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COST-EFFECTIVENESS OF HARD AGGREGATE SOURCES

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This report documents and presents the results and methodology used in the evaluation of the cost-effectiveness of using harder aggregate in Alaska in an effort to reduce asphalt pavement wear caused by studded tires. The 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 aggregate transportation was needed. Performance models, based upon the existing wear rates within the Anchorage, Fairbanks and Juneau regions were developed.

Based upon 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. Based upon cost and performance data gathered, asphalt pavement wear caused by studded tires can be reduced, resulting in increased pavement performance in a cost-effective manner.

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- ALASKA HARD AGGREGATE PERFORMANCE STUDY -

FINAL REPORT

Prepared for
Alaska Department of Transportation and Public Facilities

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Table of Contents

List of Figures

List of Tables

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Abstract

This report documents and presents the results and methodology used in the evaluation of the cost-effectiveness of using harder aggregate in Alaska in an effort to reduce asphalt pavement wear caused by studded tires. The 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 aggregate transportation was needed. Performance models, based upon the existing wear rates within the Anchorage, Fairbanks and Juneau regions were developed.

Based upon 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. Based upon cost and performance data gathered, asphalt pavement wear caused by studded tires can be reduced, resulting in increased pavement performance in a cost-effective manner.

Summary of Findings

The citizens of Alaska utilize studded tires to operate vehicles during the winter months. As have many other highway agencies, the Alaska DOT has concluded that the pavement wear resulting from the use of these studded tires results in accelerated pavement damage. Alaska has initiated an investigation into the use of more wear resistant aggregates for pavement wearing surfaces based upon Scandinavian research, as a potential solution to reducing this accelerated damage. This study investigates pavement performance in three regions within the state, Anchorage, Juneau, and Fairbanks. The study further concludes that Fairbanks does not have a studded tire wear problem, for undefined reasons that appear to be independent of aggregate hardness. Further economic assessment of potential benefits of utilizing harder aggregates in pavements have been conducted on the basis of this performance information and local aggregate and hot mix asphalt costs.

Results of analysis from rut study data collected in the Anchorage area clearly show that, on average, approximately two thirds of the rut depth developed can be attributed to studded tire wear. Using performance data from all three regions, it is also clear that pavements in the Fairbanks area are significantly older, and exhibit a much lower wear rate than those in the Anchorage and Juneau regions.

The ADOT&PF has investigated the use of a test for the "Determination of the resistance to wear by abrasion from studded tyres-Nordic test", commonly referred to as the Nordic Abrasion Test. Scandinavian research and limited results with this test on aggregates in Alaska provide promise that aggregates can be rated on the basis of resistance to wear damage.

Economic analysis of the cost of hot mix asphalt materials, including aggregates, enhanced by the potential improvement in rut resistance resulting from harder aggregates, indicate that both the Anchorage and Juneau regions could benefit significantly from importing harder aggregates. The practice of importing harder aggregate to these regions can be accomplished within the additional cost justified by the improved pavement performance resulting from resistance to studded tire wear.

CHAPTER 1 - INTRODUCTION AND RESEARCH APPROACH

High-quality aggregates are crucial to the long-term performance of hot-mix asphalt concrete (HMA) pavements. Research has shown that the use of high quality, hard aggregates can reduce the surface deterioration caused by studded tires. Very few Alaskan aggregates have been located which have the required high quality. Therefore, the Alaska Department of Transportation and Public Facilities (ADOT&PF) felt that a study of the cost-effectiveness of high-quality aggregate sources was needed.

Project Scope

The primary objective of the study was to evaluate the economic feasibility of transporting high-quality aggregate for use in HMA surfacing. A secondary objective was to provide the ADOT&PF with a method of performing the benefit/cost analysis such that it can be used for future aggregate movement studies into other areas of the state.

The project scope developed to achieve these objectives contained the following two items:

1. Determine the benefit-to-cost ratio of the improved aggregate based on pavement performance comparisons.
2. Develop and implement a methodology that identifies the allowable aggregate cost increase for enhanced performance.

Background

The Alaska DOT, as well as numerous other agencies found in the literature, has experienced extensive problems with pavement wear resulting from the use of studded tires. 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 trade-off in marginally improved safety in the form of stopping ability on ice. Since this ice 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. Alaska, following the lead of some Scandinavian countries, is interested in improving pavement wear resistance by utilizing harder aggregates in their pavement mixes. The challenge addressed herein is to identify the potential cost effectiveness of such action.

ADOT&PF research and observations have identified premature deterioration of pavements due to studded tire wear. Northern European literature and research has also shown that the use of harder, high-quality aggregates significantly reduces this damage. In essence, when a soft aggregate is used in the surface HMA, 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 causes 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, resulting in a potential safety hazard.

Since it is not feasible to eliminate the use of studded tires at this time, 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 hard and durable to significantly resist this surface abrasion problem. Therefore the economic benefit of transporting aggregates, in terms of pavement performance, must be evaluated.

CHAPTER 2 - FINDINGS

TASK 1 - DATA COMPILATION

Task 1 of the project consisted of gathering useful data regarding the surface materials utilized and the rates of wear occurring in Alaska. Information was gathered from several different resources and was then compiled into a Microsoft Access database. The data gathered and the resources used are discussed in the following sections.

Literature Review

A complete listing of research reports reviewed for the completion of this project is provided the Reference and Literature Review section. It should be noted, that the northern European countries have been working on this problem for more than 20 years. Results of their studies have led to the ADOT&PF instigation of this approach to mitigating pavement wear. Many of the references reports were provided by the ADOT&PF, including several reports that have not been formally published. Additional information regarding current rut studies was provided by the ADOT&PF as well.

Pavement Performance Data

Pavement performance data was compiled for two recently constructed rutting test segments as well as approximately 30 projects 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 upon regions, which could then be related to the standard materials utilized within each region. In total, pavement performance data for nearly 100 roadway segments have been included in the project's Microsoft Access database.

All performance data was taken directly from the 2001 version of the ADOT&PF pavement management database. Additional rut depth information was provided for select Juneau pavement sections and gleaned from previous wear studies completed by the ADOT&PF.

In addition to Alaska roadway data, performance models and specification tables developed and utilized by the Scandinavian countries 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 Nordic Abrasion data available for Alaskan roadways.

Materials Data

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

Aggregate Durability

Aggregate quality was a key aspect to this study. The ADOT&PF has reviewed many publications and have performed some of their own research into hard aggregate performance, particularly in the area of Nordic Abrasion testing. Unfortunately, at this time only limited Nordic Abrasion testing has been performed on Alaskan aggregates. As a result, very few of the sections studied had Nordic Abrasion values for the aggregate utilized. For this reason, comparisons were performed using the LA abrasion values (LAR) reported in the mixture design, along with pavement performance data. Previous ADOT&PF work has illustrated that a solid correlation between LA and Nordic abrasion factors does not exist.

The aggregate abrasion requirement included in standard ADOT&PF paving specifications are generally on the upper end of the AASHTO recommended band. In comparison, for example, the Maryland SHA requires an LAR value of 30 for their SMA mixes. Supplementing the LAR test requirement with Nordic Abrasion testing should result in more wear resistant aggregates. Increasing the level of aggregate hardness required through the application of the Nordic test is expected to result in improved pavement performance. This expectation correlates with the results from the project performance evaluation.

LA Abrasion is a routine test the ADOT&PF performs during the mixture design process. Of the 95 study sections, LA Abrasion values were reported for 76 (80%) of the sections. The reported LA Abrasion values ranged from a low of 11 to a high of 37 as illustrated in Figure 1. It has been found that the LA values do not represent pavement performance. Consequently, it can be concluded that LA Abrasion does not provide a good measure of rut resistance.

The Nordic Abrasion (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). Results from this test indicate differences in the resistance of various aggregates to wear from tire studs, unique from the usual LA Abrasion resistance results. The ADOT&PF recently began performing the Nordic Abrasion testing on a routine basis that will, in the future, provide additional data for calibration of the models presented later in this report. 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 majority of these were for aggregates in the Fairbanks areas. As illustrated by Figure 2, these LA values bear little relationship to Nordic values. Generally NA values are lower than LA values, but in some cases the opposite is true. Neither does there appear to be a consistent relationship between the two values.

Figure 1. Reported LA Abrasion Values

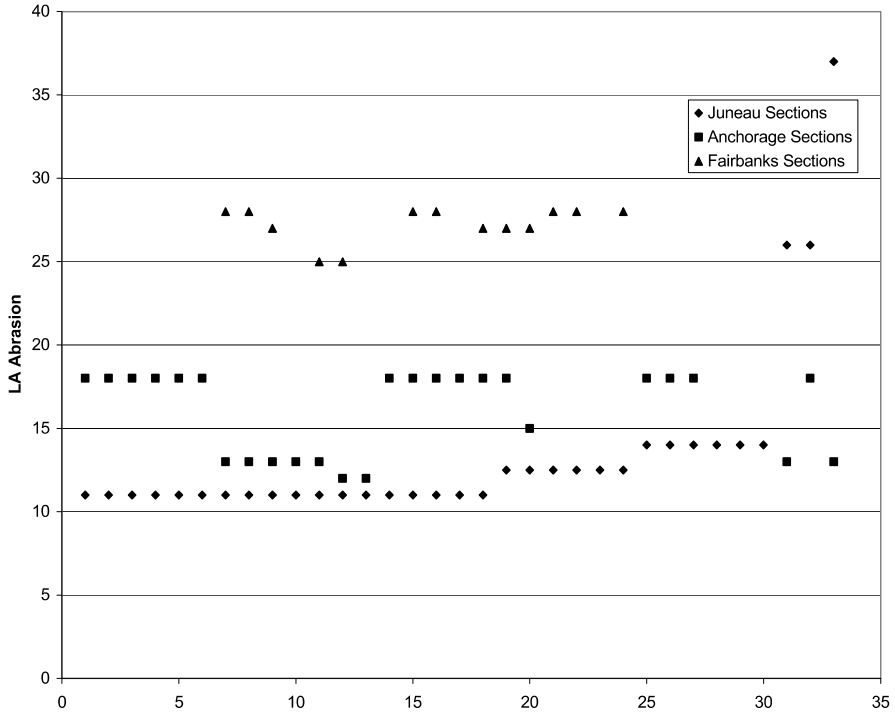
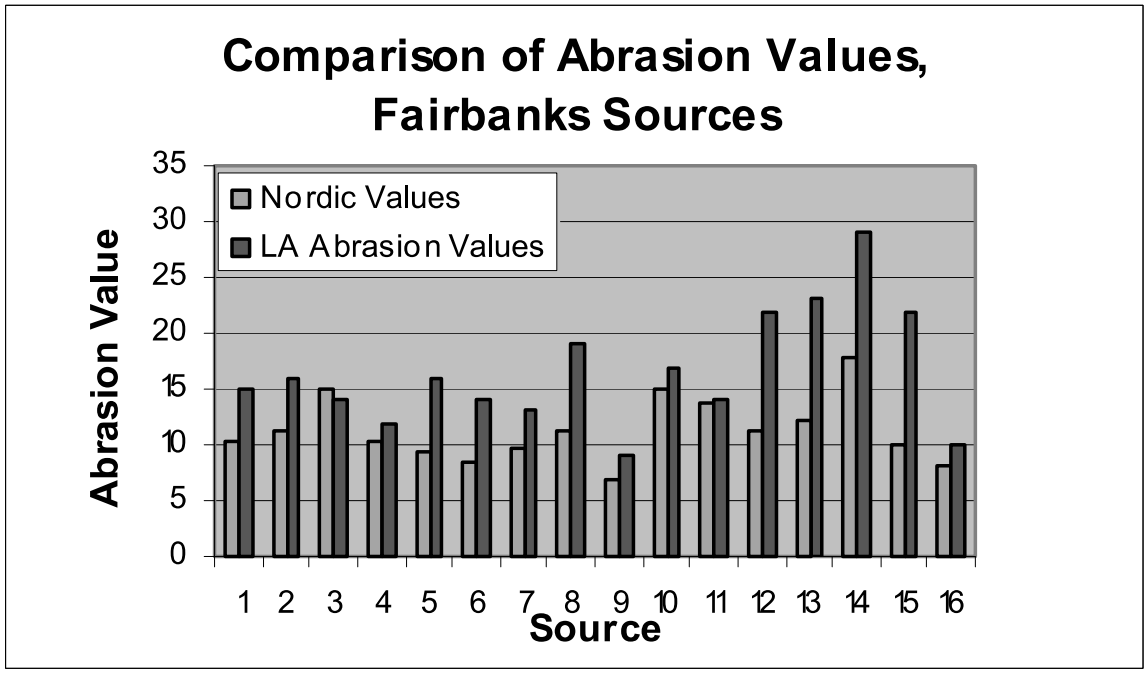


Figure 2- Nordic & LA Abrasion in Fairbanks



Another example from the Oregon study (Elizabeth Hunt, 1998) indicates a lack of correlation of abrasion values between the Los Angeles Abrasion test (LAR) and Nordic tests. While Nordic abrasion values generally tend to be lower than LAR results for the same material, in some cases the Nordic abrasion loss is higher than that from the LAR. Some of the results provided in this report are from Oregon, and others from Alaska, with the same lack of correlation between the two tests results.

The Oregon report, while primarily evaluating the Micro-Deval Test, also concludes that the Nordic values should be used to obtain an indication of studded tire wear resistance. This finding confirms earlier Alaska findings.

The available Nordic Abrasion 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 the ADOT&PF.

Asphalt Grade

The information included in the project database indicates the use of AC-2.5, AC-5, PBA-2, PBA-3, PG 58-28, and two Juneau sections with PG 64-28.

It is recommended that ADOT&PF also review the asphalt material grades being used for hot mix asphalt paving. SMA mixes reviewed in the Anchorage area during the study and standard specifications indicate the use of PG 52-28 material. Based upon conditions at the Fairbanks, Anchorage, and Juneau Airports the following grades are recommended by the LTPP Bind software.

Location	Traffic Level Million ESALs	Reliability Level %	PG Grade
Fairbanks	1	50	46-46
	1	98	52-52
Anchorage	1	50	40-34
	1	98	46-40
Juneau	1	50	40-22
	1	98	46-34
Fairbanks	3	50	52-46
	3	98	58-52
Anchorage	3	50	46-34
	3	98	52-40
Juneau	3	50	46-22
	3	98	46-40

It is notable that only in the case of the 50% reliability in the Juneau area does the low temperature grade of -28 provide adequate low temperature characteristics. The high

temperature grade of 52 provides 98% reliability in all situations above, except the 98% reliability level for the 3 million ESAL level in Fairbanks. The usual practice for constructing SMA mixes is to increase the high temperature binder grade of the material used to aid in the retention of binder film thickness. ADOT&PF should consider this adjustment, if not already implemented. The use of a higher binder grade can be expected to limit high temperature rutting, and therefore total rut depth. Interestingly, two of the Juneau sections with Nordic abrasion values of 8 and very low rutting, were Superpave mixes and also included 64-28 binder material.

As seen in Figures 3A through 3C, the assessment of asphalt grades vs. rut development for the three regions does not appear to vary from region to region. Each test section included in the figure has three chronological data points.

Figure 3A. Anchorage Rutting vs Binder Grade

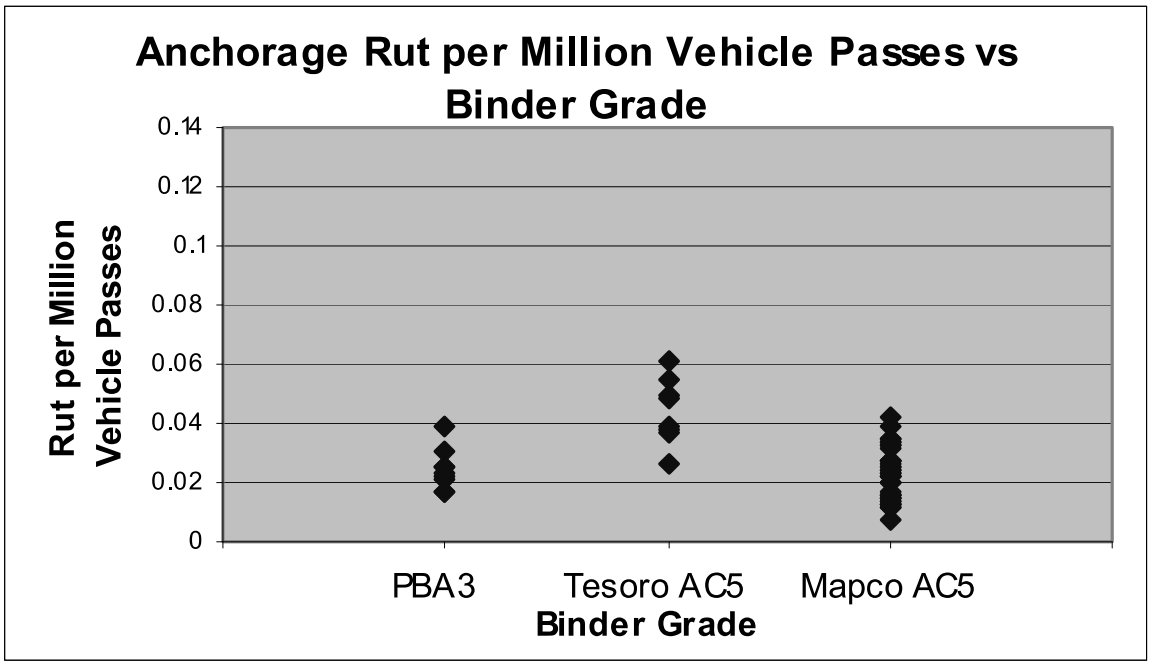


Figure 3B. Juneau Rutting vs Binder Grade

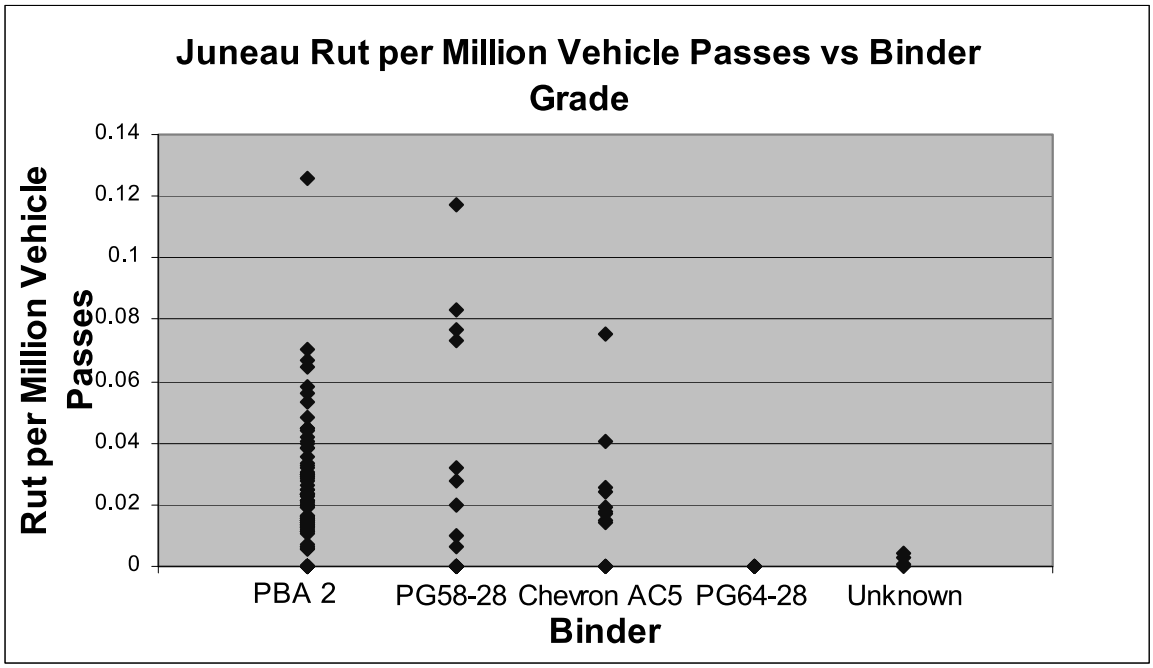
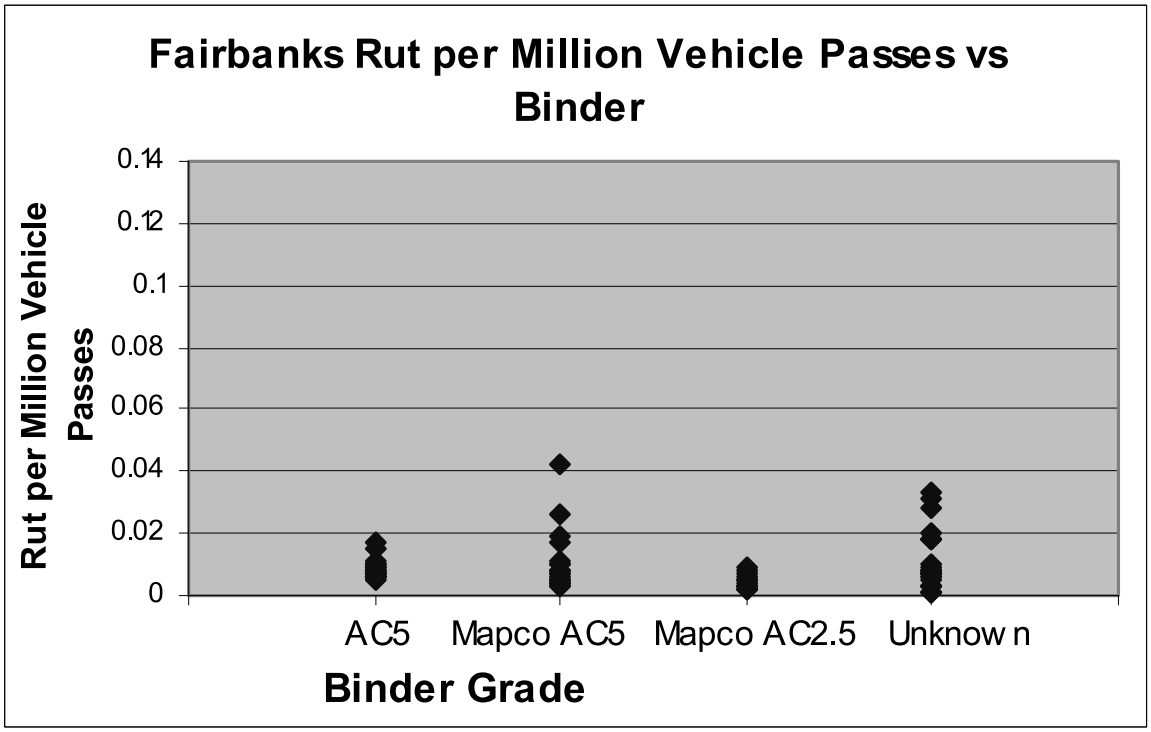


Figure 3C. Fairbanks Rutting vs Binder Grade



The information evaluated supports the lack of relationship between asphalt grade and studded tire wear. No difference in the effect of binder grade is identified between regions. From this, it can be concluded that the effect of asphalt grade upon pavement resistance to studded tires should be eliminated as a primary factor. The performance of the PG 64 high temperature material does appear promising from the limited data available.

Project Database

QES provided a complete Microsoft Access database for the roadway segments studied in this effort. Four tables exist in the database. One table contains specific location information for each segment reviewed. A second data table contains the materials information received from ADOT&PF and local aggregate suppliers. A third table contains all available Nordic Abrasion data collected in Alaska from various aggregate sources, many of which were not represented in the roadways selected for this study. The final table contains all available pavement performance information including rut depth, ride value, and visual rating score. The majority of the performance information was taken directly from the 2001 ADOT&PF pavement management database, however, supplemental rutting measurements have been included for those sections on which additional measurements were made.

ADOT&PF should find this database useful in future rut studies.

TASK 2 - PERFORMANCE VERSUS COST RELATIONSHIP

Task 2 consisted of using the data collected in Task 1 to develop performance trends for existing pavements in Alaska. If correlations between aggregate hardness and wear could be developed for the 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 using the provided Alaska data, then performance models from the Scandinavian literature would be utilized. Task 2 was completed in four major steps as outlined here and discussed in detail in the following paragraphs:

1. Determination of winter wear vs. summer wear,
2. Determination of pavement performance life based on wear rut only,
3. Determination of the cost of hot mix asphalt materials for various aggregate properties in the various Alaskan regions,
4. Assessment of the relative performance trade-off possible using alternative aggregates.

By comparing pavement performance and rut damage trends for the three regions it is possible to examine the effect of winter pavement wear to measure the effectiveness of increasing aggregate hardness. From this, the potential cost benefit of using aggregates with rut resistance characteristics found in the improved aggregates can be identified. This aggregate rut resistance level should be identified by applying the Nordic Abrasion test to aggregate sources within the state. On the basis of this cost-benefit assessment, it

can be determined how much additional transportation cost for aggregates can be justified to offset the costs of pavement damage resulting from the use of studded tires.

Establishment of Winter Wear Rates

The process was begun by identifying the rate of pavement wear assignable to studded tire use. To do this, pavement rut measurement data was obtained from the ADOT&PF. Test measurements made at six 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.

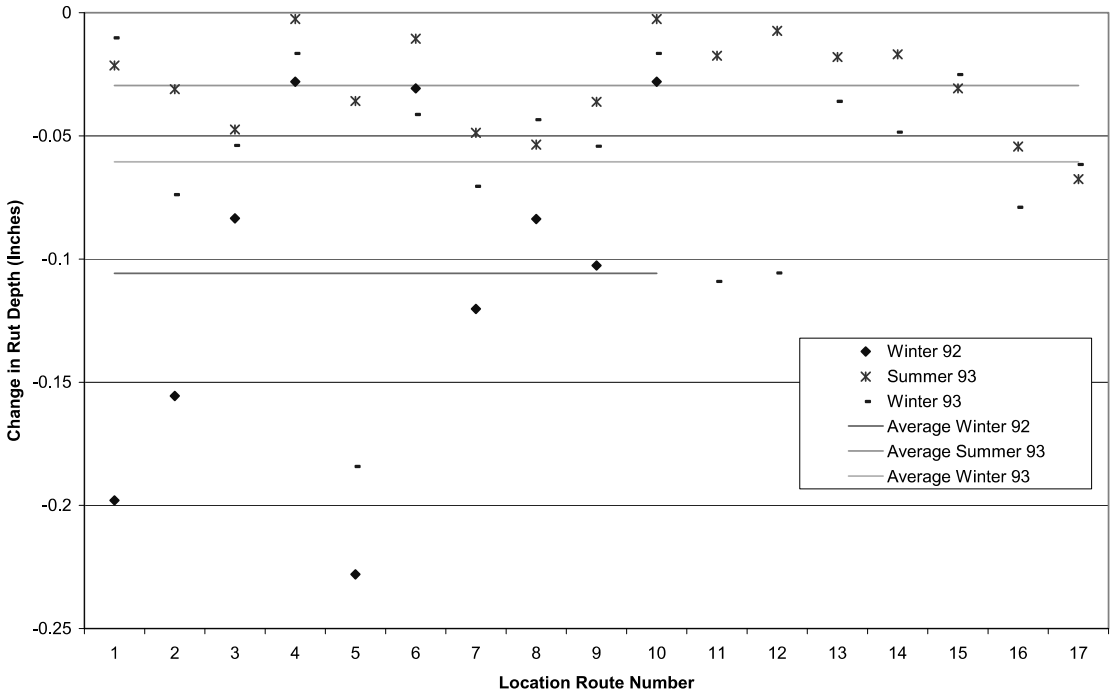
QES utilized previously collected data from a study report entitled "Rut Study" which was completed December 1995. The analysis was performed by Nelson McCullough, Regional Pavement Engineer and Anthony Kim, Central Regional Material Lab. The pavements included in this study were from the New Seward Highway, Tudor Road, Glenn Highway, Muldoon Road and Minnesota Drive, and 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 was collected in the fall of 1992, spring 1993, fall 1993, spring 1994, summer 1994, spring 1995 and fall 1995. No data was collected in the fall of 1994. A total of 17 different roadway segments were included in the study.

This seasonal rutting data was used to determine the typical amount of winter wear occurring on the Alaskan roadways. Figure 4 provides a graphical illustration of the seasonal rutting data for each of the 17 study sites.

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

Since the detailed rut measurement data necessary to perform this assessment only exists 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 4. Seasonal Rutting



Pavement Performance Curves For Wear

As previously stated, approximately 30 roadway segments, as defined in the ADOT&PF pavement management database were selected for analysis from each of three regions Anchorage, Fairbanks and Juneau. The study sections were selected from the routes having the higher AADT values using the premise that the high AADT would provide greater wear. Table 1 identifies the study routes used for the analysis.

Table 1. Study Routes Selected

Road ID	District ID	Functional Class	Maint. Camp	Name
60	2	Interstate	Anchorage	Seward Highway
61	2	Interstate	Anchorage	Glenn Highway
63	2	Principal Arterial	Anchorage	Tudor Road
64	2	Principal Arterial	Anchorage	Muldoon Road
67	2	Principal Arterial	Anchorage	Minnesota Drive (NB)
76	2	Interstate	Anchorage	Ingra Street
77	2	Interstate	Anchorage	5th Avenue (Anchorage)
82	2	Principal Arterial	Anchorage	C Street (Anchorage)
98	2	Minor Arterial	Anchorage	Northern Lights Blvd.
101	2	Minor Arterial	Anchorage	Old Seward Highway (north end)
102	2	Principal Arterial	Anchorage	O'Malley Road
104	2	Interstate	Anchorage	Glenn Highway SB
117	2	Minor Arterial	Anchorage	Dowling Road/Potter Drive
232	2	Interstate	Anchorage	Seward Highway (SB in Anchorage)
69	6	Principal Arterial	Fairbanks	Steese Highway
74	6	Interstate	Fairbanks	Richardson Highway
134	6	Principal Arterial	Fairbanks	Johansen Expy. (Westbound)
135	6	Principal Arterial	Fairbanks	Johansen Expy. (Eastbound)
136	6	Principal Arterial	Fairbanks	Gaffney Rd. (Wainwright Main Gate)
137	6	Principal Arterial	Fairbanks	Airport Way (Fairbanks)
141	6	Major Collector	Fairbanks	Farmersloop Road
142	6	Minor Arterial	Fairbanks	University Avenue
143	6	Minor Arterial	Fairbanks	Peger Road
206	6	Major Collector	Fairbanks	Chena Ridge/Chena Pump Road
418	6	Interstate	Fairbanks	Richardson Highway, SB, Fairbanks/NP
615	6	Principal Arterial	Fairbanks	Geist Road, Fairbanks
616	6	Principal Arterial	Fairbanks	Geist Road (EB), Fairbanks
47	1	Minor Arterial	Juneau	North Douglas Highway
48	1	Principal Arterial	Juneau	Thane Road
49	1	Major Collector	Juneau	Mendenhall Loop Road
49	1	Major Collector	Juneau	Mendenhall Loop Road
50	1	Major Collector	Juneau	Lemon Road
51	1	Major Collector	Juneau	Twin Lakes Drive
54	1	Principal Arterial	Juneau	Glacier/Douglas Highway (Juneau)
56	1	Principal Arterial	Juneau	Egan Drive (Juneau) SB
57	1	Principal Arterial	Juneau	Egan Drive (Juneau) NB
144	1	Major Collector	Juneau	Yandukin Drive
145	1	Minor Arterial	Juneau	South Douglas Highway

The pavement performance mechanism of interest in this study is rut depth. The data provided by the ADOT&PF contained rut depth values for the years 1998, 1999, 2000, and 2001, therefore only this time frame was considered. In addition to rut depth, traffic volumes, in the form of AADT, were provided for 1998, 1999 and 2000.

The remainder of the analyses is based upon traffic volumes or vehicle passes. Unfortunately, precise information identifying the portion of studded tire passes is not available. According to ADOT&PF personnel, the percentage of vehicles using studded tires may be lower in Fairbanks than the other regions, although they could not provide actual percentages.

Figure 5 is the result of summarizing the provided rut and traffic data. The figure shows the progression of rutting in each region with respect to the cumulative traffic volume.

From this information, it is evident that the rate of winter pavement wear is less for pavements in the Fairbanks region, even though this is the northernmost region included in the evaluation, and accordingly can be expected to have maximum winter weather. Winter wear rates identified in the Anchorage and Juneau regions are approximately 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 LA Abrasion values (Figure 1) this cannot be the logical explanation. In discussion with ADOT&PF personnel, there is something else limiting the rate of wear in the Fairbanks area, although no one is certain as to what this might be. Speculation has consisted of lower percentage of studded tires, less bare pavement time, fewer freeze-thaw cycles, and extreme cold resulting in higher material stiffness to mention a few possibilities. In any event, it is apparent that there is not a significant studded tire wear problem in the Fairbanks region, and this has not been related to aggregate hardness. At this point, the Fairbanks data was eliminated from further study or consideration.

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

The Nordic countries have developed specifications for various traffic levels based upon the Nordic Abrasion Tests. The specification is provided in Table 2.

Table 2. Nordic Abrasion 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
Non Classified	30	NA

Figure 5. Rutting vs Cumulative Traffic by Region

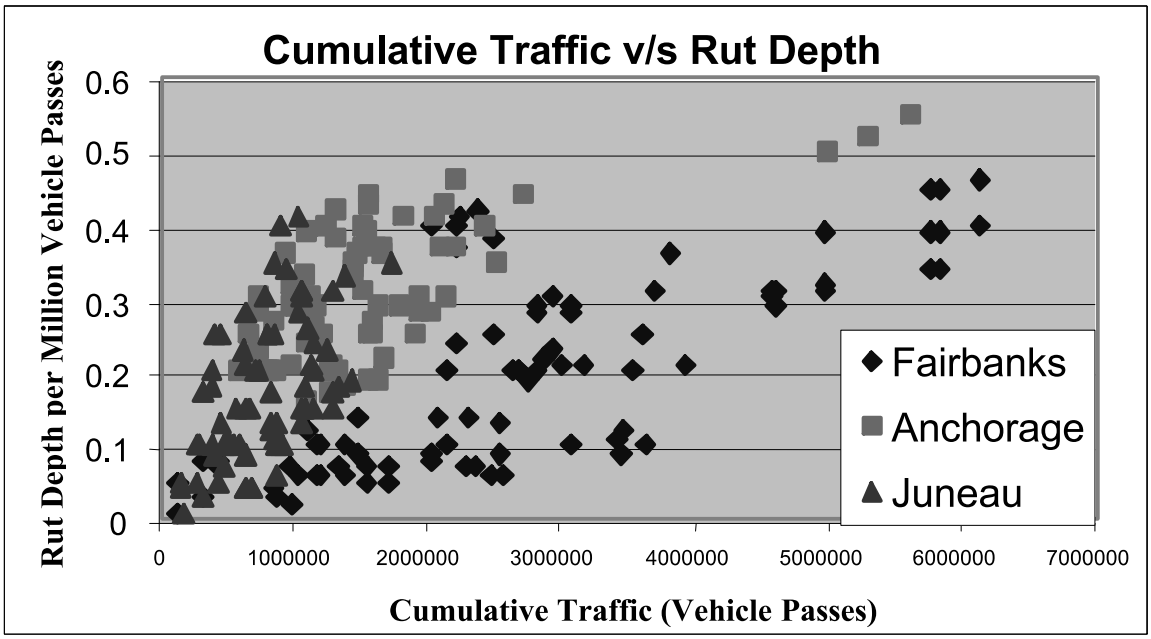


Figure 6 visually represents this specification. Performance models for each classification above can be developed, on the basis that each specification level will limit the amount of annual wear on a particular roadway. For example, if a Class III roadway has a Nordic Abrasion (NA) equal to 14, then 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. If however the AADT double to 5,000, logically then, the wear would double as well (to 2 mm). Likewise, if a roadway classified as level I has a NA value of 7 and only experiences 5,000 vehicles per day, then the anticipated wear would be one-half of that expected. This effort results in the performance models based upon traffic levels as illustrated in Figure 7. 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 upon the implementation of this specification and the use of high quality aggregates.

In an effort to calibrate these models to Alaskan roadways, data provided by the ADOT&PF was plotted as illustrated in Figure 8. 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 utilized in the 2000 overlay. The New Seward Highway study was reported by Eric Johnson and Dan Pavey in a ADOT&PF report dated May 2000. This study consisted of controlled test panels constructed with both typical and high quality aggregates. The general study data consists of Pavement Management System (PMS) information for roadway 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.

Figure 6. Nordic Abrasion Specification

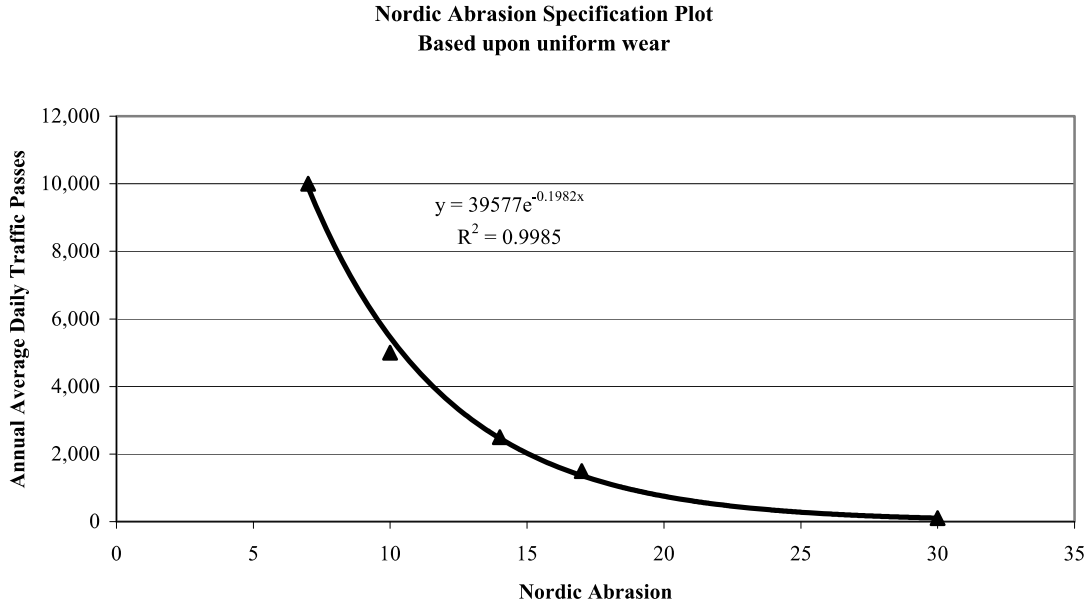


Figure 7. Estimated Performance Curves Based Upon Nordic Specifications

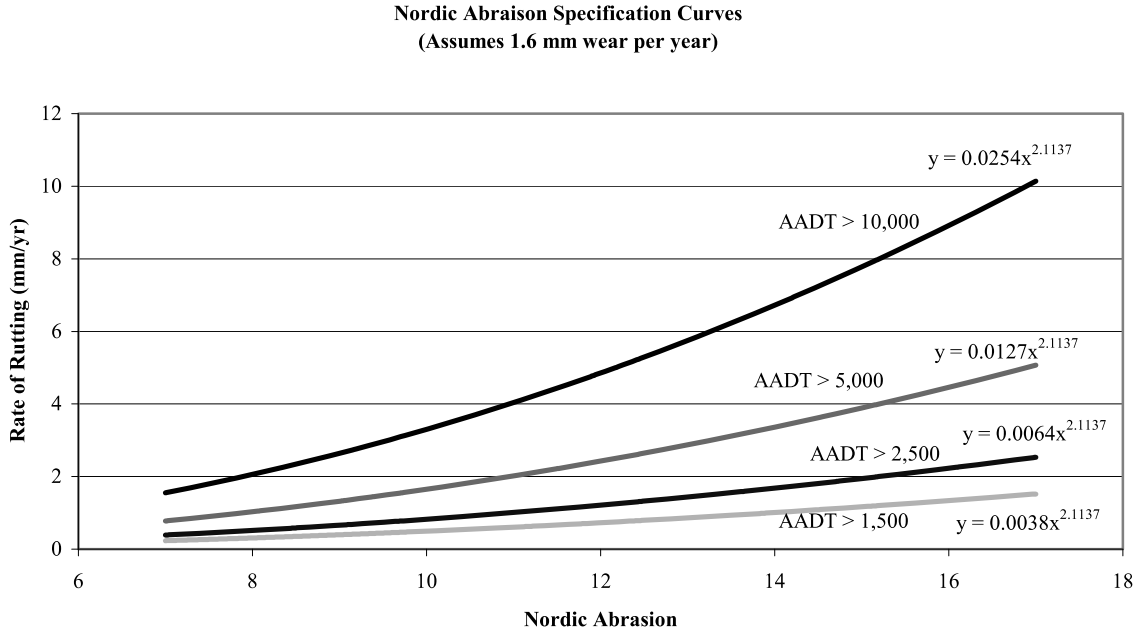
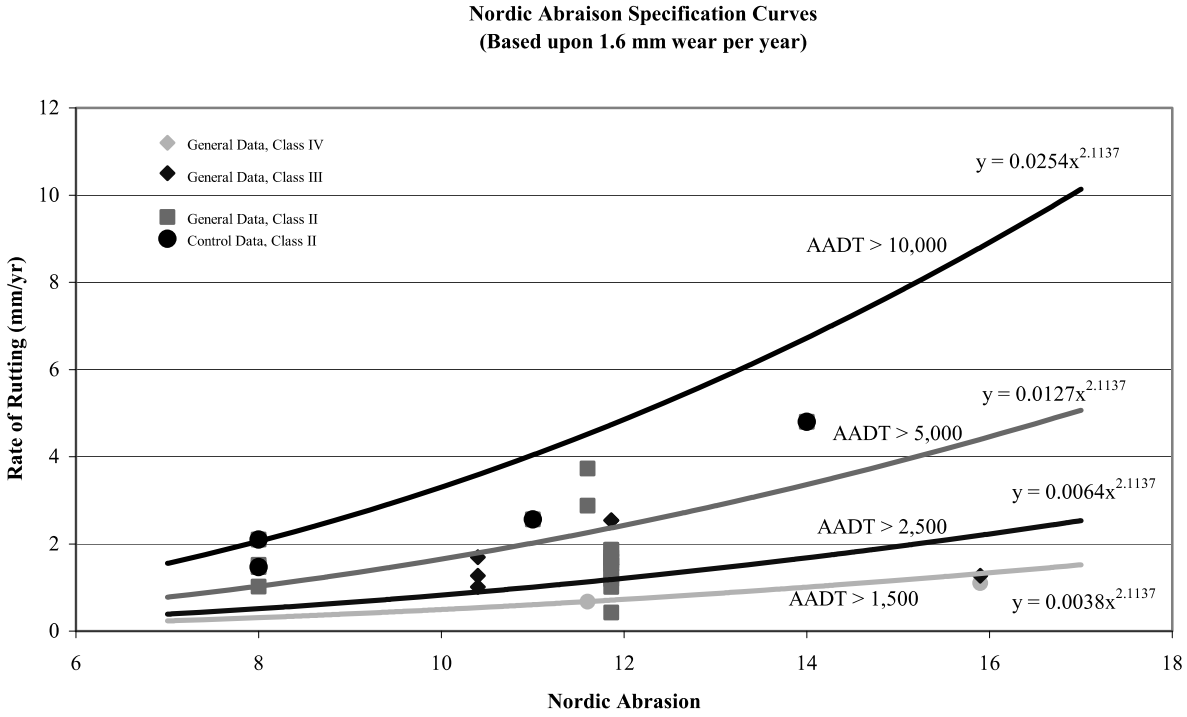


Figure 8. Calibrated Performance Curves Using Alaska Data



Based upon 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. Obviously, 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

The relative pavement performances of the selected sections in the Anchorage and Juneau regions are provided in Figures 9A and 9B. These figures illustrate that the difference in rut performance not only exists between regions, but also that these differences correlate strongly with the construction year (age of the system). On average, as illustrated in Tables 3A and 3B, the performance of sections from these Alaskan regions based on rutting rate is:

- Anchorage 12.6 years
- Juneau 12.8 years

Pavement performance life predictions have been developed from these data fits for each of the regions. Alternative pavement life predictions are available depending on the functional rut depth criteria selected. The above estimates are based entirely upon the prediction models generated to achieve 0.5 inch rutting.

Further breakdown of performance by mix type is provided in Tables 3A and 3B. The majority of sections evaluated in Anchorage are SMA mixes. These have a slightly shorter life expectancy, based on rutting only, than either the overall average or that representing other mixes. The rut resistance performance expected from SMA mixes is less than for Type II mixes. The increased exposure of aggregate on aggregate and to traffic contact inherent in SMA mixes, without including more durable aggregate requirements is likely responsible for this decrease in performance.

Table 3A: Performance by Mix Type for Anchorage

Anchorage					
Mix Type	Predicted Life (M Vehicle Passes) (0.5" Total Rut)	AADT Avg	No. of Sections	Life Years	R-sq
SMA	35.56	9973	24	9.77	0.25
Type II *	51.41	7798	7	18.06	0.40
Average	41.5			11.44	
Overall	44.35	9836	25	12.59	0.43

*Includes one section of Plus Ride-Crumb Rubber Asphalt, two Type I, and four Type II mixes.

Table 3B: Performance by Mix Type for Juneau

Juneau					
Mix Type	Predicted Life (M Vehicle Passes) (0.5" Total Rut)	AADT Avg	No. of Sections	Life Years	R-sq
AC Type II	22.3	5024	25	12.81	0.28
Overall	22.3	5024	25	12.81	0.28

Figure 9A-1. Overall Performance Prediction (Anchorage)

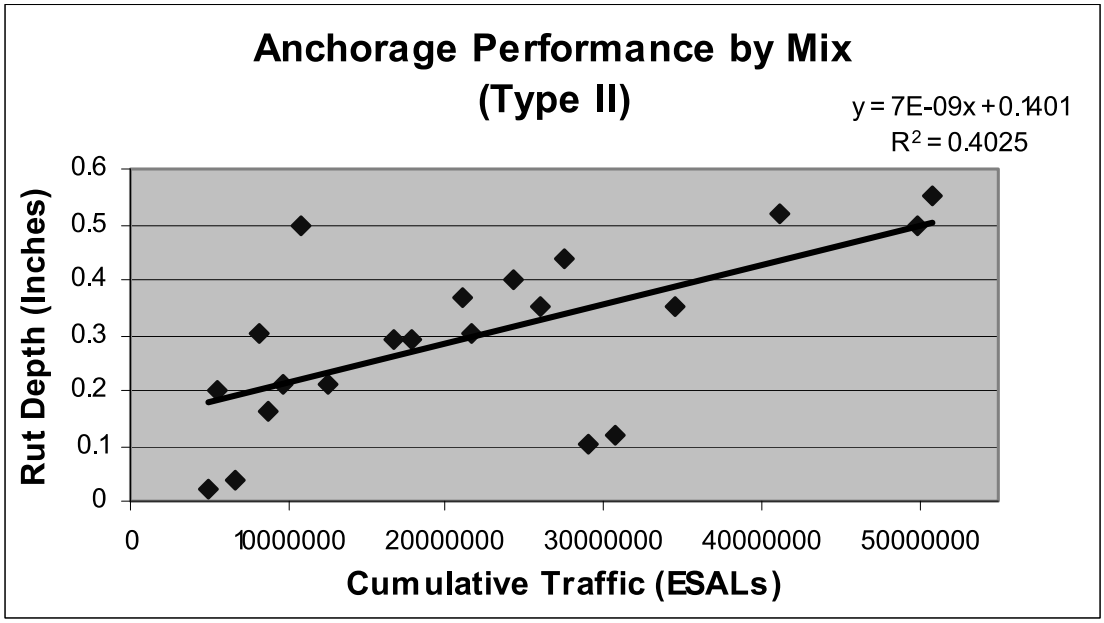


Figure 9A-2. Performance Predictions by Mix Type (Anchorage – SMA)

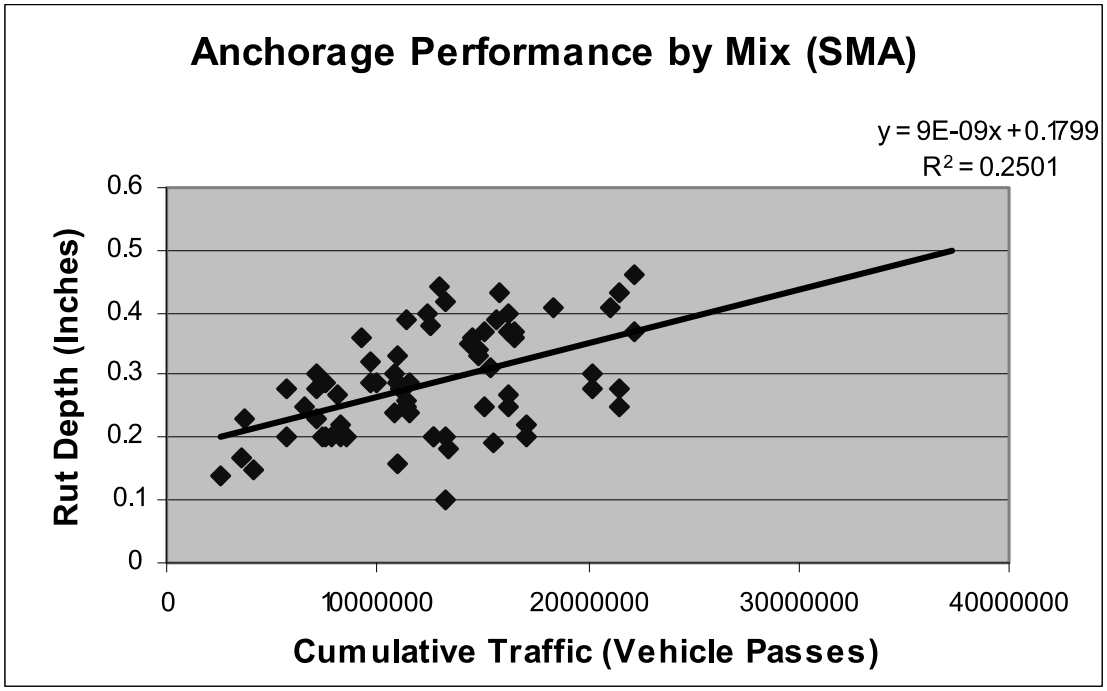
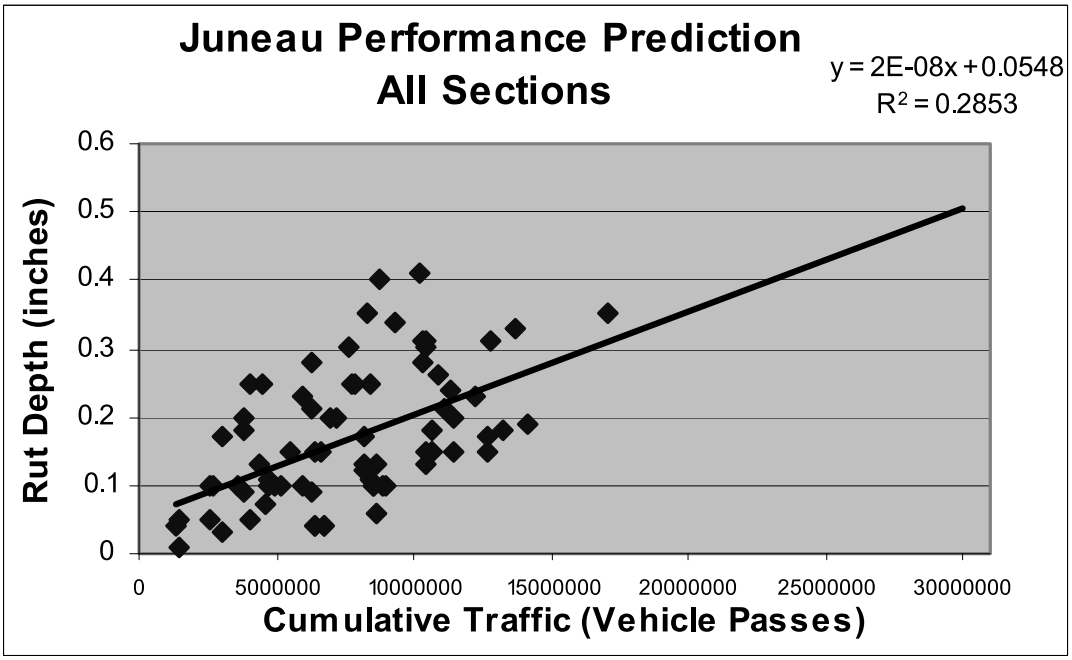


Figure 9B. Overall Performance Prediction (Juneau)



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 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 rather 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.

For the remainder of the analysis the same criterion, based upon 0.5" total rut depth, has been used. This limit is considered by many organizations, including ADOT&PF, as a safety threshold for rutting.

When considering the significance of these pavement rut (wear) development predictions, it is important to also 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 (TSI) 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:

Region	Years to a TSI of 2.5
Anchorage	17.5
Juneau	24.6

From this information, it can clearly be seen that longer life can be expected if the winter wear problem can be solved, or not considered. The importance of this information arises when considering the improvement in overall pavement performance to be attained by utilizing harder aggregates. What is conveyed is that the performance of pavements in Anchorage and Juneau can be increased by a factor of 1.5 and 1.8, respectively.

Performance Comparisons

The performance models in Figure 8 can be used to directly compare the anticipated wear performance of various levels of aggregate hardness. When an improved aggregate is compared with the typical regional performance, Figure 10 is used. Figure 10 illustrates the relationship between aggregate quality and the predicted rate-of-rutting (RR) of the typical pavements studied in the Anchorage and Juneau areas. This plot is based upon the typical NA value in Juneau, of blended aggregates, being equal to 11.6. This value was determined by averaging NA values from 27 roadway segments in the Juneau region that had NA values reported by the ADOT&PF. The Anchorage relationship is based upon the typical 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 in which

they stated “The Ball Mill Value of the Valley aggregate is 11 (Level III of the Nordic specification).”

Figure 10 provides the predicted change in the 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 8. This RR becomes the baseline for comparison. When an aggregate with a NA value other than the typical is used, a new RR is calculated, again using the same performance curve from Figure 8. 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 resulting in the percent change in RR. By varying the NA value of aggregates and repeating this process the curves illustrated in this figure are created. The performance models presented in Figure 8 all have a consistent exponent, with varying 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 10 is not dependent upon the class of roadway in question.

For example, in Anchorage, the typical aggregate has a NA value of 11.0 and if used on a class II roadway, the predicted RR would be 2.02 mm/year. If we wish to compare an aggregate having a 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 we can say the RR is reduced by 35% when an aggregate with a NA of 9 is used as compared to the typical aggregate having a NA value of 11.

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

Figure 10 is used to determine the predicted improvement to rate of rutting (RR) for various Nordic Abrasion values. This figure must be created for each individual region of Alaska based upon the typical NA value for that region.

Cost Analysis

Table 4 performs a calculation of the expected rutting life for improved aggregates by entering a NA value for the improved 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 10. A justified cost increase is also calculated in Table 4. This justifiable cost increase can be illustrated as shown in Figure 11.

As actual aggregate importation costs are determined for each region, cost trends such as illustrated in Figure 12 can be developed. Provided in this figure is the relationship between in-place 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 such that wear will not be the failure mode of

the pavement. Thus, the predicted life is based upon other failure mechanisms, such as fatigue cracking, and aggregate hardness no longer needs to increase.

Figure 10. Predicted Change in the Annual Rate of Rutting for Anchorage & Juneau Pavements

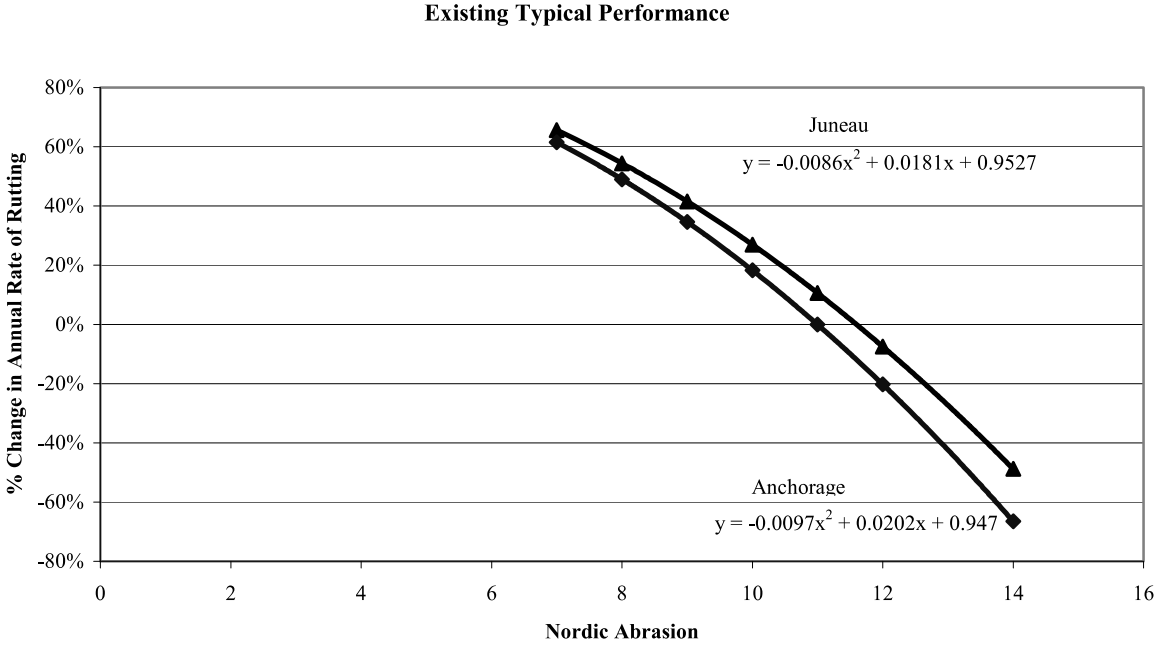


Table 4. Cost Calculation Table

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%

Figure 11. Example of Justified Cost Increase, Anchorage

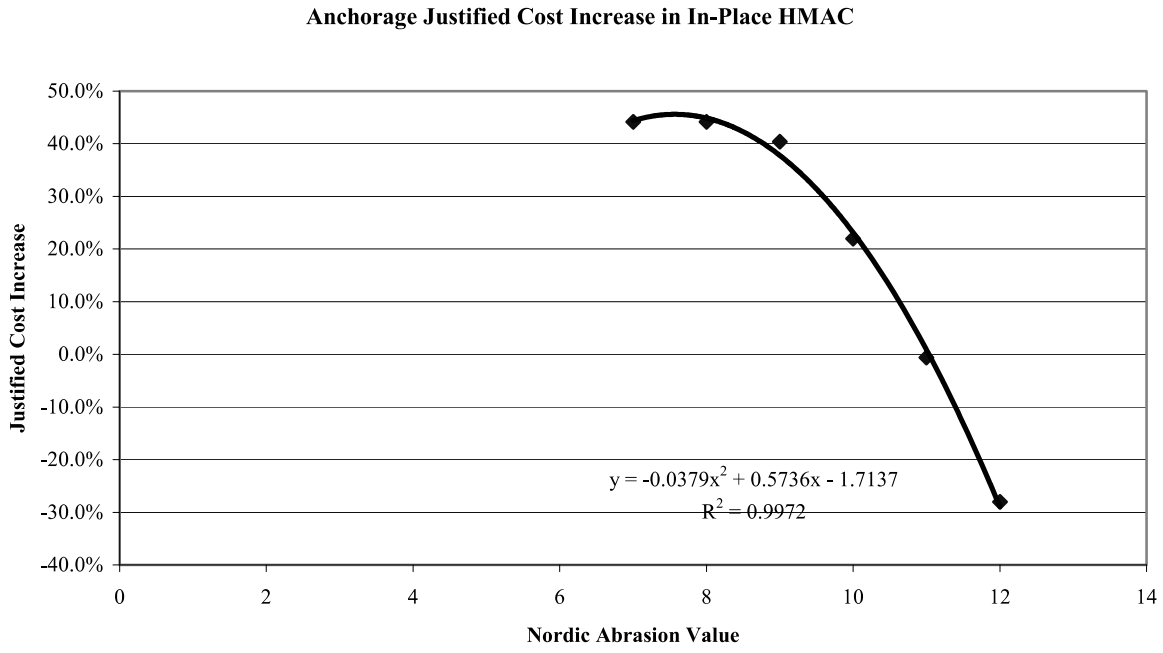


Figure 12. Life Verses Cost Curve for Example Cost Data in Anchorage

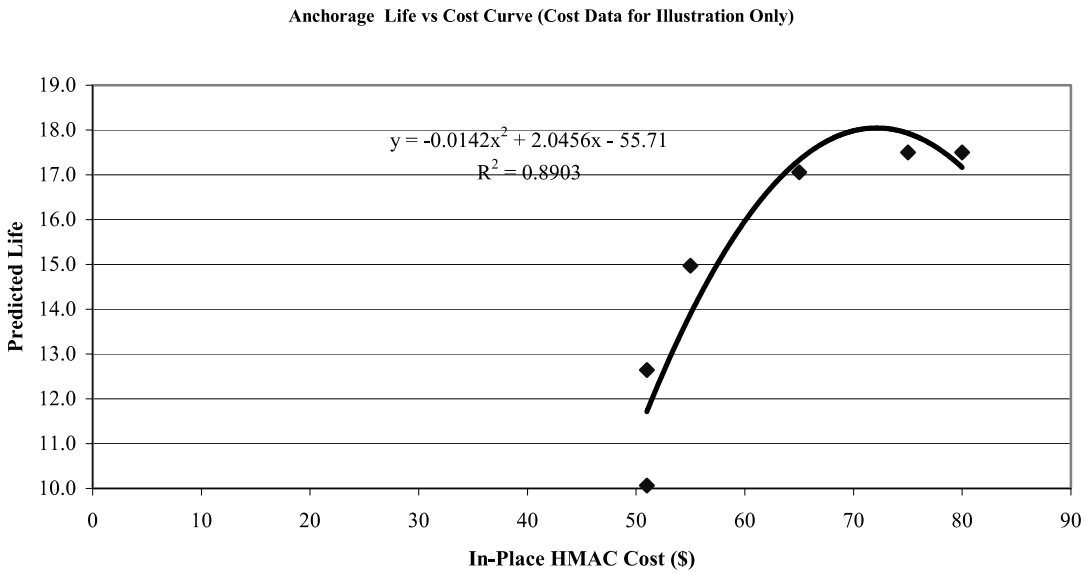
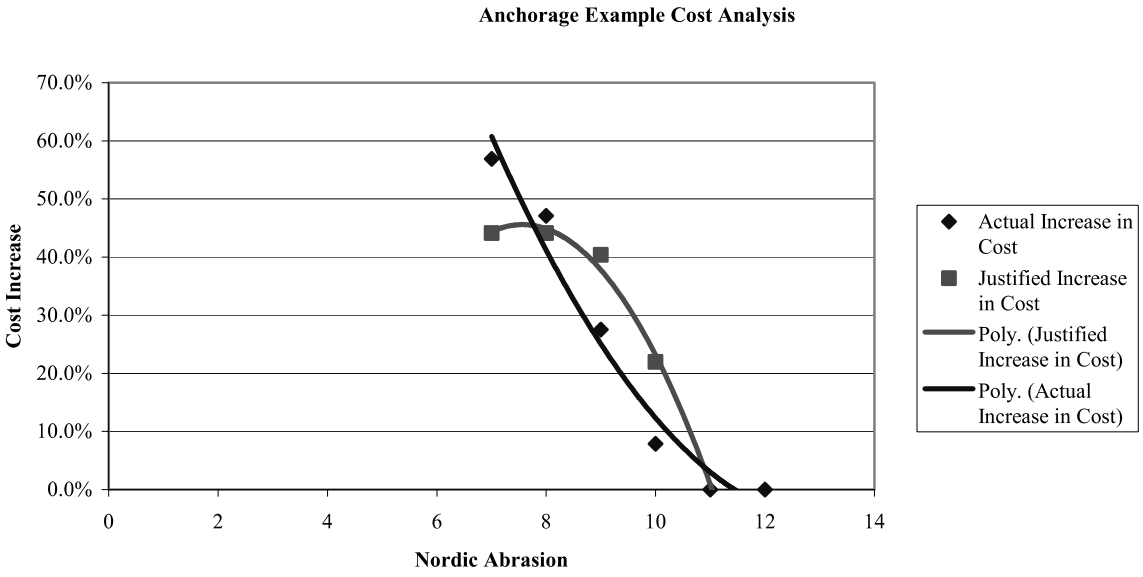


Figure 13. Example Cost Comparison



As a final step, for a specific project, given the optional aggregate hardness and cost values, a direct cost comparison can be illustrated, as shown in Figure 13. Compare the justified cost increase to the actual cost increase for the optional improved aggregate. If the ratio of the justified cost to the actual cost is greater than one, then the optional improved aggregate should be used. If, however, the ratio of justified cost to actual cost is less than or equal to one, then the original aggregate would prove to be more beneficial. In Figure 13, those aggregates with an actual cost increase less than the justified cost increase (where the actual line is below the justified line) would be cost effect to import.

Using the above noted performance predictions, and the cost information provided in Table 5, relative cost effectiveness was developed for mixes in the three regions.

Some relative difference in hot mix asphalt costs has been identified between the regions. Surface pavement material, assuming a two-inch surface thickness, is estimated as between $31/ton in Anchorage and $52/ton in Juneau for Type II material. SMA mixes, in Anchorage, range from $51-63/ton.

By comparing the adjusted mix costs (based on potential pavement life) for Anchorage and Juneau versus that for higher quality aggregates, the potential additional investment in harder aggregate can be determined. This is based on the finding that the use of harder aggregates improves pavement wear resistance and consequently pavement performance.

Table 5. In-Place HMA Costs by Region

Region	Mix Type	Costs of In-Place HMA Material/Ton	Cost of AC	Cost of Agg [1]	Percent of Agg Cost to Total Cost
Fairbanks	Various	$41.87	$14.00	$27.87	67
Anchorage	SMA	$50.98 (-63.11)	$20.28	$30.69	60(-66)
Juneau	Various	$52.35	$13.50	$38.85	74

Note 1: The Cost of Aggregate includes all costs associated with aggregate purchasing, HMA mixing, transportation, laydown and compaction.

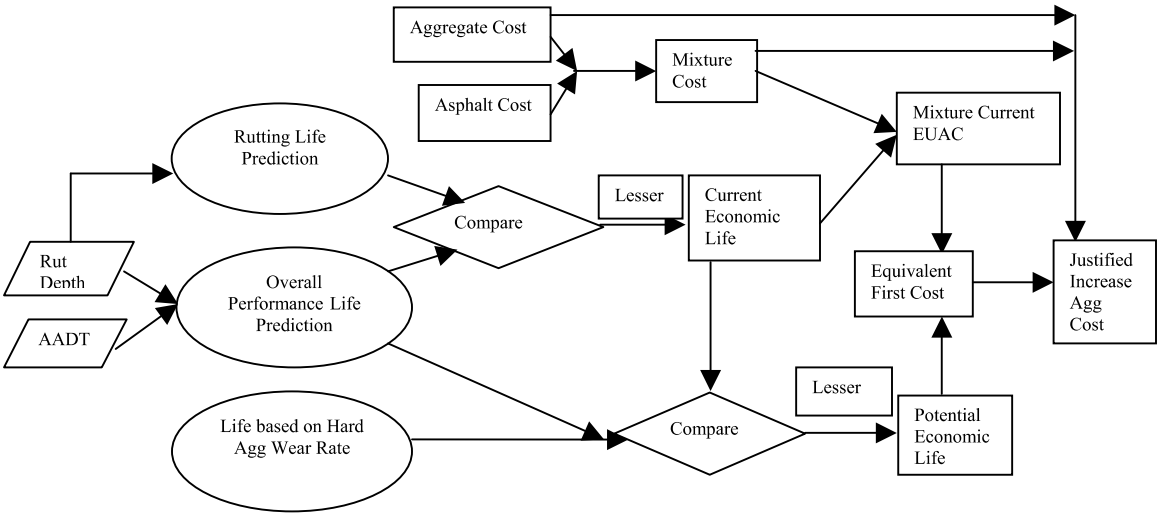
Using existing typical aggregate costs as the standard, comparative potential costs for improved aggregates in Anchorage and Juneau for Type II mixes are computed. The procedure for performing this calculation is illustrated in Figure 14 and previously illustrated in Table 4.

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 upon other factors, assuming that rutting failure is eliminated by increasing aggregate hardness, is important. This then 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.

Detailed explanation of the cost analysis methodology is contained in Appendix A.

Figure 14. Flow Diagram of Economic Analysis Process



Obstacles to implementation

While these relationships provide clear evidence that the rut resistance of pavements can be increased by the use of harder aggregates, and that the expenditure of increased cost for aggregate can be justified, there are other obstacles to implementing such a change in ADOT&PF policy.

Importing aggregate is likely to not only result in some increase in the cost of hot mix asphalt, but also will impact local contractors and aggregate producers. Local aggregate producers will lose this portion of their market, while the DOT can expect to experience an increase in hot mix asphalt costs. At present, it is unknown how the loss of this portion of aggregate business will impact the local producers. It should be noted however, that only the wearing course of the pavement structure would require the improved aggregate material. This significantly reduces both the cost impact to ADOT&PF and the impact on the local aggregate suppliers.

The ADOT&PF must find ways to implement the indicated changes. Two options appear to be available: provide sufficient incentive to contractors to import the higher quality aggregate, or based on the ADOT&PF economics, mandate the use of higher quality material by the adoption of restrictive specifications.

Elements of Aggregate Importation

Aggregates can be imported to the Anchorage and Juneau areas either from within Alaska, or from outside the state. A significant difference was identified in aggregate

prices at the plant received from suppliers in the three different regions. Costs for aggregate at the plant were reported as:

Fairbanks	$9.15/ton
Anchorage	$14.25-16/ton
Juneau	$15.00/ton

Typical trucking costs obtained from producers in each region are provided below. These have been calculated from hourly trucking rates, assuming an average of 50 mile per hour haul speed, and are averages from 10 to 20 ton trucks, depending upon the individual source. The second cost provided in the above table, represents costs for the larger haul units, which generally appear to be more economical (in dollars per ton) where feasible.

Region	Trucking Cost in $/mile
Fairbanks	$1.50-$1.80
Anchorage	$1.52
Juneau	$1.30-$1.80

Transporting Aggregates Within Alaska

Cost information was solicited from local aggregate suppliers in each region. When considering the cost of transporting aggregate via rail or highway to areas within Alaska, we must account for the cost of the aggregate and the transportation of such material. For example, if a high quality aggregate source is located in the Fairbanks area, this material could be provided to a job site in Anchorage for approximately $45/ton, which could be within the justified cost increase. This $45/ton was estimated assuming 18-ton haul units, resulting in a hauling costs of $30/ton plus the "at plant" cost of $15/ton.

Aggregate Availability Outside Alaska

Based on past project efforts, QES has identified the potential for importing aggregates from Vancouver, BC, or from the Seattle, WA area. We have been informed that very high quality materials can be shipped by barge to Anchorage, for example, for about $14/ton, which is slightly less than the cost of aggregate at the quarry in Anchorage and Juneau. This cost is based upon the use of 60,000 ton super-barges. As in many other instances of economic exchange with Canadian provinces, the monetary exchange rate enables Canadians to provide product at a relatively low cost, in U.S. dollars.

Contractors in the Juneau region have been using Western Towboat out of Seattle. Western Towboat has used 6,000 and 10,000 ton barges to transport material from the Glacier Northwest site at Dupont, Washington. The delivery cost of this material is approximately $12 per ton. Thus, it appears to be both feasible and cost effective to import aggregate into Alaska from the Pacific Northwest Region.

Several aggregate sources in the Vancouver area have very hard aggregates, based upon L.A. Abrasion results of a variety of mineral types. Some of these sources provide

granites or basalts for example. It is a common practice for these sources to ship aggregates to west coast destinations by barge, and shipment to Alaska should be equally available. There may also potentially be other competitive aggregate sources available in the Seattle, Washington area and along the Columbia River basin in Oregon.

Some examples of potential material sources are;

Source Type	Mineral	L.A. Abrasion
Lafarge at Earl Creek	granite	14
Pit River at New Westminster	granite	10-11
Jack Cewe at Jervis Inlet	granite	14
Texada Island	granite	unknown
Ocean in Sechelt	granite	unknown

These very hard granite aggregate materials can be expected to provide improved studded tire resistance. It is recommended that ADOT&PF test some of these sources for studded tire wear resistance using the Nordic Abrasion test, to verify that they can provide improved pavement performance.

Seaspan International LTD is a Vancouver based barge company. They do ship these aggregates to west coast destinations in the states of Washington and California. Depending upon location, and barge access, material can be shipped in 8,000, 16,000, and the new 60,000 ton barges. The delivery of very cost competitive aggregate material is the result.

Additional transportation costs on land have been identified as indicated above for trucking. For example, barge shipment is potentially available to Seward, Whittier, and Valdez. Based on approximate trucking distance from these ports to Anchorage, additional costs of trucking can be computed as:

Location	Distance Miles	Haul Cost $/ton[1]
Seward	125	13.57
Whittier	60	6.51
Valdez	300	32.57

Note 1: Costs based on 14 ton haul units

Based on the haul distance, it would be best to barge to Whittier, but Seward could also be feasible. Using the barged aggregated cost of $14/ton plus the trucking cost of $6.51, aggregate in the Anchorage area could be delivered to a project site for $20.51/ton, well within the justified additional aggregate cost increase discussed above.

Similarly, if aggregate is shipped to Seward, the estimated cost of delivery to the Anchorage area is $14 plus $13.57 for a total of $27.57/ton, also well within the justified aggregate cost increase.

Similar costs computation can be made for providing the Vancouver materials to Juneau. Since barge shipping directly to Juneau is feasible, an average haul distance of 6 miles is assumed. Using a cost of $1.50/mile for a ten-ton haul unit, this would add $9 to the cost of project available aggregate, for a total of $23. Again, this would be well within the justifiable cost increase for aggregate material in the Juneau area.

CHAPTER 3 - CONCLUSIONS AND RECOMMENDATIONS

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. Four 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,
3. Studded tire wear can be reduced in the Anchorage and Juneau regions with the adoption of the Nordic Ball Mill Specification, and the recommended cost analysis methodology
4. Transporting and importation of harder aggregates appears to be cost effective.

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. Since 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 the ADOT&PF are summarized below:

- Implement the Nordic Ball Mill Specifications on roadways with volumes exceeding 5000 AADT, and other roadways showing excessive wear.
- Perform additional wear studies to further validate the performance models illustrated in Figure 8.
- Utilize harder aggregate requirements for pavement surface courses only.
- Provide information to hot mix producers regarding the availability of harder aggregate materials in the Vancouver, Canada and Pacific Northwest regions available at reasonable costs by barge.
- ADOT&PF should evaluate some of the potential aggregate sources inside and outside of the state for properties, particularly including the Nordic Abrasion Number.
- Review the Performance Graded asphalt binder selection criteria for low temperature binder selection to assure maximum benefit is being achieved from pavement investment.
- For highways with 1 million or greater design ESALs in colder climates such as Fairbanks, increase the high temperature binder grade.

- Develop a strong partnering program with the hot mix and aggregate production industries within the state in the implementation of the aggregate requirement changes. Emphasize the benefits in pavement resistance to studded tires available.

One of the most critical elements in improving the pavement wear resistance of Alaska highways will be implementation of changes to the current specifications and processes for procuring aggregates for hot mix asphalt. It will be important to partner with the industry in accomplishing these significant changes. Certainly some loss of market share is likely to be experienced by local aggregate producers in the Anchorage and Juneau areas, even though the recommended changes only affect the wearing surface. Also, some additional cost for in-place hot mix pavement surface is to be expected. A careful process for overcoming these barriers to implementation is needed. The analysis shows that the benefit to ADOT&PF in the form of pavement performance significantly exceeds the anticipated cost of harder aggregates in the state's more southern regions.

Sharing information with the hot mix producers regarding the availability and transportation of aggregates from other areas will be important to successful implementation of harder pavement aggregate requirements.

It is recommended that the harder aggregate requirements be implemented on roadways with traffic volumes exceeding 5000 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 herein is only applicable to surface course paving. Other layers can continue to utilize locally available materials. The effect of this is to minimize the loss of market share experienced by local aggregate producers, and minimize the increased cost to ADOT&PF.

Prior to implementing a specification based upon Nordic Abrasion 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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APPENDIX A - DETAILS OF ECONOMIC ANALYSIS OF AGGREGATE BENEFITS

Project Background

The Alaska DOT, as well as numerous other agencies found in the literature, has experienced extensive problems with pavement wear resulting from the use of studded tires. Alaska, following the lead of some Scandinavian countries, is interested in improving pavement wear resistance by utilizing harder aggregates in their pavement mixes. The challenge addressed herein is to identify the potential cost effectiveness of such action. 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 hard and durable to resist this surface abrasion problem. Therefore, the economic benefit of transporting aggregates, in terms of pavement performance, must be evaluated.

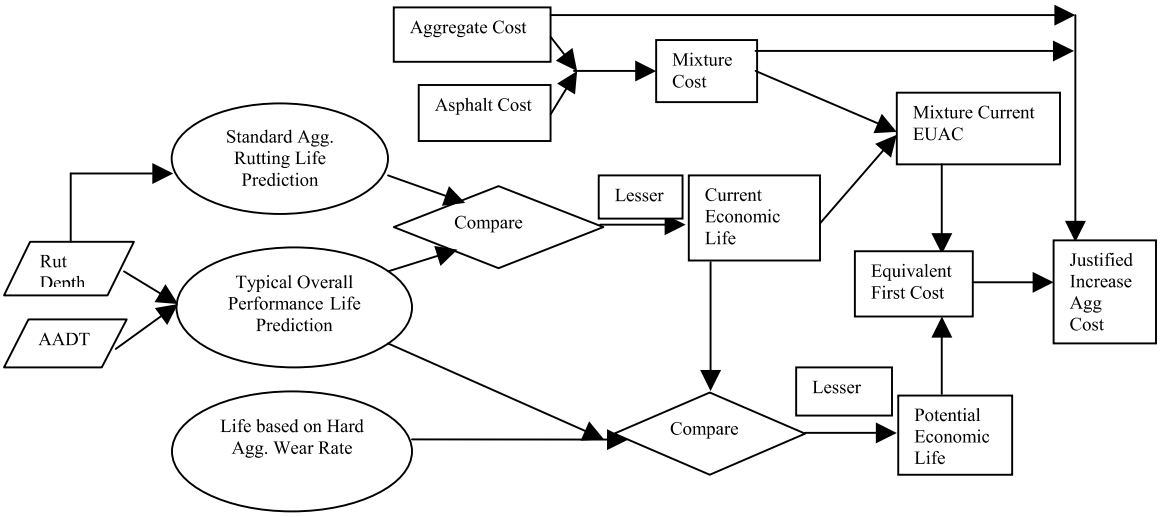
Project Scope

The primary objective of the study was to evaluate the economic feasibility of transporting high-quality aggregate for use in HMA surfacing. A secondary objective was to provide the ADOT&PF with a method of performing the benefit/cost analysis such that it can be used for future aggregate movement studies into other areas of the state. The scope of this document is to provide the methodology developed for achieving the cost evaluation.

Methodology

The methodology used for comparing the cost effectiveness of using harder aggregates is based upon comparing the performance life of the standard aggregate (that aggregate typically used within a region) to the expected performance of the improved aggregate. The improved life is then compared to the cost increase of the improved aggregate, thereby determining the cost benefit. Assuming the studded tire wear is reduced with the harder/higher quality aggregate, there still remains a point at which that pavement will reach its terminal serviceability life, based upon other distresses, such as roughness or cracking. Therefore, the predicted life with the higher quality aggregate is compared to the terminal serviceability life of the pavement. Engineering economic evaluation techniques are then used to quantify the relative cost benefit of improving aggregate hardness in each region. The cost benefit in each region is evaluated by comparing the performance of the typical regional pavement against the predicted pavement performance using improved aggregates. The flow chart below outlines the steps required to complete the assessment.

Figure A1: Flowchart Showing Economic Analysis



Step 1: Using the AADT, the failure rut depth and terminal serviceability index (TSI), determine the performance of standard pavements within each region. Determine both the standard life to rutting failure and the standard life to TSI, excluding rutting.

Step 2: Predict the change in the rate of rutting using higher quality aggregate. A performance model based upon rut depth and NA values is required.

Step 3: Determine the predicted increase in pavement life using the harder aggregate. Compare the predicted life of the higher quality aggregate pavement to the typical overall pavement life for that region. The lower life will be the controlling life.

Step 4: Determine the justifiable cost increase, based upon the increased life, using the mixture equivalent uniform annual cost (EUAC) methodology.

Step 5: Determine the actual cost of importing a particular improved aggregate.

Step 6: Using the ratio of justified cost (Step 4) divided by actual cost (Step 5), determine the cost benefit. If this ratio exceeds 1.0, then import the aggregate, if it is less than 1.0, then it would not be economically feasible to use the improved aggregate being studied.

Implementation of the Methodology

The above methodology was implemented for the Anchorage and Juneau regions. Fairbanks pavement life and cost information is included, although, since there is not a studded tire wear problem in that region, the process was not completed.

The "Standard Agg. Rutting Life Prediction" based upon the 30 sections analyzed for each region resulted in the life predictions shown below. Also, a typical NA value of 11.0 has been reported for the Anchorage region and a NA value of 11.6 appears reasonable for the Juneau region. The "Typical Overall Performance Life Prediction" was determined for each of the three regions evaluated using the pavement management data and developing performance trends without considering rutting as a failure mechanism. This means, that without rutting, pavements in each region can typically be expected to last the number of years shown in the following table. This life becomes the limiting value once the wear problem has been overcome.

Region	Typical NA Value	Standard Rutting Life	Typical Overall Performance Life
Anchorage	11.0	12.7	17.5
Juneau	11.6	12.8	24.6
Fairbanks	11.7	46	28.1

To calculate the potential economic life of pavements in each region, a comparison of the predicted rut life and the pavement performance based upon other factors assuming that rutting failure is reduced to the harder aggregate level by increasing aggregate hardness, is important. This then represents the potential economic life. The potential economic life value is then used to calculate the EUAC of the mixes in each region. Computing the present worth, 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 that could be spent on in-place aggregate in each region.

Two Excel spreadsheets were developed to facilitate the computation process in the cost benefit implementation. The purpose, function and operation of both spreadsheets are defined in the following sections.

Mixture Cost Spreadsheet

The first spreadsheet entitled "Mixture Cost" is used to calculate the cost of in-place hot mix asphalt pavement as follows. For the project information provided by the Alaska DOT & PF, the average asphalt content of Type II material has been used. In this example, the recommended Asphalt Content of the mixture is 5.6% by weight. Consequently, the weight of aggregate in the mix is calculated as 100 – 5.6 = 93.4 %.

The cost of aggregate in-place and asphalt per mega gram were obtained from previous ADOT&PF bid prices. These costs were converted to cost per ton and used to calculate the individual material costs in one ton of HMA mixture. The sum of these two gives the cost per ton of mixture in-place.

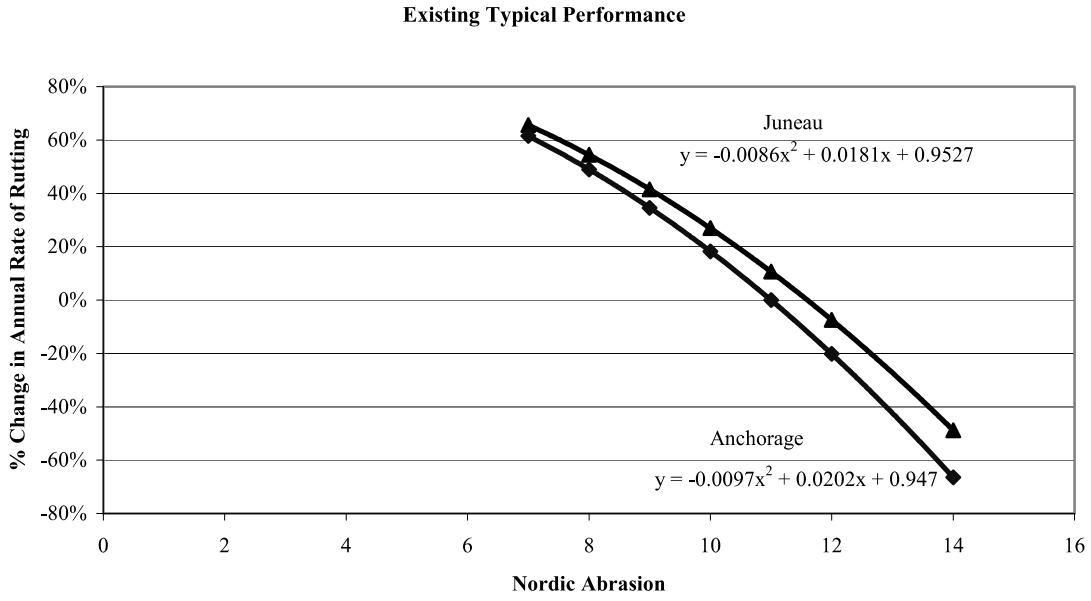
Type 2 B	Anchorage				
	% by wt	Weight in one Ton	Cost / Ton	Total	
Asphalt	5.6	0.056	203.86	11.42	
Aggregate	94.4	0.944	39.96	37.72	
Total	100	1		49.14	$49.14

Equivalent Uniform Annual Cost Spreadsheet

The second spreadsheet, entitled "EUAC", is used for calculating the justified increase in cost of importing aggregate of various hardness's to each individual region. To calculate the potential economic life of pavements in each region, a comparison of the predicted rut life and the pavement performance based upon other factors assuming that rutting failure is eliminated by increasing aggregate hardness, is necessary. From this comparison, the potential economic life is determined. It represents the greater of the rut predicted life, and performance prediction ignoring rutting damage.

For purposes of the "Improved Aggregate Predicted Rut Life" calculation, the rut development using the improved aggregate rutting rate is modeled from the curves in Figure A2. The column titled "Life With Improved Agg" provides this predicted value. This plot is specific for the Juneau and Anchorage areas and is based upon the "typical" Nordic Abrasion values used within each region. If the standard aggregate NA value changes, this model will change as well.

Figure A2. Predicted Change in Rate of Rutting based upon Aggregate Properties



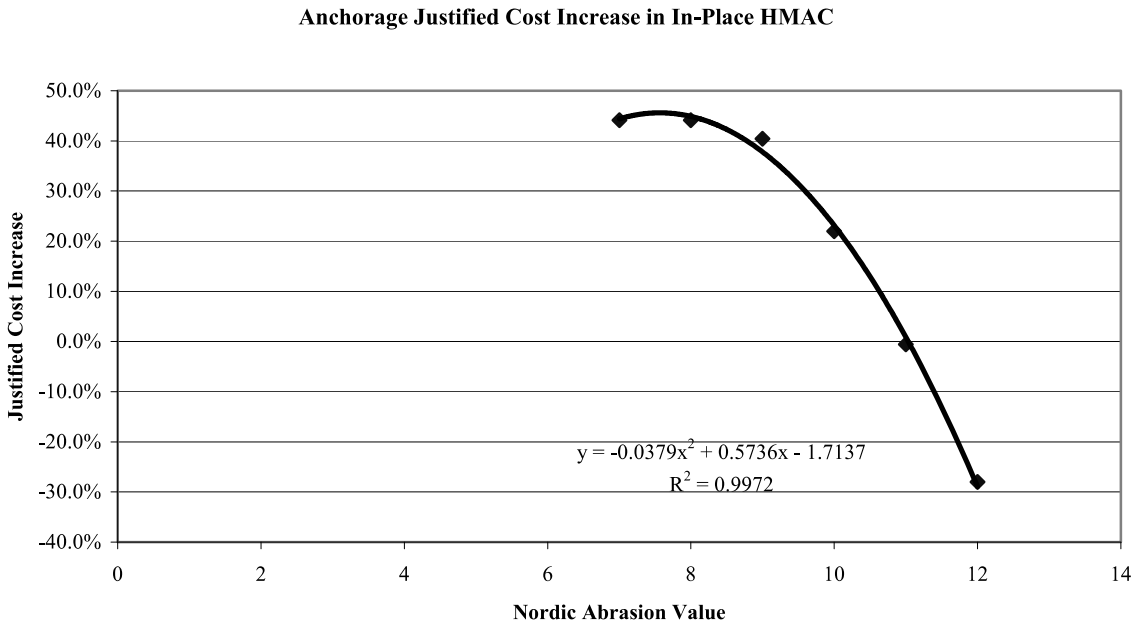
This potential economic life value is then used to calculate the equivalent uniform annual cost (EUAC) of the aggregates commonly used in each region. Computing the present value, based on the EUAC, provides the equivalent first cost of the mixes. The difference between the current cost of mixes and the equivalent cost of mixes represents the potential increase that could be spent on in-place aggregate. The column headings in the spreadsheet below identify the individual values, and computational steps.

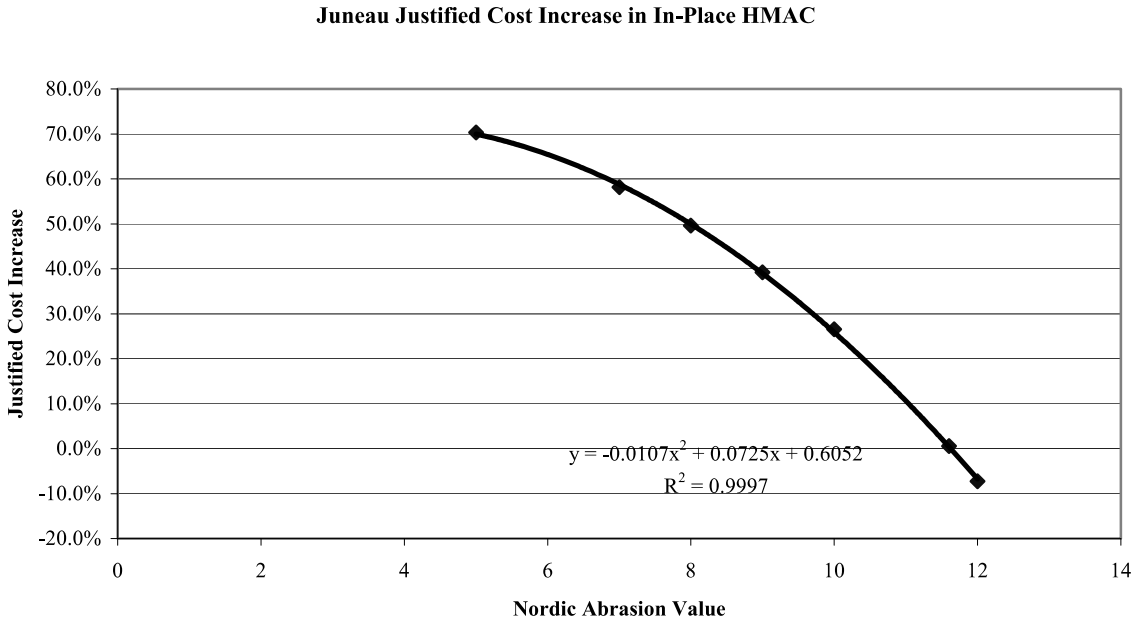
Region	Mixture Cost ($/in-place ton)	Plant Aggregate ($/ton)	Aggregate in Mix ($/ in-place ton)	Typical or Predicted Rutting Life (yr)	PSI Life (years)	Hard Agg		Life with harder Agg Wear (yr)	Current Economic Life	Potential Economic Life	Mixture Current EUAC	Equivalent First Cost	Justified Increase in In-Place Agg
						Predicted Rut Life (yr)	Nordic Abrasion						
A	B	C	D	E	F	G	H	I	J	K	L	M	N
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%

Steps in Completing EUAC Spreadsheet

1. The mixture cost is calculated from the "Mixture Cost" spreadsheet and input into column B.
2. The cost of a ton of aggregate at plant and cost of a ton of in-place aggregate is obtained from the Alaska DOT bid estimates and entered into columns C and D respectively.
3. The life prediction based on rutting and that predicted from visual rating is obtained from the regression equations developed from pavement sections in each region and entered into columns E &F.
4. The predicted rutting life for aggregates with various NA values is computed by entering potential hardness values in column H. The predicted life is calculated and placed in column I.
5. Column J represents the current pavement life, which is the lesser of columns E & F, i.e. the life the pavement is currently expected to last.
6. The potential economic life (column K) is the lower of the life predicted based on visual rating and predicted life based on the improved aggregate qualities.
7. The mixture current Equivalent Uniform Annual Cost (column L) for the mixture is calculated using the discount rate of 4%, initial cost of aggregate per ton in each mixture and the current economic life predicted.
8. The justified equivalent potential cost of the each mixture using improved aggregate performance is calculated in column M using the same discount rate, potential economic life and the mixture EUAC.
9. Finally the difference between the equivalent potential cost of the mixture using improved aggregate performance and the cost per ton of mixture, divided by the cost of in-place aggregate gives the justifiable increase in using improved aggregate (column N).

The result of this effort is provided in the following two charts, one for Anchorage and one for Juneau. These plots are based upon the standard aggregate hardness values as previously reported and upon the predicted lives of the regional pavements with currently used aggregates.





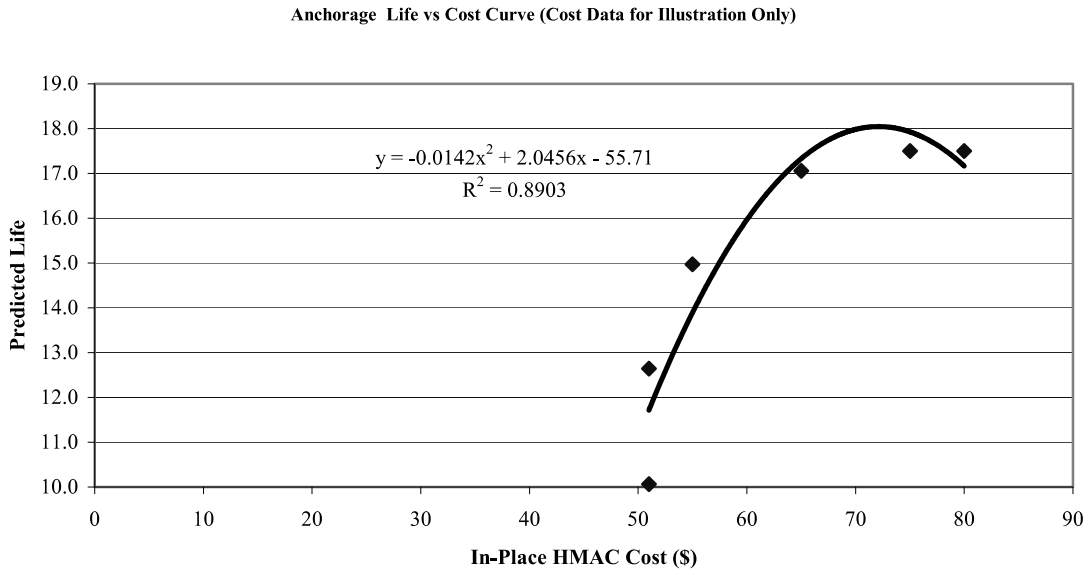
Determination Of Transported Aggregate Costs

To consider the transportation costs necessary to import aggregate to Anchorage and Juneau, it is necessary to identify and estimate costs of delivering the material to potential project sites within each region. In the analysis provided in the report, it has been assumed that project sites are in the greater Anchorage and Juneau areas.

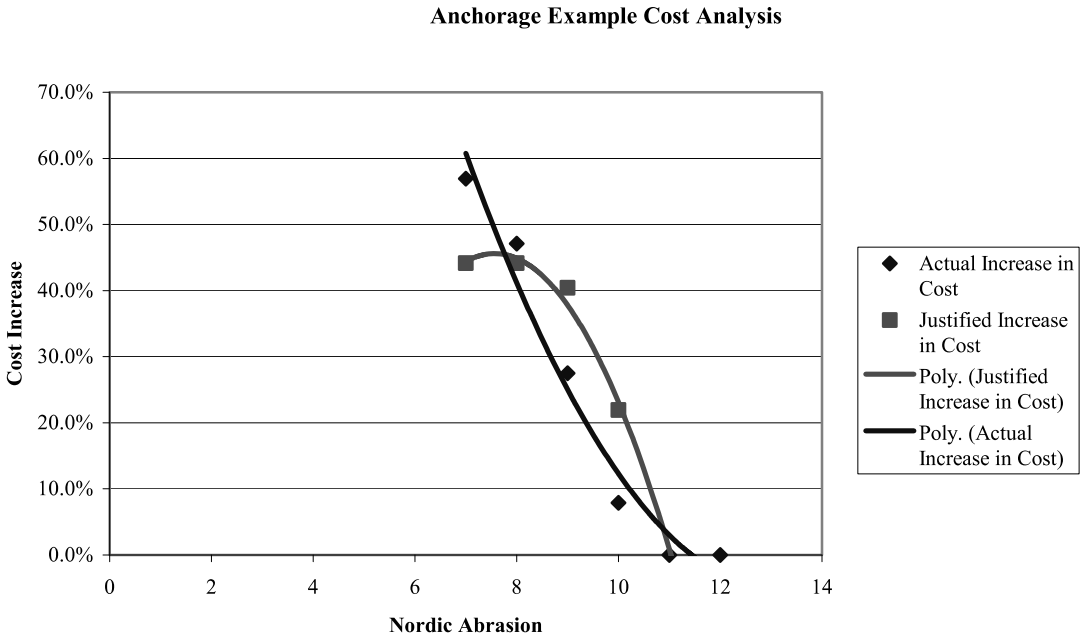
Trucking costs were obtained from individual aggregate sources within each region. Cost structure for delivery by hauling units of various sizes was provided. Using an average haul speed of 50 miles per hour, and a haul capacity of 18-tons, cost for delivery of various trip lengths were calculated.

Similarly, barge costs were obtained from shipping companies, for various sizes of haul capacity. It is obvious that better economy is achievable using the largest haul units feasible for each portion of delivery. For example, a shipping company representative provided shipping costs via the 60,000-ton mega-barge from Vancouver to Anchorage. The cost using the 6,000-ton barge from Anchorage (or Valdez) to Juneau was also provided by a shipping company representative. Although this size barge was indicated as the available means of transport, a larger barge unit might be used were the shipper actually asked to move the material between these two locations, resulting in lower per ton costs.

As actual costs are developed for varying aggregate hardness levels, from various sources, the following plot can be developed. The data used to develop this plot is fictitious since actual material sources for which both cost and aggregate hardness values were known is limited at this time.



The combined cost of material at the source, and those of transportation and handling of the material from the location of origin to the designated destination represents the total potential cost of moving aggregate from remote sources. When this cost is found to be less than the economically viable costs identified for each region, transporting aggregate can be economically justified. If the cost of material, including shipping and handling is greater than the justified cost, it is not economically feasible to bring material from that specific source. A graphic illustration is provided below.



Summary

This document provides both the methodology and the details of the cost-benefit evaluation conducted for identifying the benefit of improving aggregate hardness in the different ADOT&PF regions, and potential for providing harder aggregate material to locations which can benefit from improved pavement performance.

This economic assessment is based upon the assumption that the imported material will improve pavement performance as a result of providing improved rut resistance. Material from individual aggregate sources should be evaluated using the Nordic Abrasion test, prior to committing to move material to another location.

However, it is clear that pavement performance can be improved in the Anchorage and Juneau regions by providing greater wear resistance to studded tire damage by the use of harder aggregates in pavements. Further, the benefit to the pavement can clearly be justified on the basis of aggregate and transportation costs for several scenarios.