparation techniques are included in Table 4.1. The total application cost includes preparation costs plus material costs. Fine tooth milling was not considered in the economic analysis as a preparation type since the availability of the equipment and the costs are uncertain.

Table 4.1 Preparation Costs

Preparation Type	Unit Cost (per m^2)	Cost/lane km
Diamond Grinding	$6.00	$21,530
Rotomilling	$0.90	$3,230
Microsurfacing	$1.00	$3,600
"C"/"B" Mix	$1.91	$6,890

4.1.2 Microsurfacing Costs

Using a per square meter cost of $1 for microsurfacing, the total cost (leveling and surface course materials) to resurface one lane kilometer of PCC ranges from $7,200 to $25,130. The cost to resurface one lane kilometer of AC ranges from $6,830 to $10,490. The service life of microsurfacing is approximately six years. Therefore, the process will be repeated once in the 10-year analysis period and the residual value of the treatment will be $2,400.

4.1.3 Stone Mastic Asphalt Costs

With a cost of $1.70 per square meter, the total cost using stone mastic asphalt for resurfacing PCC ranges from $12,530 to $30,460. For AC, the costs range from $12,160 to $15,820. Since the service life is approximately 15 years, the residual value at 10 years is $2,980.

4.1.4 Thin Overlay Costs

The cost used for the thin overlay alternative is based on information identified in the literature from work done in Michigan and the estimated costs for an "E" mix. The thin overlays (excluding SMA) were grouped together for simplicity. The cost for the thin overlay used in the analysis is $1.75 per square meter. The total cost for using a thin overlay for resurfacing one kilometer of PCC ranges from $9,900 to $27,830. The cost for resurfacing one kilometer of AC ranges from $9,530 to $13,190. The service life is estimated to be eight years, based on Michigan's experience. The residual value at 10 years, after repeating the surfacing once is $4,730.

4.1.5 Conventional Overlays Costs

The unit cost for an "F" mix overlay is $3 per square meter. Typically, "F" mix overlays have a 12-year service life. The total cost for PCC ranges from $14,400 to $32,330, for AC the cost ranges from $14,030 to $17,690 and the residual value at year 10 is $1,800.

4.2 ANALYSES OF ALTERNATIVES

4.2.1 Alternatives for Portland Cement Concrete Pavements

Twelve alternative PCC combinations were evaluated to determine the cost effectiveness. The results of the cost analysis are shown in Table 4.2. Based on the analysis, the most cost effective alternative is to use microsurfacing as a leveling course followed by an SMA wearing course.

Table 4.2 Summary of EUACs of the Viable Alternatives over PCC

PREPARATION	SURFACE TREATMENT	EUAC
DIAMOND GRIND	MICROSURFACING[1]	$3,600
DIAMOND GRIND	THIN OVERLAY[2]	$3,900
DIAMOND GRIND	STONE MASTIC ASPHALT	$3,510
DIAMOND GRIND	"F" MIX	$3,840
MICROSURFACING	MICROSURFACING[1]	$1,400
MICROSURFACING	THIN OVERLAY[2]	$1,690
MICROSURFACING	STONE MASTIC ASPHALT	$1,300
MICROSURFACING	"F" MIX	$1,630
"C"/"B" MIX	MICROSURFACING[1]	$1,800
"C"/"B" MIX	THIN OVERLAY[2]	$2,090
"C"/"B" MIX	STONE MASTIC ASPHALT	$1,700
"C"/"B" MIX	"F" MIX	$2,030

[1]This option would be overlaid at year 6 with a microsurfacing leveling and surface course.
[2]This option would be overlaid at year 8 with another thin overlay after rotomilling to level the pavement.

Since microsurfacing and SMA would both be new to the Agency, it may be preferable to gain experience with one type of material at a time like microsurfacing. The cost of using microsurfacing for the leveling and wearing course is only $100/km more than using SMA as the wearing course.

Although microsurfacing has an advantage of a quick construction time, it is not recommended for night construction which would preclude its use in high volume traffic areas requiring night paving. At a cost of $400/km more, an SMA wearing course over a dense-graded leveling course may be most appropriate for PCC pavements in areas requiring night paving. The SMA with a dense-graded leveling course would have the advantage of using a known material as a leveling course with a material that provides some structural support and resistance to studded tire wear.

4.2.2 Alternatives for Asphalt Concrete Pavements

Twelve alternative AC pavement combinations were evaluated for cost effectiveness. The results of the cost analysis are shown in Table 4.3. Dense-graded and open-graded mixes were considered as one pavement type. The final consideration, however, should include the influence of the material type on the open-graded mix. That is, some of the alternatives may reduce the porosity of the pavement reducing the splash and spray resistance of the mix.

Based on the analysis, the most cost effective alternative is to use rotomilling as a leveling course followed by an SMA wearing course. The cost of using rotomilling with microsurfacing should also be considered since it is only $90/km more than an SMA wearing course. The advantage of the SMA over microsurfacing is that it would provide some structural support as well as some resistance to additional studded tire wear and have a longer service life. The advantage of microsurfacing is the quick construction time.

Table 4.3 Summary of EUACs of the Viable Alternatives over AC

PREPARATION	SURFACE TREATMENT	EUAC
ROTOMILLING	MICROSURFACING[1]	$1,340
ROTOMILLING	THIN OVERLAY[2]	$1,640
ROTOMILLING	STONE MASTIC ASPHALT	$1,250
ROTOMILLING	"F" MIX	$1,580
MICROSURFACING	MICROSURFACING[1]	$1,400
MICROSURFACING	THIN OVERLAY[2]	$1,690
MICROSURFACING	STONE MASTIC ASPHALT	$1,300
MICROSURFACING	"F" MIX	$1630
"C"/"B" MIX	MICROSURFACING[1]	$1,800
"C"/"B" MIX	THIN OVERLAY[2]	$2,090
"C"/"B" MIX	STONE MASTIC ASPHALT	$1,700
"C"/"B" MIX	"F" MIX	$2,030

[1]This option would be overlaid at year 6 with a microsurfacing leveling and surface course.
[2]This option would be overlaid at year 8 with another thin surface after rotomilling to level the pavement.

5.0 PREVENTION TECHNIQUES

Besides consideration of alternatives to repair the existing studded tire ruts, prevention techniques should also be evaluated. Light weight studs and the careful selection of rut resistant materials may lead to longer pavement serviceability and protection of the pavement investment.

In Sweden, studded tires are used extensively in the winter, causing considerable surface wear on roads with high traffic volumes. Swedish Road and Traffic Research Institute (VTI) has been working on the development of wear-resistant asphalt pavements and other means to control pavement wear. They have determined that light weight studs cause only half as much wear compared with a heavier steel stud. Therefore, heavy weight studs have been banned and only light weight studs are permitted. The Oregon legislature recently passed Senate Bill 708, which requires studded tires sold in Oregon after November 12, 1996 to use light weight studs only *(29)*.

Of all the parameters that have been studied, the durability of the coarse aggregate has the most influence on pavement wear resistance. More than half of the pavement mixture's wear resistance is due to the quality of the aggregate and a further 20 percent is attributable to the amount of coarse aggregate. The difference in wear between similar mixes with different aggregates may vary by as much as a factor of three. The aggregate should not be selected on the basis of the rock type, because rocks of the same type generally vary greatly in terms of their durability. According to the Finnish mix design guidelines, the aggregate is always selected on the basis of standard test results (the point loading test, TIE 241) and the abrasion test (TIE 236). A complete set of the Finnish aggregate specifications are in the appendix *(27,28,31)*.

Tests have shown that the proportion of coarse material in the pavement has a considerable influence on stud induced wear. In principle, wearing resistance to studded tires increases with aggregate content. This means that stone mastic asphalt has substantially better wear resistance than dense-graded bituminous mixture. Porous asphalt mixes may also have good wear resistance, but may have inferior wearing qualities as compared to stone mastic asphalt because of problems with ravelling. On tests run on both stone mastic asphalt and dense-graded mixes with the same aggregate, the wear of stone mastic is 20 -50 % lower than that of the dense-graded mix *(27)*.

The ODOT Materials Unit is evaluating several pavement types for resistance to studded tire wear. Cores have been obtained that will be sent to the Finnish Road Engineering and Geotechnology Institute for testing. The cores will be tested in the "SKR" device which simulates studded tire wear by running three miniature studded tires against the sides of the core. The wear rate can then be correlated to road wear.

With the results of the evaluation currently underway, and further investigation into the durability of Oregon aggregates, possible modifications to the ODOT specifications and mix design procedures should be identified and implemented.

6.0 CONCLUSIONS & RECOMMENDATIONS

6.1 CONCLUSIONS

A summary of the information on the alternatives available for studded tire rut repair is shown in Table 6.1. Stone mastic asphalt appeared to be the most viable alternative for repairing ruts caused by studded tires.

Table 6.1 Summary of Alternatives

TREAT-MENT	MIX TYPE	THICKNESS (mm)	COST (per m^2)*	TIME BEFORE TRAFFIC	EXPECTED LIFE	CONSIDERATIONS
Micro - surfacing	Dense	10-15	$1.00	1 hour	6 years	Not to be used over open-graded mixes, short traffic delays
SMA	Gap /Open	13-19	$2.48	3 hours	15 years	Can be used on open-graded mixes, more stringent quality standards, resistant to studs
NOVA-CHIP®	Gap	-	-	-	6 years	Equipment must be imported from France
Austria	Dense	20	$4.50	3 hours	10 years	Some structural capacity
Michigan	Dense	20	$2.00	3 hours	8 years	Some structural capacity
RCC	N/A	150	-	24 hours	20 years	Labor intensive, not thin
Thin Concrete	N/A	89	$10.00	7 days	20 years	Labor intensive, long motorist delay
Fine Tooth Milling	N/A	-	$0.47	-	-	Short term solution, loss of structural capacity
Diamond Grinding	N/A	-	$6.00	-	-	Short term solution, cost does not include traffic control, long motorist delay
Hydro - blasting	N/A	-	$32.00+	7 days	15 years	Labor intensive, long motorist delay
"F" Mix	Open	40-50	$3.00	3 hours	12 years	Not a thin surface, some structural capacity
Shifting Travel Lanes	N/A	-	$2013/km	3 hours	4 years	Needs further investigation into the safety issues

*Costs shown are for information only and should not be used as a direct comparison between treatments. Costs may vary due to quantity, thickness, location, etc.

The performance of microsurfacing when subjected to studded tires is unknown, therefore, the microsurfacing sections being placed in Corvallis and Washington County should be monitored for performance. Since it has a quick setting time and does not require additional work like a standard overlay, microsurfacing may be a good alternative for pavements that will be overlaid or reconstructed within a couple of years.

Fine tooth milling may also be a good alternative for AC pavements that will be overlaid or reconstructed within a couple of years. The loss of structural capacity should be evaluated if this alternative is considered.

SMA is reported to offer the best resistance to studded tire wear. The resistance of SMA compared to conventional mixes subjected to studded tires is unknown. Additional monitoring of existing conventional mixes and the field testing of an SMA section is warranted for evaluation.

Consideration should also be given to designing a specialized mix. The best alternative may be to design a mix incorporating the positive features of SMA, thin overlays, and open-graded mixes.

6.2 RECOMMENDATIONS FOR THE PAVING COMMITTEE

The ODOT Paving Committee should consider:

> Constructing an SMA wearing course to compare the performance with conventional mixes. At a minimum, one section should include PCC using a dense-graded mix as a leveling course and another section should include AC using rotomilling for leveling. Construction of an SMA wearing course will require laboratory testing to establish an appropriate mix design.

6.3 RECOMMENDATIONS FOR FURTHER RESEARCH

The recommendations for further research include:

1) Investigating the preventive techniques Scandinavian countries have initiated. The investigation would entail identifying the aggregate properties that reduce wear caused by studded tires, based on Finland's aggregate specifications; evaluating sources that would meet the properties, and finally, modifying the ODOT aggregate specifications.

2) Identifying pilot projects and investigating surface preparation requirements and/or tack coats for thin overlays.

3) Conducting a more detailed investigation into the advantages and disadvantages of shifting travel lanes in certain areas as a preventive measure.

A work plan will be developed to incorporate the recommendations for further research.

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APPENDIX

Finland's Aggregate Specifications

3.2 MINERAL AGGREGATES

3.2.1 General

The mineral aggregate in an asphalt mixture is normally crushed aggregate, sand and filler. The fitness for use of mineral aggregate depends on its grading, cleaniness, strength, shape of grains, water content and petrological properties.

Crushed slag can be used in an asphalt mixture as a replacement raw material, (replacing mineral aggregate). Its use and requirements are designed individually.

3.2.2 Sampling

Mineral aggregate samples can be taken as preliminary samples in order to choose the deposit and in connection with production or from stock-pile to assure quality. The samples are taken randomly in connection with production according to a generally accepted sampling manner from the lot to be researched. Sampling and the density of sampling are presented in the specifications of crushing works, [6] and specifications for rock quality testing, [7] - published by the National Road Administration (FinnRA). There must be information in the sampling form on the sample itself, on the sampling place, on the sampling method, on the date and on the person who has taken the sample.

3.2.3 Requirements for Mineral Aggregate

3.2.3.1 General

The mineral aggregate in pavements is crushed gravel and crushed rock. These must be produced using such methods that guarantee the best possible quality of crushed aggregate. The quality of crushed aggregate is researched in a laboratory accepted by the client. Crushed gravel must contain at least 30% weight of fully crushed grains the diameter of which exceeds 6 millimetres and grains that are not crushed at all can be included at 30% of the weight the most.

3.2.3.2 Fraction Limits

The fraction limits for mineral aggregates in pavements are 0 millimetres, 2 millimetres, 6 millimetres, 8 millimetres, 12 millimetres, 16 millimetres, 20 millimetres, 25 millimetres and 32 millimetres. The upper and lower limits of the fractions can be exceeded as follows:

Table 7. Permissible excess of the upper and lower limits of mineral aggregate fractions

Proportioning category *)	Sieve size (mm)			
	< 1.2 * D	D	d	d/2
	OVER THE UPPER LIMIT weight %		BELOW THE LOWER LIMIT weight %	
A or SIP or SOP	0	< 5	< 10	< 4
Others	< 2	< 10	< 15	< 5

D=the upper limit of a fraction
d=the lower limit of a fraction

*) The proportioning categories are defined according to table 16.

If the sieve size of 1.2*D is not available, the requirement is applied to the closest larger sieve size. If the sieve size of d/2 is not available, the requirement is applied to the closest smaller sieve size.

The coarse aggregate, which has been measured with wet sieving, must not contain aggregate over 2% of the weight that passes the 0.074 millimetre sieve.

3.2.3.3 Purity of Mineral Aggregate

Mineral aggregate must not contain impurities, such as clay, turf, humus, soil, wood, ice or salt, to a harmful extent. In addition, mineral aggregate must not grade when stored, nor get mixed either with other aggregates or with the ground. The humus content class of crushed gravel, determined with a NaOH-test for cold pavements (TIE 221 method), is allowed to be II at the maximum. If the humus content class is III or worse, the suitability of mineral aggregate must be determined with the help of adhesion tests for test mixtures. The cleanliness of fine aggregate is of significant importance when using cold mixing technology.

3.2.3.4 Weathering Sensitivity

Weathering sensitivity is researched with the TIE 243 method. If the limits of the TIE 243 method are exceeded, weathering sensitivity is determined with the help of a freezing-thawing test (draft CEN TC 154/TG 9.122), a water absorption test (TIE 214) or the specific surface area test (TIE 215).

Weathered or easily weathered mineral aggregates are not to be used in pavements. Mineral aggregates that have been noticed to be strong and resistant against weathering are impervious and fine graded rocks. The portion of mica and other soft elements (strength in Mohs' scale below 3) in mineral aggregate for pavement must be below 30%. If the portion of these minerals is between 20 to 30% when they appear homogenously distributed, or if the portion is between 10 to 20%, when they appear in separate deposits or sedimented, then weathering sensitivity is determined more accurately with the help of a freezing-thawing test or is evaluated with the help of water absorption or specific surface test area. A mineral aggregate that contains over 5 % sulphide minerals is not to be used in pavements. The mineral aggregate used in pavements must not contain magnetic sulphide at all.

3.2.3.5 Adhesion

In addition to the effect of impurities, the physical and chemical quality of the mineral aggregate affects the adhesion. The adhesive properties of mineral aggregate are described in terms of an absorption power per square metre that must be below 10 milligrams/m^2. Furthermore, the adhesive properties are examined with the help of a water absorption test (TIE 214) and a specific surface area test (TIE 215).

3.2.3.6 Strength and Shape Requirements for Crushed Aggregate

Strength and wear resistance of mineral aggregate cannot be bound to rock types. They must be researched from case to case. Strength and properties concerning the shape of grains for mineral aggregate the diameter of which exceeds 8 millimetres are researched using methods described later in detail. Mineral aggregate is classified into strength classes IA, IB, IC, ID and II (table 8), and into shape classes I to IV (table 9) according to the strength and the properties concerning the shape of grains. The classes are determined according to the class that has the weakest value. The letter that is included in the marking of the strength class (A to D) indicates the proportioning category, which in turn depends on the volume of traffic (table 16). The raw materials of crushed aggregate the diameter of which is below 8 millimetres must fulfil the requirements for the mineral aggregate for pavements, because of the requirements for strength, stability and weather resistance.

The matters to be determined from mineral aggregate:

- Point load index Is(50), (to be determined from a core sample of rock). Point load index is to be determined wherever possible. Point load index for the IA - IB strength class crushed aggregate must be shown based on test results.
- Ball mill abrasion value must be determined when the mineral aggregate is divided into different classes according to the strength.

- Elongation and flakiness are determined according to the TIE 233 method from the 8 to 12 millimetre fraction. If the grain size is greater than 12 millimetres, elongation is determined from the 12 to 16 millimetre fraction. In this case the fraction must be mentioned separately. Elongation can also be determined according to the draft method of CEN prEN 933-6:1992.

Table 8. Strength classes of mineral aggregate

Class	Point load index Is(50) TIE 241 MPa	Ball mill abrasion value TIE 242 %
IA	≥ 13	≤ 7
IB	≥ 10	≤ 11
IC	≥ 8	≤ 14
ID	≥ 6	≤ 17
II	≥ 4	≤ 30

Table 9. Shape classes of mineral aggregate

Shape class	Shape value TIE 233				CEN-draft prEN 933-6:1992 Flakiness %
	Elongation (c/a) researched fraction (mm)		Flakiness (b/a) researched fraction (mm)		
	8 - 12	12 - 16	8 - 12	12 - 16	
I	≤ 2,5	≤ 2,3	≤ 1,5	≤ 1,4	≤ 10
II	≤ 2,6	≤ 2,4	≤ 1.7	≤ 1,6	≤ 15
III	≤ 2,7	≤ 2,5	≤ 1.8	≤ 1,7	≤ 20
IV	≤ 2,9	≤ 2,7	≤ 1.9	≤ 1,8	≤ 25

3.2.3.7 Requirements for Fine Aggregate

Fine aggregate consists of a mixture of fine, crushed aggregate and fine elements of sand and filler, which are added separately to the mixture. The filler must be such that the mixture of fine aggregate fulfils the requirements stated in table 10. The matters to be determined from the mixture of fine aggregate are the following:

- Mineral composition
- Specific surface area
- Voids content
- Purity

If the rock where the mineral aggregate initially comes from has not been examined, the mineral composition is determined with an X-ray diffraction apparatus. The requirements concerning cleanliness and adhesion are the same for fine aggregates as for all the other mineral aggregates discussed in chapters 3.2.3.3 and 3.2.3.5. The fine aggregate must be proportioned and its grading curve must be continuous. Voids in fine aggregate are an important property in relation to proportioning. They are determined with the help of grading and a specific surface area test. The voids content is determined from a compacted sample with the TIE 216 method in a laboratory.

Fine aggregate must fulfil the requirements stated in table 10 in relation to grading, voids content, water content and specific surface area.

Table 10. Requirements for fine aggregate

Aim of testing	Unit	Requirement	Method
Grain size < 0.002 mm	weight %	≤ 10	TIE 203
Voids content	%	36 - 44	TIE 216
Water content	weight %	≤ 0.6	TIE 212
Specific surface area	m^2/kg	1000 - 5000	TIE 215

3.3 ADDITIVES

3.3.1 Fibres

Fibres are used as a binding additive for bitumen in porous mineral aggregate mixtures (eg. in stone mastic asphalt (SMA)). Fibres can be classified into three categories, i.e. cellulose fibres, mineral fibres and glass fibres.

Fibres in asphalt pavements must fulfil the requirements stated in table 11 concerning moisture and heat. The fibres must be homogeneous in composition and they must not contain material that contains impurities or is hard to grind. In addition, fibres must be such that they get homogenously mixed in the asphalt mixture while the mixture is being produced. The fibres are delivered to the work site so that they are well enough packed or granulated, taking into consideration the circumstances.

The values in table 12 concerning specific gravity, fibre length and specific surface area are not mandatory requirements. They are target values, which are intended to be reached. If fibres are used in asphalt production, the added amount of fibres is determined with a binding test (TIE 321). The amount of fibres can be roughly evaluated with the help of table 13.