# Hard Aggregate Resistance to Studded Tires

## Alaskan Experience

Douglas J. Frith, Dennis A. Morian,
Shelley M. Stoffels, and Steve Saboundjian

**The results and methodology used to evaluate the cost-effectiveness of using harder aggregate in Alaska in an effort to reduce the wear caused by studded tires are presented. Scandinavian countries have studied the relationship between aggregate hardness, as measured by the Nordic abrasion value, and studded tire wear and have shown that harder aggregates have resulted in improved pavement performance. High-quality aggregates are not readily available throughout Alaska; therefore, a cost-effectiveness study of improved aggregate hardness was needed. Performance models based on the existing wear rates within the Anchorage, Fairbanks, and Juneau regions were developed. On the basis of existing performance data, studded tire wear is not a problem in the Fairbanks region, although this cannot be explained by aggregate hardness. Areas of greatest concern are the Anchorage and Juneau regions. Performance models relating pavement wear to the Nordic abrasion value of aggregates were developed. A methodology for evaluating the cost-effectiveness of transporting improved aggregates is provided. On the basis of the cost and performance data gathered, pavement wear caused by studded tires can be reduced and result in improved performance of the pavement in a cost-effective manner. Through the use of harder aggregates conforming to the Nordic abrasion specification, pavement performance can be increased by 1.4 to 1.9 times that currently experienced in the Anchorage and Juneau regions, respectively.**

Before 1992, the Alaska Department of Transportation and Public Facilities (ADOT&PF) was spending about $5 million per year repairing ruts in pavements caused by studded tire wear (E. Johnson and D. Pavey, Studded Tire Wear Resistant Aggregate Study, Final Report; unpublished report available from ADOT&PF, May 2000). Since that time, ADOT&PF has diligently been seeking to reduce the pavement rehabilitation costs related to studded tire use. Research conducted during the 1980s and 1990s has confirmed that studded tire wear is a significant cause of rutting in Alaska as well as in other states and provinces (N. McCullough and A. Kim, Rut Study; unpublished report available from ADOT&PF, Dec. 1995) (*1*). A vast array of evaluations conducted by many agencies including state agencies, Canadian provinces, and European highway agencies have identified that excessive pavement wear and pavement repair costs result from the use of studded tires for a trade-off in marginally improved safety in the form of stopping ability on ice. Because this icy surface condition has been identified by many agencies as representing a very small percentage of total driving conditions, many U.S. agencies have opted to control or discontinue the use of studded tires. After 1992, following the lead of some Scandinavian countries, ADOT&PF began researching improving pavement wear resistance by using harder aggregates in their pavement mixes. The challenge addressed here is to identify the potential improvement created by using harder aggregates and to evaluate the cost-effectiveness of such action.

In an effort to reduce the effect of studded tire wear, ADOT&PF sent several engineers to Norway, Sweden, and Finland to determine how those countries had become successful at reducing the wear. “Research done in Nordic countries showed that by using hard fine-grained aggregates, those typically volcanic/metamorphic in origin will reduce studded tire wear rates by a factor of three to five. Their research also determined that standard aggregate durability tests do not correlate to wear due to studded tires” (E. Johnson and D. Pavey, *Studded Tire Wear Resistant Aggregate Study,* Final Report; unpublished report available from ADOT&PF, May 2000). This research also indicated that the Los Angeles abrasion test did not adequately correlate to studded tire wear. Therefore, based on these findings, ADOT&PF has recently begun testing aggregate by using the Nordic ball mill test (*2*).

Northern European literature and research (*3–7*) have also shown that the use of harder, high-quality aggregates significantly reduces this damage. In essence, when a soft aggregate is used in the hot-mix asphalt (HMA) surface, the pavement develops depressions in the wheelpaths (wear-induced rutting) caused by excessive surface abrasion due to studded tires operating under bare pavement conditions. On bare roads, the high-stress-load applications between each tire stud and the surface aggregate cause binder and surface aggregate erosion, resulting, over time, in a loss of surface material in the wheelpaths that is then exhibited as rutting. Rutting is a serious pavement distress in that it allows water to collect in the wheelpaths, causing hydroplaning, reducing friction, and allowing rapid ice formation in these critical areas, which results in a potential safety hazard.

Because it is not feasible to fully eliminate the use of studded tires in Alaska at this time (currently, studded tires are banned from May 1 to October 1), an alternative solution is to use aggregates with increased hardness in the surface courses of these high-volume roadways. The problem is to quantify the cost-effectiveness of transporting harder aggregates to project locations. Studies have shown that many Alaskan aggregates currently in use are not sufficiently

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D. J. Frith, Quality Engineering Solutions, Inc., 888 West Second Street, Suite 108, Reno, NV 89503. D. A. Morian, Quality Engineering Solutions, Inc., 405 Water Street, Conneaut Lake, PA 16316. S. M. Stoffels, Pennsylvania State University, 208 Sackett Building, University Park, PA 16802-1408. S. Saboundjian, Alaska Department of Transportation and Public Facilities, 2301 Peger Road, Fairbanks, AK 99709-5399.

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hard and durable to significantly resist this surface abrasion problem. Therefore, the economic benefit of transporting aggregates, in terms of pavement performance, was evaluated. Quality Engineering Solutions, Inc., recently completed a research study for ADOT&PF, and the findings in the paper are based on the results documented in the project final report (*8*).

## PROJECT SCOPE

The primary objective of the study was to evaluate the economic feasibility of using high-quality aggregate [based on the Nordic abrasion (NA) value] in HMA surfacing. The project scope developed to achieve these objectives contained the following three tasks:

1. Determine the relationship between aggregate hardness (NA) and studded tire wear.
2. Determine the benefit-to-cost ratio of the higher-quality aggregate based on pavement performance comparisons.
3. Develop methodology that identifies the allowable aggregate cost increase for enhanced performance.

## METHODOLOGY

One of the first challenges of this project was to use the pavement management data provided by ADOT&PF to develop performance trends for existing pavements in Alaska. If correlations between aggregate hardness and wear could be developed for regional Alaskan pavements, then these would be the basis for determining the cost-effectiveness of transporting harder aggregates. However, if realistic correlations could not be developed with the Alaska data provided, then performance models from the Scandinavian literature would be used. As such, the following methodology was used to achieve the desired results:

1. Determination of winter wear versus summer wear,
2. Determination of pavement performance life based on wear rut only, and
3. Assessment of the relative performance trade-off possible with alternative aggregates.

### Pavement Performance Data

Pavement performance data were compiled for two recently constructed rutting test segments as well as about 30 in-service pavements each from the Anchorage, Fairbanks, and Juneau regions. The 30 projects were randomly selected from the higher-volume routes within each region. The initial approach was to develop performance trends based on regions, which then could be related to the standard materials used within each region. In total, pavement performance data for nearly 100 roadway segments were included in the study.

All performance data were taken directly from the 2001 version of the ADOT&PF pavement management database. These data contained rut depth and pavement condition index values for the years 1998, 1999, 2000, and 2001 and traffic volumes, in the form of annual average daily traffic (AADT), for 1998, 1999, and 2000. Additional rut depth and traffic information was provided for select Juneau pavement sections and was gleaned from previous wear studies completed by ADOT&PF.

In addition to Alaska roadway data, performance models and specification tables developed and utilized by the Scandinavian countries (*3*) were used to enhance the predicted relationship between aggregate hardness and studded tire wear rates. These established relationships were critical to the successful completion of this project given the limited NA data available for Alaskan roadways.

### Material Data

HMA material data, including aggregate hardness and geological classification, were requested for each of the study sections identified. Unfortunately, not all requested data were available for all roadway segments; in fact, only limited NA data were available for the in-place Alaskan roadways. All the materials data used in the completion of this study were provided by ADOT&PF or by aggregate suppliers.

Aggregate quality was a key aspect to this study. ADOT&PF has reviewed many publications and performed some of its own research into hard aggregate performance, particularly in the area of NA testing. The NA test, formally titled “Determination of the resistance to wear by abrasion from studded tyres—Nordic test” is specifically calibrated to measure wear resulting from the use of studded tires. This test is available in Part 9 of the European Standards (EN 1097-9-Resistance to Abrasion by Wear from Studded Tyres) (*2*). A description of the Nordic ball mill test, the Los Angeles abrasion test, and the micro-Deval test is presented in Table 1.

Results from the Nordic test indicate differences in the resistance of various aggregates to wear from tire studs, unique from the usual Los Angeles abrasion or micro-Deval results. ADOT&PF recently began performing NA testing on a routine basis that, in the future, will provide additional data for calibration of the models presented later in this paper. However, at this point in the study, only limited NA test results were available corresponding to the in-service pavements studied. As a result, future calibration of these models with more robust data will likely be needed. The available NA data (from Scandinavian countries, Oregon, and Alaska studies) appear to support the hypothesis that this test provides a useful measure of resistance to studded tire wear. The validity of this hypothesis is critical to the conclusions of this study and, although outside the scope of the study, should be verified for additional aggregates used by ADOT&PF.

## RESULTS

### Establishment of Winter Wear Rates

The rate of pavement wear assignable to studded tire use was the first step in the analysis. To accomplish this, pavement rut measurement data were obtained from ADOT&PF. Test measurements made at 6-month intervals were used. Those measurements made in the spring season are interpreted as representing winter wear (predominantly resulting from studded tire use) while measurements made in the fall are interpreted as representing pavement deformation during the hot weather seasons.

Quality Engineering Solutions, Inc., used previously collected data from a study report entitled Rut Study (N. McCullough and A. Kim, unpublished report available from ADOT&PF), which was completed in December 1995. The original analysis was performed by Nelson McCullough, a regional pavement engineer, and Anthony Kim of Central Regional Material Lab. The pavements included in this study were from the New Seward Highway, Tudor Road, Glenn Highway,

**TABLE 1 Comparison of Los Angeles Abrasion, Micro-Deval, and Nordic Ball Mill Tests**

| | Los Angeles Abrasion Test | Micro-Deval Test | Nordic Ball Mill Test |
|---|---|---|---|
| Aggregate Material Size | 2.36 to 25.0 mm (four grading types) | 4.75 to 16.0 mm (three grading types) | 11.2 to 16.0 mm |
| Cylinder Size (Inside Diameter) | 711 +/- 5 mm | 194 +/- 2.0 mm | 206.5 +/- 2 mm |
| Inside Cylinder Length | 508 +/- 5 mm | 170 +/- 2.0 mm | 335 +/- 1 mm w/three ribs |
| Rotation Speed | 30 to 33 rpm | 100 +/- 5 rpm | 90 +/- 3 rpm |
| Total Revolutions | 500 | 9,500 to 12,000 | 5,400 |
| Ball Bearing Size | Approximately 46.8 mm in diameter | 9.5 +/- 0.5 mm in diameter | 15.00 + 0.01/- 0.05 mm in diameter |
| Abrasion Charge | 2,500 to 5,000 g depending on grading | 5,000 +/- 5 g | 7,000 +/- 10 g |
| Sample Preparation | • Wash and dry to constant mass at 110 +/- 5 °C.<br>• Separate the aggregate into the individual size fractions, recombine to the grading that most nearly corresponds to the range of sizes in the aggregate furnished for the work.<br>• Total mass is 5,000 +/- 10 g.<br>• After the prescribed number of revolutions, remove the material and make a preliminary separation of the sample on a sieve coarser than the 1.70 mm (No. 12). Wash the material coarser than the 1.70 mm sieve. Oven dry at 110 +/- 5 °C to constant weight and weigh to nearest gram.<br>• % loss = 100 (initial dry mass - dry mass after test)/initial dry mass. | • Wash aggregate until water is clear.<br>• Oven dry to constant mass at 110 +/- 5 °C for 15 hrs +/- 2 hrs. Cool to room temperature. Weigh sample.<br>• Half of mass of sample is 9.5 to 12.5 mm; three gradings possible.<br>• Total mass of sample is 1,500 +/- 5g.<br>• Saturate with 2,000 +/- 50 ml tap water for 1 hr.<br>• Place in drum, add steel balls, and run.<br>• Pour through 4.75 mm sieve and 1.18 mm sieve until clean.<br>• Oven dry combined material to 110 +/- 5 °C.<br>• % loss = 100 (initial dry mass - dry mass after test)/initial dry mass. | • Wash and dry to constant mass at 110 +/- 5 °C.<br>• Sieve the sample on the 11.2, 14. 0, 16.0 mm sieves, include 60 – 70 % of 11.2 to 14.00 mm; 30 – 40 % of 14.0 to 16.0 mm.<br>• Mass of sample varies from 996 to 1,147 g, depending on particle density.<br>• Place in drum, add 2,000 +/- 10 ml water, add steel balls, and run.<br>• Wash the sample, including ball charge, on the 14, 8, 2 mm sieves.<br>• Dry aggregate to 110 +/- 5 °C.<br>• Weigh the aggregate fractions together.<br>• Nordic Abrasion = 100 (initial dry mass – dry mass after test)/ initial dry mass. |

Muldoon Road, and Minnesota Drive, and they involved several different surfacing materials, including SMA AC-5 Vestoplast, SMA AC-5 Cellulose, SMA AC-20 Cellulose, IA AC-5, and a concrete surface. Rut data were collected in fall 1992, spring 1993, fall 1993, spring 1994, summer 1994, spring 1995, and fall 1995. No data were collected in fall 1994. A total of 17 different roadway segments were included in the study.

These seasonal rutting data were used to determine the typical amount of winter wear occurring on the Alaskan roadways. Figure 1 presents a graphical illustration of the seasonal rutting data for each of the 17 study sites.

The average increase in rut depth during summer 1992 was 0.03 in., whereas the increase during winter 1992 was 0.06 in., and during winter 1993 the average increase in rut depth was 0.11 in. Another way of stating this is that winter 1992 experienced 67% more rutting than did summer 1992, while winter 1993 was even more severe, causing 78% more rutting than occurred during the previous summer. These data clearly indicate that a significant amount of rutting in the Anchorage area occurs during the winter months.

Because the detailed rut measurement data necessary to perform this assessment exist only for select sections in the Anchorage area, similar assessments could not be conducted in the other regions. However, an initial study on one route in the Juneau area has also indicated a similar component of winter wear. Therefore, it appears to be reasonable to assume this trend is valid throughout the state, so subsequent analyses have included this assumption. A conservative assumption that two-thirds of annual rutting is the result of winter wear has been used.

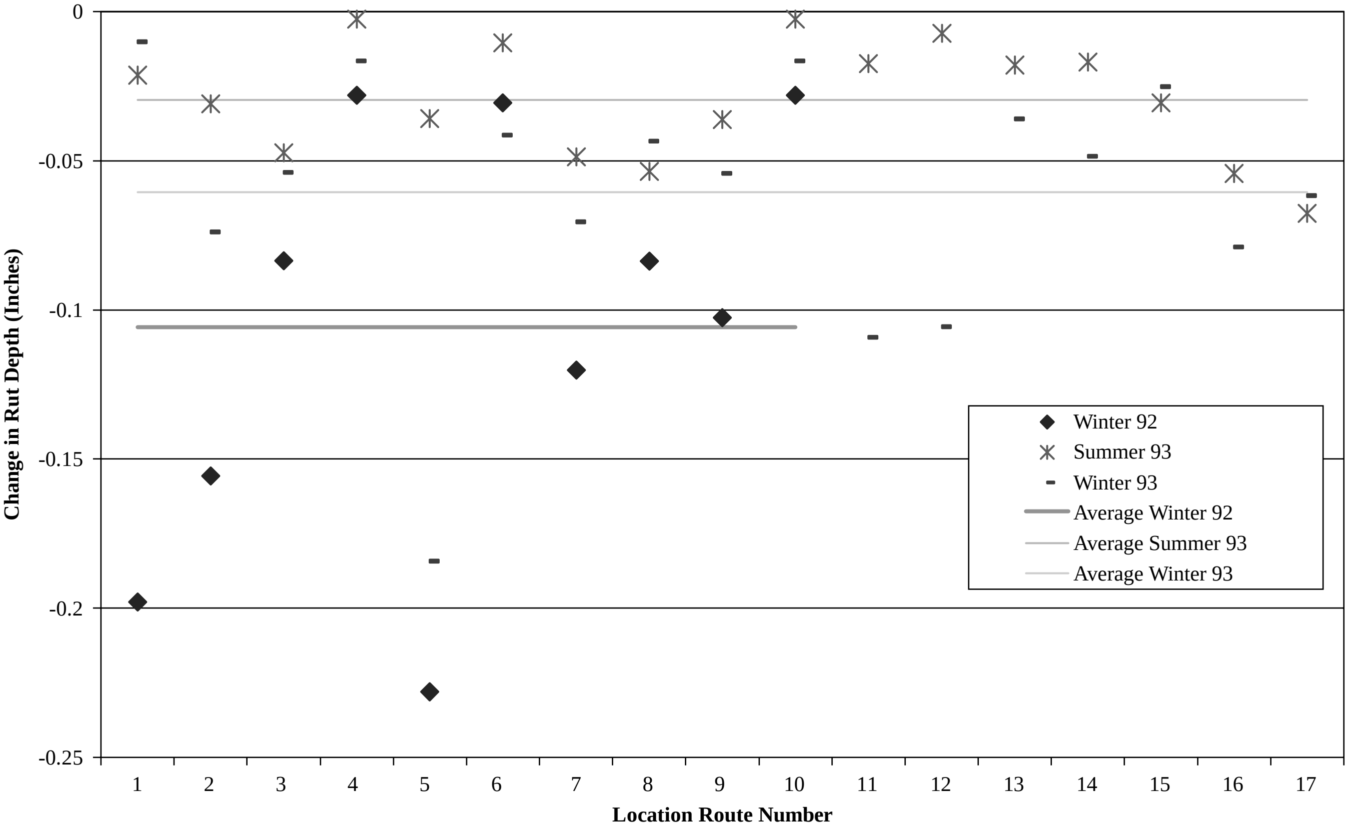

**FIGURE 1** Seasonal rutting values.

## Pavement Performance Curves for Wear

The second step in the analysis process was to determine the wear rates of pavements based on aggregate hardness. As previously stated, about 30 roadway segments were selected for analysis from each of three regions: Anchorage, Fairbanks, and Juneau. The study sections were selected from the routes with the higher AADT values under the premise that the high AADT would provide greater wear.

From this information, it was evident that the rate of winter pavement wear is less for pavements in the Fairbanks region. Winter wear rates identified in the Anchorage and Juneau regions are about 3.8 times that of the wear rate in the Fairbanks region. Initially, this would suggest that the aggregate durability of pavement materials in the Fairbanks region is superior to those used in the more southern areas. However, as evidenced by the available aggregate hardness data, this is not the case. Several speculations have been made about why these Fairbanks pavements show lower wear; however, none has been confirmed. Therefore, the Fairbanks data were eliminated from further study or consideration as studded tire wear is not an issue and is not explained by aggregate hardness.

Also, there does not appear to be a significant difference in wear rates between the Anchorage and Juneau pavements; therefore, a direct comparison of the two is not warranted. Because no clear performance trends are evidenced with the Alaska provided data, information in the Scandinavian literature was used in development of the performance model.

The Nordic countries have developed specifications for various traffic levels based on the NA tests. The specification is presented in Table 2.

Figure 2 visually represents this specification. Performance models for each classification can be developed on the basis that each specification level will limit the amount of annual wear on a particular roadway. For example, if a Class III roadway has an NA value equal to 14, then this roadway should limit the wear to a given amount (say 1 mm) per year as long as the AADT does not exceed 2,500. However, if the AADT doubles to 5,000, logically then, the wear would

**TABLE 2** NA Ball Mill Specification

| Class | Ball Mill Abrasion Value (less than or equal to) | Average Daily Traffic Per Lane (greater than) |
|---|---|---|
| I | 7 | 10,000 |
| II | 10 | 5,000 |
| III | 14 | 2,500 |
| IV | 17 | 1,500 |
| Nonclassified | 30 | NA |

NA = not applicable.

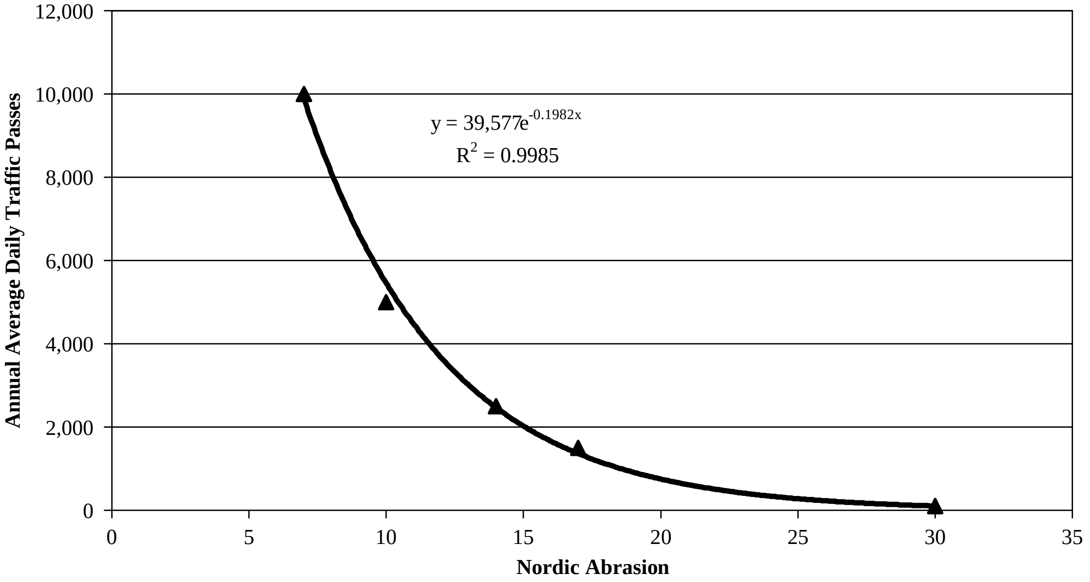

FIGURE 2 NA specification plot based on uniform annual wear rates.

double as well (to 2 mm). Likewise, if a roadway classified as Level I has an NA value of 7 and experiences only 5,000 vehicles per day, then the anticipated wear would be one-half that expected. This effort results in the performance models based on traffic levels as indicated in Figure 3. An assumption of the limiting annual wear rate is needed to develop these performance curves. An initial annual wear rate of 1 mm was assumed, which matches that reported by the Scandinavian countries based on the implementation of this specification and the use of high-quality aggregates (*4*).

In an effort to calibrate these models to Alaskan roadways, data provided by AKDOT&PF were plotted as indicated in Figure 4. Two different levels of Alaskan data were available for this calibration: controlled studies and general studies. The controlled studies consist of two roadway segments where precise rut measurements have been reported and both NA and traffic levels are available. These controlled sections consist of Egan Drive in Juneau and the New Seward Highway in Anchorage, both of which meet the Class II traffic criteria. The Egan Drive pavement has been monitored since the application of an overlay in 1995 and was again overlaid in 2000. A hard aggregate was used in the 2000 overlay. The New Seward Highway study was reported by Eric Johnson and Dan Pavey in *Studded Tire Wear Resistant Aggregate Study*, Final Report, a report dated May 2000

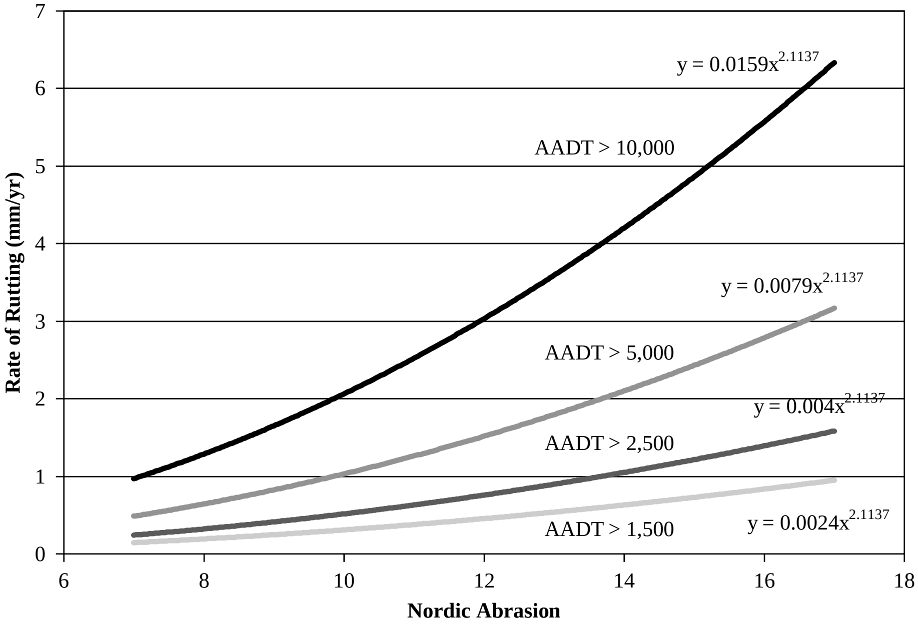

FIGURE 3 Estimated performance curves based on Nordic specifications, at 1 mm of wear per year.

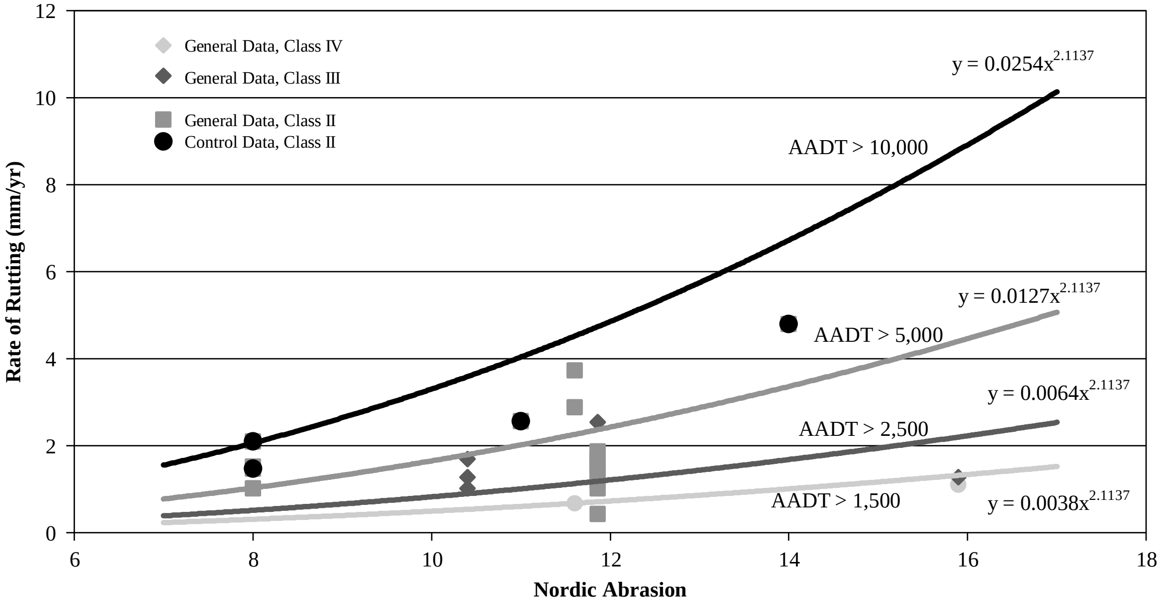

**FIGURE 4 Calibrated performance curves with Alaska data, at 1.6 mm of wear per year.**

(unpublished report available from ADOT&PF). This study consisted of controlled test panels constructed with both typical and high-quality aggregates. The general study data consist of pavement management system (PMS) information for roadways where the aggregate NA values are available. The PMS rutting data are more variable and include all segments of the roadway including both curves and tangent sections, which do not necessarily produce uniform wear rates.

Based on the limited control data and the general study data, it appears that a wear rate of 1.6 mm per year provides the most reasonable performance models. Significant scatter is apparent in the general data, but as more control study information is gathered these models can, and should, be refined.

## Pavement Wear Resistance

Because studded tire wear is most evident in the Anchorage and Juneau regions, the remainder of the study focused on those areas. With the performance data from the 30 sections within each region, the relative pavement performance was calculated. On average, the performance of sections from these Alaskan regions based on rutting rate is 12.6 years for Anchorage and 12.8 years for Juneau.

The preceding estimates are based entirely on the prediction models generated to achieve 0.5-in. rutting.

These performance predictions are based on observations of performance normalized versus vehicle passes and therefore have factored out any difference in traffic volumes in the different regions, although perhaps not fully the differences in studded tire application rates. It must be remembered that these predictions do not necessarily indicate that pavements in these Alaskan regions will last these predicted lives but instead that these predictions indicate the relative rut resistance of pavements using the current aggregates. Considering the diversity of mix types included in the data, it is reasonable to conclude that aggregate quality is a major factor in the predicted differences in regional pavement performance.

When one considers the significance of these pavement rut (wear) development predictions, it is important also to consider the actual performance life of pavement sections in each region. By using the results of ADOT&PF visual rating score in the pavement management database, and applying a terminal serviceability index of 2.5, an estimated average pavement performance (for all types of mixtures) in the two regions, predicted by other distress types, excluding rutting, is 17.5 years for Anchorage and 24.6 years for Juneau.

This information clearly indicates that a longer life can be expected if the winter wear problem can be solved. The importance of this information arises when one considers the improvement in overall pavement performance to be attained by using harder aggregates. What is conveyed is that the performance of pavements in Anchorage and Juneau can be increased by factors of 1.4 and 1.9, respectively.

## Performance Comparisons

The performance models in Figure 4 can be used to directly compare the anticipated wear performance of various levels of aggregate hardness. When a higher-quality aggregate is compared with the typical regional performance, Figure 5 is used. Figure 5 presents the relationship between aggregate quality and the predicted performance of the typical pavements studied in the Anchorage and Juneau areas. This plot is based on the average NA value in Juneau of blended aggregates being equal to 11.6. This value was determined from 27 roadway segments in the Juneau region that had NA values reported by ADOT&PF. The Anchorage relationship is based on the average NA value of pavements currently being constructed in Anchorage to be 11.0. A value of 11.0 was taken from the *Studded Tire Wear Resistant Aggregate Study,* Final Report, developed by Eric Johnson and Dan Pavey in May 2000 (unpublished report available from ADOT&PF), where they stated, “The Ball Mill Value of the Valley aggregate is 11 (Level III of the Nordic specification).”

Figure 5 presents the predicted change in the rate of rutting (RR) for Anchorage and Juneau pavements as the NA value of the aggregate changes. The RR for the typical regional aggregate is used as the baseline for comparison. First, the RR for the typical regional aggregate is determined from the proper curve in Figure 4. This RR

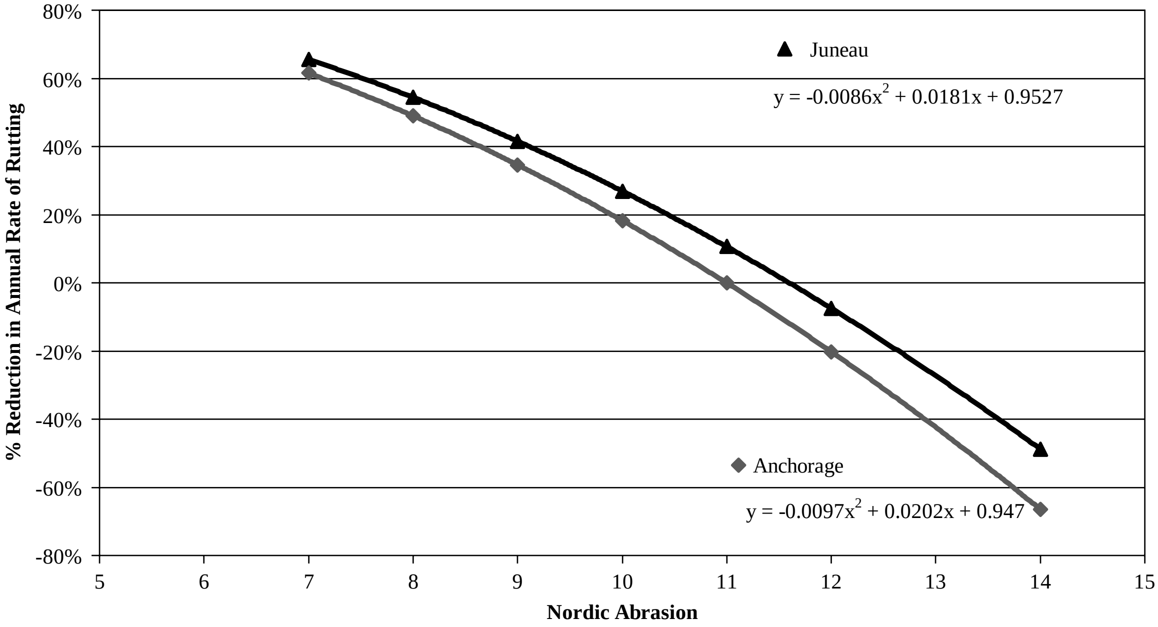

**FIGURE 5** Predicted change in annual rate of rutting for Anchorage and Juneau pavements.

becomes the baseline for comparison. When an aggregate with an NA value other than the typical one is used, a new RR is calculated, again using the same performance curve from Figure 4. The percent change in RR is determined by subtracting the RR of the improved aggregate from the RR of the typical aggregate and then dividing by the RR of the typical aggregate. This value is then multiplied by 100, which results in the percent change in RR. By varying the NA value of aggregates and repeating this process the curves in Figure 5 are created. The performance models presented in Figure 4 all have a constant exponent, with various coefficients. Therefore, when the change in performance is referenced to a typical aggregate, the effect of the coefficient (i.e., class of roadway) cancels out and is not critical to the change in performance. Therefore, Figure 5 does not depend on the class of roadway in question.

For example, in Anchorage, the typical aggregate has an NA value of 11.0 and, if used on a Class II roadway, the predicted RR would be 2.02 mm/year. If one wants to compare an aggregate with an NA value of 9.0 in this region, on a Class II roadway, the predicted RR would be 1.32 mm per year. Therefore, the change in the rate of rutting is $(2.02 - 1.32)/2.02 = 0.35$ or one can say the RR is reduced by 35% when an aggregate with an NA of 9 is used compared with the typical aggregate having an NA value of 11.

If additional information is available, or is collected in the future, a more accurate representation of typical NA values being used in each region can be developed, thus increasing the accuracy of this comparison.

Figure 5 is used to determine the predicted improvement to RR for various NA values. This figure must be created for each individual region of Alaska based on the typical NA value for that region.

## Cost Analysis

Table 3 presents a calculation of the expected rutting life for higher-quality aggregates by entering an NA value for the high-quality aggregate. The expected rutting life is determined by multiplying the typical rutting life (for that region, as explained elsewhere) by one plus the value from Figure 5. A justified cost increase is also calculated in

**TABLE 3** Cost Calculation Table

| Region/Mix | Mixture Cost ($/in-place ton) | Plant Aggregate ($/ton) | Aggregate in Mix ($/ in-place ton) | Predicted Rutting Life (yr) | PSI Life (years ) | Hard Agg | | Life with Hard Agg Wear (yr) | Current Economic Life | Potential Economic Life | Mixture Current EUAC | Equivalent First Cost | Justified Increase in In-Place Agg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Predicted Rut Life (yr) | Nordic Abrasion | | | | | | |
| | | | | | | | | | | | | | |
| Anchorage | $50.98 | $15.13 | $30.69 | 12.7 | 17.5 | 20.5 | 7 | 20.5 | 12.7 | 17.5 | ($5.20) | $64.53 | 44.2% |
| Anchorage | $50.98 | $15.13 | $30.69 | 12.7 | 17.5 | 18.9 | 8 | 18.9 | 12.7 | 17.5 | ($5.20) | $64.53 | 44.2% |
| Anchorage | $50.98 | $15.13 | $30.69 | 12.7 | 17.5 | 17.1 | 9 | 17.1 | 12.7 | 17.1 | ($5.20) | $63.38 | 40.4% |
| Anchorage | $50.98 | $15.13 | $30.69 | 12.7 | 17.5 | 15.0 | 10 | 15.0 | 12.7 | 15.0 | ($5.20) | $57.72 | 21.9% |
| Anchorage | $50.98 | $15.13 | $30.69 | 12.7 | 17.5 | 12.6 | 11 | 12.6 | 12.7 | 12.6 | ($5.20) | $50.80 | -0.6% |
| Anchorage | $50.98 | $15.13 | $30.69 | 12.7 | 17.5 | 10.1 | 12 | 10.1 | 12.7 | 10.1 | ($5.20) | $42.39 | -28.0% |

PSI = present serviceability index; Agg = aggregate.

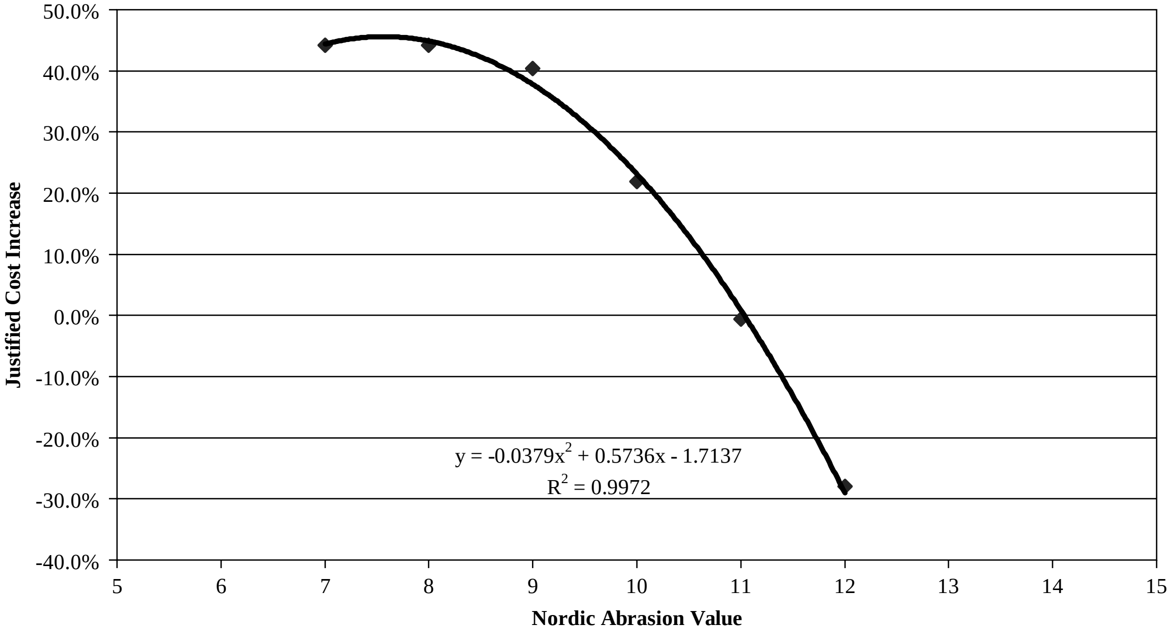

**FIGURE 6** Example of justified cost increase for in-place HMAC, Anchorage.

Table 3. This justifiable cost increase can be illustrated as indicated in Figure 6.

As actual aggregate importation costs are determined for each region, cost trends such as indicated in Figure 7 can be developed. Figure 7 presents the relationship between in-place HMA concrete (HMAC) costs and the predicted life of that pavement. It may not be cost-effective to import the highest-quality aggregate available, but it may turn out that a slightly improved aggregate may be more cost-effective. There is a point at which the wear from studded tires has been reduced so that wear will not be the failure mode of the pavement. Thus, the predicted life is based on other failure mechanisms, such as fatigue cracking, and aggregate hardness no longer needs to increase.

As a final step, for a specific project, given the optional aggregate hardness and cost values, a direct cost comparison can be illustrated, as indicated in Figure 8. Compare the justified cost increase with the actual cost increase for the optional high-quality aggregate. If the ratio of the justified cost to the actual cost is >1, then the optional high-quality aggregate should be used. If, however, the ratio of justified cost to actual cost is ≤1, then the original aggregate would prove to be more beneficial. In Figure 8, those aggregates with an actual cost increase less than the justified cost increase (where the

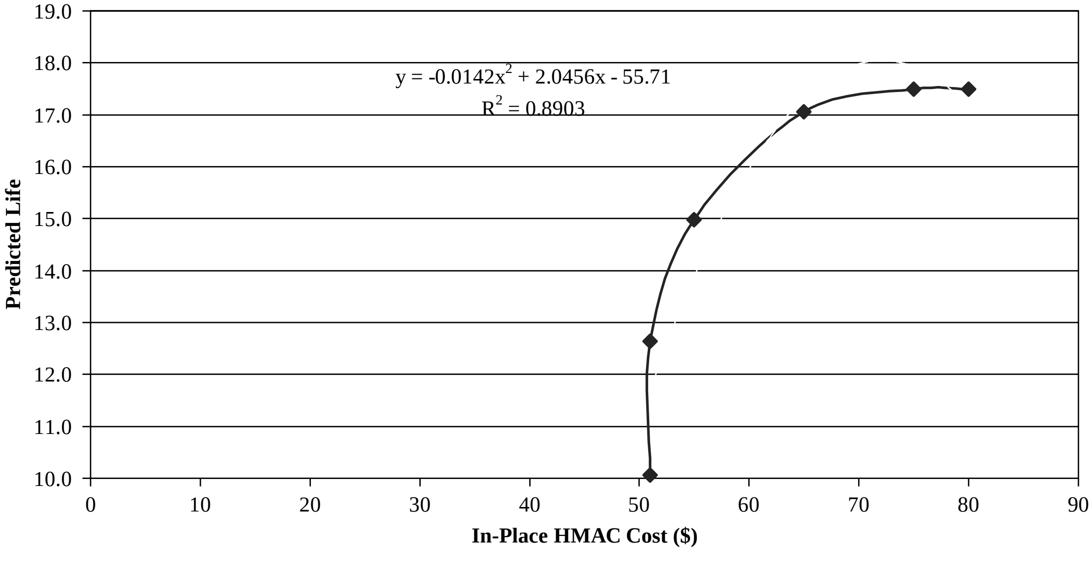

**FIGURE 7** Life versus cost curve for example cost data, Anchorage.

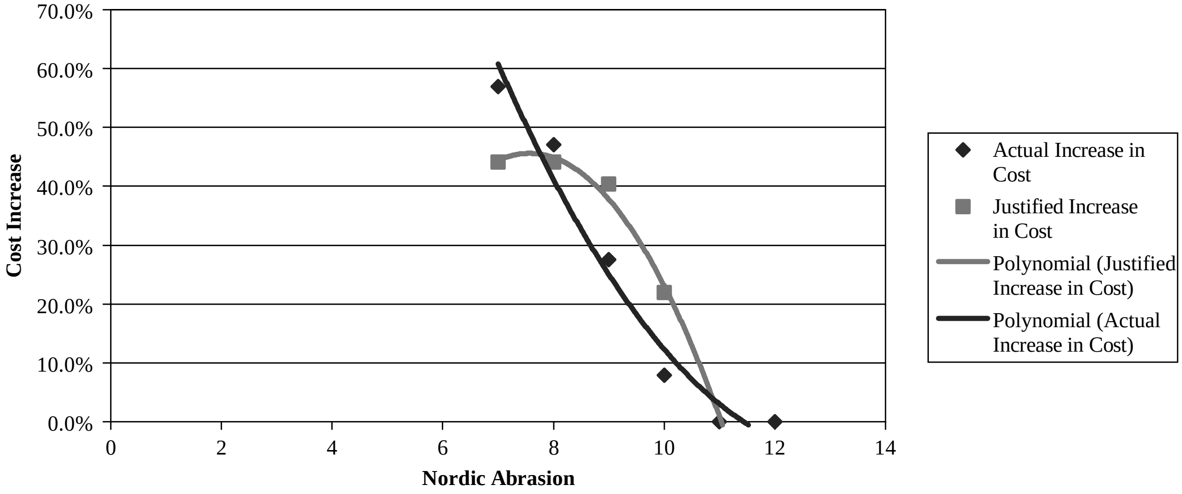

**FIGURE 8** Example of cost comparison analysis, Anchorage.

actual line is below the justified line) would be cost-effective to import.

Using existing typical aggregate costs as the standard, comparative potential costs for high-quality aggregates in Anchorage and Juneau for Type II mixes are computed. The procedure for performing this calculation is presented in Figure 9 and is indicated in Table 3.

To calculate the potential economic life of pavements in each region at a given NA value, a comparison of the predicted rut life and the pavement performance based on other factors, assuming that rutting failure is eliminated by increasing aggregate hardness, is important. This represents the potential economic life. The potential economic life value is then used to calculate the equivalent uniform annual cost (EUAC) of the mixes in each region at the improved NA value. Computing the present value, based on the EUAC, provides the equivalent cost of the mixes. The difference between the current cost of mixes and the equivalent cost of mixes represents the potential increase, which could be spent on in-place higher-quality aggregate.

## CONCLUSIONS

The conclusions of this study support the adoption by ADOT&PF of requirements for the use of harder aggregates within the surface mixtures on many of the Alaskan roadways. Five basic conclusions were drawn in this study:

1. There is currently a studded tire wear problem in the Anchorage and Juneau regions.
2. A studded tire wear problem is not evident in the Fairbanks area and this cannot be explained by aggregate hardness.

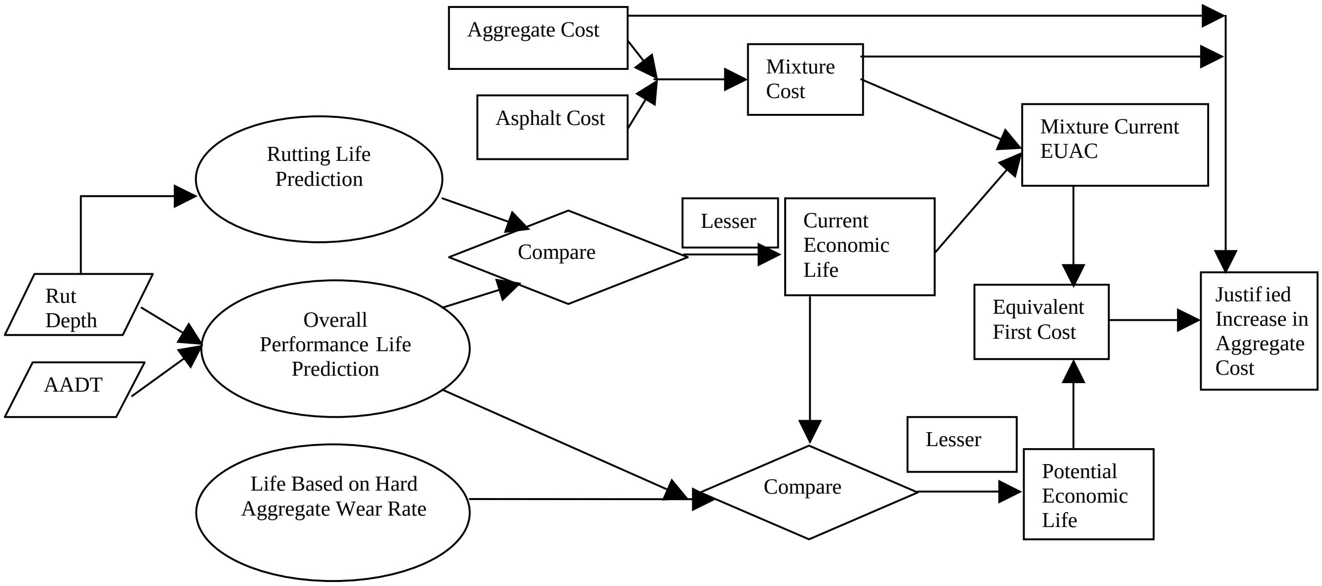

**FIGURE 9** Flow diagram of economic analysis process.

3. Studded tire wear can be reduced in the Anchorage and Juneau regions with adoption of the Nordic ball mill specification and the recommended cost analysis methodology.
4. Transporting and importing harder aggregates appears to be cost-effective.
5. Solving studded tire wear can increase the life of pavements in the Anchorage and Juneau regions by factors of 1.4 and 1.9, respectively.

Results from the study indicate that the economy of aggregate materials supports the transportation costs for importation of aggregates to the Anchorage and Juneau regions. While it is not inherently conclusive that the use of better quality (i.e., harder aggregates) will improve overall pavement performance with respect to pavement wear resulting from the use of studded tires, the improvement in performance is well justified. Because this appears to be the greatest pavement performance problem faced by ADOT&PF highways, improvement in this area is likely to result in significant improvement in overall pavement performance and cost-effectiveness, particularly in the larger population centers.

## RECOMMENDATIONS

Recommendations for action by ADOT&PF are summarized as follows:

- Implement the Nordic ball mill specifications on roadways with volumes exceeding 5,000 AADT and other roadways showing excessive wear.
- Perform additional wear studies to further validate the performance models presented in Figure 4.
- Use harder aggregate requirements for pavement surface courses only.
- Provide information to hot-mix producers about the availability of harder aggregate materials in the Vancouver, Canada, and the Pacific Northwest regions available at reasonable costs by barge.
- ADOT&PF should evaluate some of the potential aggregate sources inside and outside the state for properties, particularly determining the NA value.
- Develop a strong partnering program with the hot-mix and aggregate production industries within the state in implementation of the aggregate requirement changes. Emphasize the benefits in pavement resistance to studded tires.

It is recommended that the harder aggregate requirements be implemented on roadways with traffic volumes exceeding 5,000 AADT. This will preserve market share for lower-volume highways and preserve the "premium" aggregate for use in higher-volume highways. It is also important to remember that the harder aggregate material discussed here is applicable only to surface course paving. Other layers can continue to use locally available materials. The effect of this is to minimize the loss of market share experienced by local aggregate producers and to minimize the increased cost to ADOT&PF.

Before implementing a specification based on NA number requirements, ADOT&PF should evaluate additional out-of-state aggregates to confirm alternative sources are available to fill the need for material.

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