Simplified Modeling of Pavement Deterioration in Cold Regions

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Abstract

The Alaska Department of Transportation and Public Facilities, AKDOT&PF, tracks roughness data formaintained roads. This is done by using laser mounted beam on an SUV style vehicle. The equipment is operated and maintained by an outside consulting firmand has occurredannually since 2007. The values provided are IRI (International Roughness Index), rutting and PSR (Present Serviceability Rating) for every 20 feet of length per one lane in one direction. The data is storedinspreadsheet form along with GIS (Global Information System) information. The purpose of this study is to explore a simplifiedapproach method for predicting IRI and rutting that could be used in decision making for AKDOT&PF's, pavement management system (PMS). Four years of IRI and rutting data were obtained from AKDOT&PF for a major arterial. Subsection and section lengths were selected and averages performed into a final one mile average. Each year's section average was plotted and a multi-linear regression performed. The equation describing the trend line is then used to predict deterioration of the IRI or rutting value.A PSR was calculated and compared to what had been last measured. Finally a comparative analysis through visual inspection was performed and compared to the data. The outcome is that a multi- linear regression that can be performed and used to predict future pavement deterioration in terms of IRI and rutting. A calibration of the model was implemented using visual inspection. No significant differences were found between the derived model and visual inspection.

INTRODUCTION

Funding for any enterprise needs to be evaluated in a pragmatic manner that leads to the most efficient use of dollars spent. A strategy is formulated and projects are planned based on data that best represents what is important to the users and road longevity. In the past road projects were performed on worst first. Today many states, Provinces, regions, and countries have adopted a life cycle cost analysis approach. Pavement preservation or road preventive maintenance is a set of treatments applied to a road surface for the purpose of extending the life of a section. These treatments are not intended to be structural but improve distresses and impede water infiltration. Examples are crack sealing, fog seals, chip seals, thin overlays, microsurfacing, bonded wear courses, hot and cold in place recycling, etc. for flexible pavement systems.

A common phrase in literature concerning pavement preservation is to perform these treatments for the right distress at the right time, (O'leary 2002). Places that have integrated pavement preservation into their pavement management systems use data that is cost effective to obtain and manage as well as representing actual conditions accurately. Most road agencies use International Roughness Index (IRI)and rutting data to calculate a service index.In some cases IRI is used alone but seldom seen. When this data is taken on a time interval basis it can be graphed and surface condition deterioration can be trended.

Some facilities will apply treatments based solely on a so many years basis but it is more pragmatic to select sections to treat on an actual needs basis. An analogy would be to change an air filter on a production paint booth on a monthly basis as opposed to using a manometer and change a filter based on data. It will be more cost effective in the life of that particular booth and it will avoid unnecessary costs from doing it too soon or creating issues by waiting too long.

IRI came from World Bank funded research in the 80's to have a common way to measure road quality that could be equally applied to their funded projects anywhere in the world (Sayer, 1998).This research lead to NCHRP Report 228 report that is the basis for IRI measurements. Several ASTM standards provide detailed descriptions applicable to longitudinal profile measuring such as ASTM E867 and E950.
AKDOT&PF maintains approximately 3500 miles of lane miles of road per year.A third partyconsulting company is contracted to perform road surface profiling and data collection.

PROBLEM STATEMENT

A predictive model currently used in Alaska for determining end of life for Alaska's roads but it does notbest represent Alaska's conditions.

PURPOSE

The purpose for this study is to develop a simplified local model for road deterioration to aid in decision making of funding for AKDOT&PF road work based on life cycle costs.

LITERATURE REVIEW

There were few references where a state or a region uses IRI data only for serviceability of a road. One example found is "GIS-based Highway Maintenance Prioritization Model: an integrated approach for highway maintenance in Nepal", (Pantha 2009). This article speaks of using IRI data for decision making for road maintenance in a place that has both high mountain roads as well as flat and flood prone roads. A major concern for them in this case is drainage and landslides.

According to the report "Ride Specifications: Virginia's Experience, Accomplishments and Challenges", Nair, et al 2010, Virginia Department of Transportation use of IRI data as measured per ASTM E950 has been beneficial in terms of ride smoothness, deferred resurfacing activities by 2 years, greater fuel efficiency, less congestion due to deferred resurfacing, and less vehicle maintenance cost. VDOT provides incentive payments to contractors adhering to the smoothness specifications. This can also work against them if they do not adhere to the specifications. Many states combine rutting and/orcracking along with IRI into a serviceability calculation for pavement distress. Examples states are Montana, Arizona and Pennsylvania (Baladi 2002 et al). There are several ASTM specifications for IRI, road surface profiling, and distress indexes. ASTM E867-06 lists terminology for vehicle pavement systems, ASTM E950-09 provides standards for measuring longitudinal profile data of traveled surfaces, and ASTM 1166-00 is a standard guide for network level pavement management.

The Federal Highway Administration provides a report called the "HPMS Field Manual (2010)", HPMS – Highway Performance Monitoring System. Appendix E of this manual provides a procedure for roughness measurement.

"The Little Book of Profiling, Basic Information about Measuring and Interpreting Road Profiles" (Sayers 97), details how roughness data is measured, what equipment is used, how signals are filtered, processed and averaged to provide data that is used in an index. There is a brief explanation on the history of how IRI was formulated and for what purpose as well. The NCHRP Report 228, "Smoothness Specification ForPavements" (Smith 1997), is the result of research the World Bank had performed for the formulation of the IRI.

METHODOLOGY

The original spreadsheets from AKDOT&PF were for five miles worth of data witheach row representing 20 ft or .0038 miles. The 20 ft IRI data displays a right, left, and middle IRI. For trial purposes the data was reduced to one mile's worth. First each row is averaged andthen every 120 ft was averaged which gave 44 sections. Finally the 44 sections were averaged to make a mile average.Typical spreadsheet statistical functionality was used.Alsoin addition to averages, a max, min, and standard deviation wereperformed.

The max, min and standard deviation show therange of variability in the data from year to year. Each one mile average was then plotted on a graph versus year. Available trend lines were exercised along with their corresponding R^2 values. The available trend lines are linear, power, polynomial, averages, and power.

The trend line with the R^2 closest to 1.0 should be chosen as long as it seems reasonable to the investigator. Some trend lines with a R^2 value close to one do not necessarily provide an equation that lends itself to ease of use. Rutting is recorded at the same 20 ft intervals. There is a left max rut average, a right rut average and a full rut average. The full rut is the average of the max of all rut depths taken. Every 120 ft is averaged and then a one mile average is calculated. Also for each year a max, min and standard deviation is determined. The one mile average is graphed with a trend line and R^2 value. If the graph of the overall average shows questionable behavior then plotting the subsections can verify if the trend shown is overly smoothed or confirmed. A PSR is calculated using the graphed points for each year's IRI and Rut points determined. This PSR is compared to what is shown on AKDOT&PF's website. As a final calibration, a visual inspection was conducted by walking along Dimond Boulevard from mile 0.0 to mile 1.0. Table 1 is used as a guide for grading. The visual grading evaluation is enhanced with California DOT's Pavement Condition Survey, except the number is reversed to match AKDOT&PF's PSR system.

Table 1. AKODT&PF Present Serviceability Rating

Condition	PSR Rating
Very Good and Good	Perform preventative maintenance as needed including crack sealing and patching Good is for PSR > 3.5 and Very Good indicated PSR > 4.0
Fair	Perform preventative maintenance as needed including crack sealing, patching, overlays and chip seals. This is for PSR from 3.1 to 3.4
Mediocre	Perform corrective maintenance or rehabilitation including patching, chip seals, reclaim and overlay, mill and overlay. This is for PSR from 2.6 to 3.0
Poor	Rehabilitation or reconstruction is needed to meet National Standards. This is for PSR <2.5

DATA COLLECTION

The data is collected with lasers mounted on the front beam of a vehicle. There are two lasers for each wheel path, one in the middle, and one on each end for a total of seven. An inertial accelerometer is also mounted on the chassis of the vehicle. Every 20 ft a reading is taken from the instrumentation and recorded. This RSP, Road Surface Profiling, data is then put into IRI values according to ASTM 950 Class 1 and rutting numbers. From the IRI and rutting a PSR is calculated and stored in a database with the associated GPS location that is later used for GIS.

Figure 1 and figure 2 are pictures looking in opposite directions of the major arterial chosen.

Figure 1.Dimond Boulevard looking towards New Seward from near Old Seward intersection, 4/3/2011.

Figure 2.Dimond Boulevard looking towards C St from near intersection of Old Seward, 4/3/2011.

DATA ANALYSIS

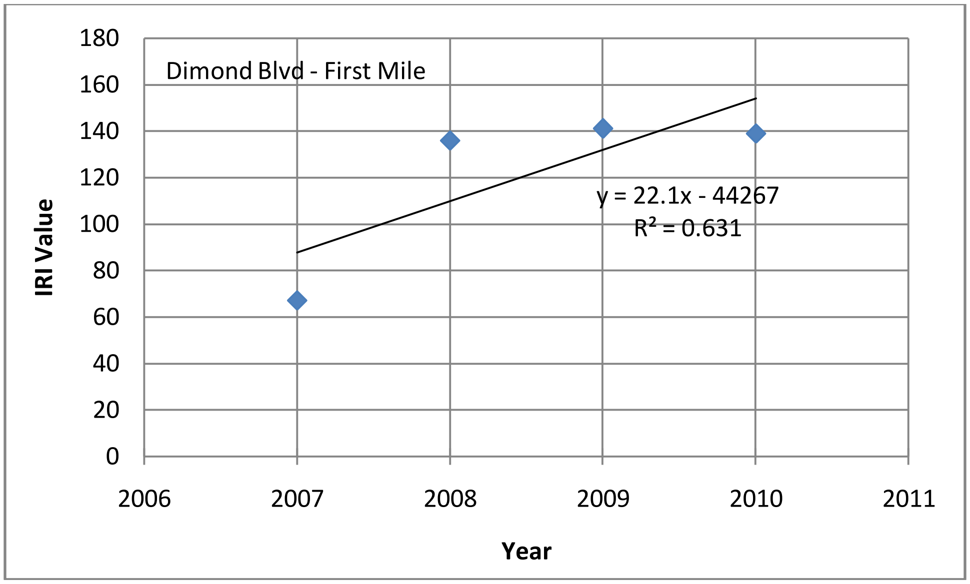

Figure 3.Graph of year versus one mile average IRI

Figure 3 is a plot of the one mile IRI average versus the year the data was taken. A linear regression gives the equation,

IRI= $22.1 * year - 44267$ (Equation 1.0)
, with a coefficient of determination, $r^2 = .63$.

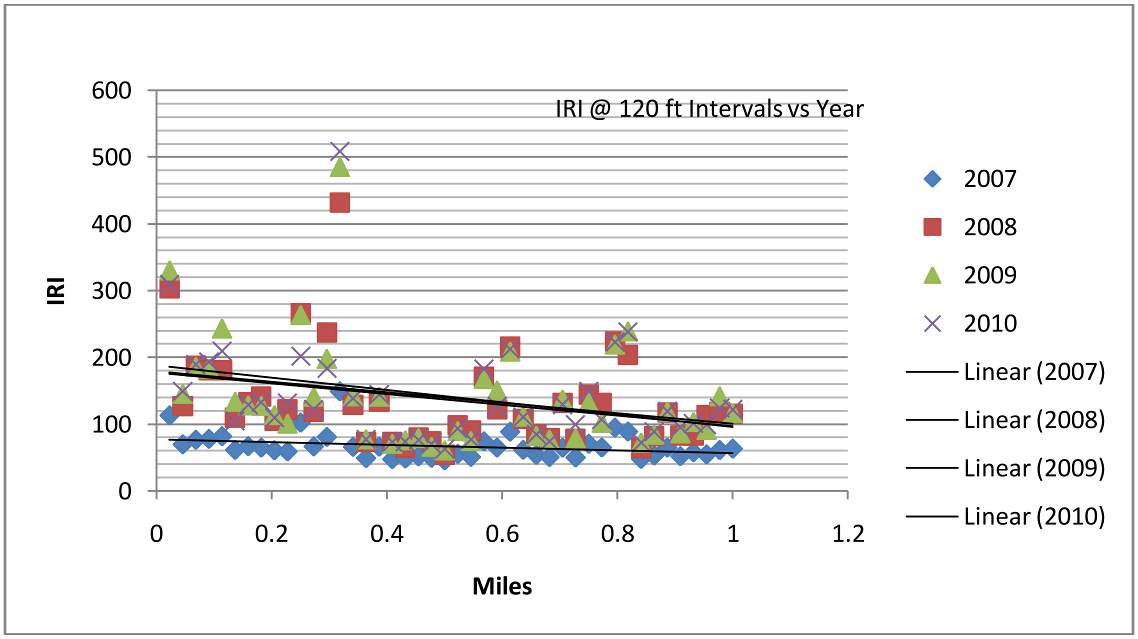

Figure 4.Graph of 120 ft, one mile versus IRI data.

Figure 4 is a graph of 120 ft IRI averages in one mile's worth of data. There are some points with much higher IRI numbers. The year 2007 shows IRI numbers being closer in value when compared to the other years. The 2007 IRI numbers being close in value those later years is due to less accumulated traffic as compared to the later years. Figure 4 also shows there is jump in overall IRI values from year 2007 to 2008 and then the IRI values remain close in value from 2008 to 2010.The jump in IRI value in 2008 as compared to 2007 could be showing that the relationship between IRI and time for this situation is more exponential than linear. The data in figure 4 also shows a maximum IRI for each year around the same point along the road.

Table 2.Standard deviation of IRI per year.

Year	2007	2008	2009	2010
Standard Deviation of IRI	39	115	110	106

According to table 2 the standard deviation of the IRI data also jumps from a value of 39 in 2007 to a value of 115 in 2008 showing more spread in the data of 2008 versus the data in 2007. This spread indicates that some sections of the road remained smooth while other section become more rough which is the result of raveling or some other abrupt deformation in the longitudinal direction.

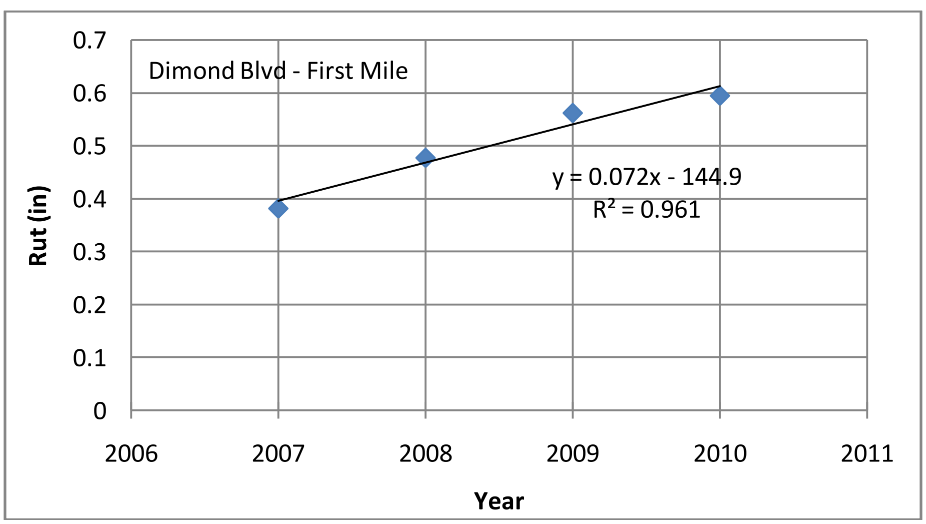

Figure 5. Graph of rut versus year.

Figure 5 is a graph of rut versus year. It also shows a line from linear regression analysis along with associated equation and coefficient of determination. The equation is,

$rut = 0.0724 * year - 144.91$ (Equation 2.0)

with a coefficient of determination, $r^2 = 0.96$.

Table 3.Standard deviation of rut versus year.

Year	2007	2008	2009	2010
Standard deviation of rut	.192	.223	.257	.246

Table 3 shows standard deviation of rut data versus year. From 2007 to 2008 there is a 16% increase. From 2008 to 2009 there is a 15% increase. And from 2009 to 2010 there is a 4% decrease in standard deviation meaning the data has less spread from 2009 to 2010.

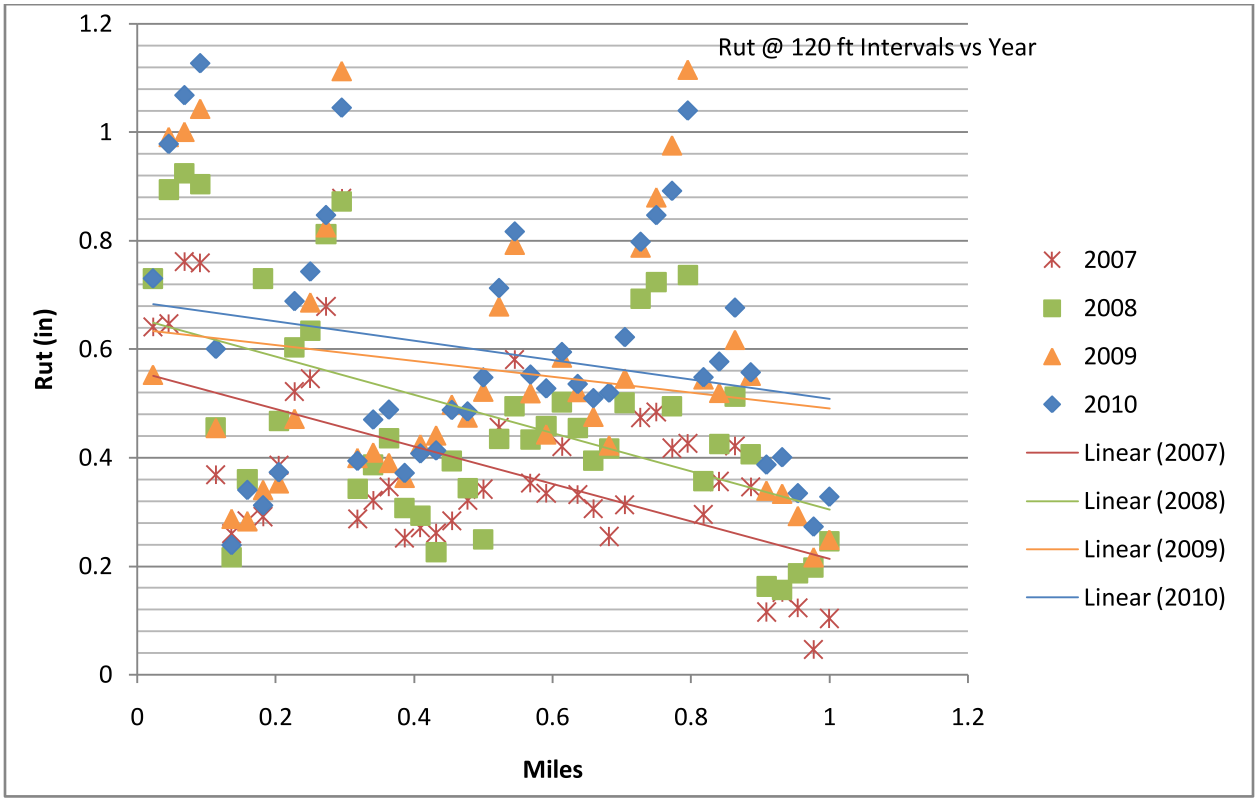

Figure 6. Graph of rut 120 ft versus year.

Figure 6 is a graph of rut values averaged for 120 foot intervals for the years 2007, 2008, 2009, and 2010. This graph shows that there is a decrease in rut value from the beginning of the mile to end of mile 1 and shows the same for each year of data analyzed. This figure also shows rut increasing every year of data taken.

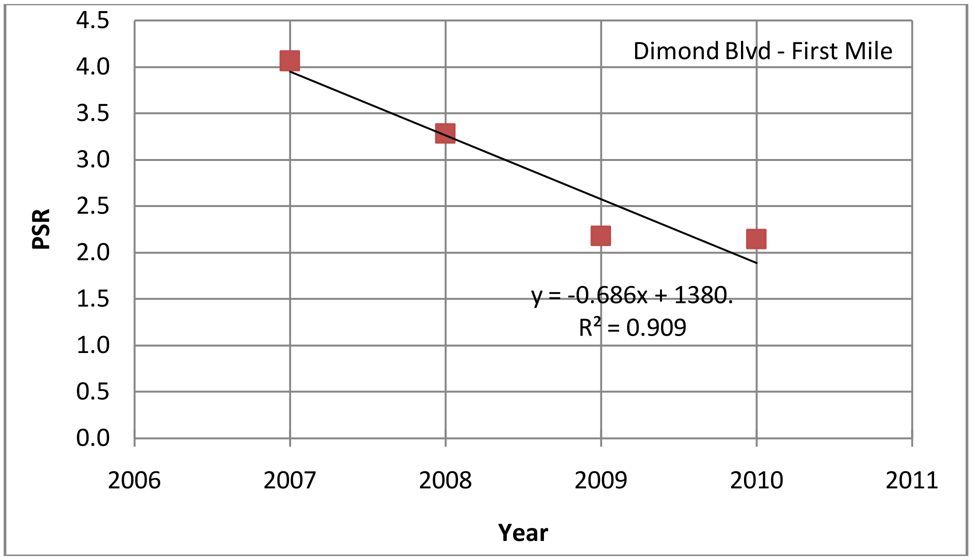

Figure 7. Graph of PSR versus year.

Figure 7 is a graph of PSR versus year along with a line, equation for the line and coefficient of determination. The equation,

$PSR = -.686 * year + 1380.7$ (Equation 3.0)

, displayed on the graph has an associated coefficient of determination $r^2 = .91$.

DATA CALIBRATION

Table 4 AKDOT&PF PSR equations.

Interstate	PSR = 5*e(-0.0041*IRI) for sections with average rut depth < 0.5" PSR = 5*e((-0.0041*IRI)-(0.7*Rut)) for section with average rut depths > 0.5"	Equation 4.0 Equation 5.0
Other	PSR = 5*e(-0.0031*IRI) for sections with average rut depth < 0.5" PSR = 5*e((-0.0031*IRI)-(0.7*Rut)) for section with average rut depths > 0.5"	Equation 6.0 Equation 7.0

Table 4 shows the equations used for calculating PSR by AKDOT&PF. A check and calibration for the derived linear equation for PSR is to use IRI and rut data given for a given year and calculate the PSR using an equation in table 4 appropriate for the situation. Then compare to what the linear equation gives in figure 7.

For year 2010 the linear equation in figure 3 gives an IRI of 154, figure 5 gives a rutting value of .61", and figure 7 gives a PSR equal to 1.8. Dimond Boulevard is not an interstate so the equation for "Other" in table 4 is used. More specifically, since the rut is over .5" the equation for rut depths over .5" is used, equation 7.0. The PSR using this equation is equal to 2.0. This gives a 10% difference.

Another calibration was performed using statistical software for linear regression with PSR being the dependent variable and IRI and Rut data each being independent variables. The result provids coefficients for each of the independent variables and a constant or "Y" intercept. The resulting equation is the following:

$PSR = 5.101 - .006\ x\ IRI - 2.798\ x\ Rut$ (Equation 8.0)

The coefficient of determination, R^2, associated with this analysis is 0.84.

Using the same IRI = 154 and Rut = 0.61" gives a PSR = 2.5 using equation 8.0. This is a .5, 25%, from the equation used from table 4. At first glance this would say that one of the equations must have some deficiency but when comparing a one mile average of all of the 120ft averages Equation 8.0 gives a PSR = 2.7 and the average of 120 ft averages from AKDOT&PF data the one mile PSR = 2.6 which is only a 4% error. The equations from table 4 are a natural exponential function representing the PSR from IRI and Rutting data actually taken on Alaskan Roads. Equation 8.0 is a linear regression using both the IRI and Rut for the independent variables. The PSR from equation 8.0 is the dependent variable derived from the same IRI and Rut data. So both equations are data from Alaska's roads.

A visual inspection was conducted on April 24, 2011. This was conducted by walking the sidewalk along the West bound traffic lane starting at the 0.0 mile point. This coincides with on ramp of the New Seward highway north. Note this visual inspection was conducted months after the 2010 data had been taken by AKDOT&PF' to include a studded tire season.

The visual inspection was broken into six sections, each at an intersection crossing Dimond Boulevard. There was rutting just before the stop and go areas.

Table 5.Visual evaluation of section.

I	West Bound Dimond just East of the New Seward overpass.
	• Deep rutting • Raveling • Maybe some polishing • No cracking • Estimate IRI over 190 • Estimate rutting at 1" in some places • Estimate PSR < 2.5
II	Between New Seward and Old Seward
	• By off ramp from New Seward potholes • Much less rutting than previous section • Raveling • Few transverse cracks • Start of longitudinal crack in between lanes • Estimate IRI 130 – 150 • Estimate rutting < .5" • Estimate PSR < 3.0
III	Old Seward Intersection
	• Estimate some ruts to at 1" or more • No cracking • Raveling • Some polishing • Estimate IRI to be 190 or greater • Estimate PSR < 2.5
IV	Old Seward to Dimond Center Road
	• Transverse cracks start shortly after Old Seward Intersection and continue every 60' plus. • Ruts diminish shortly after Old Seward intersection • Some intermittent longitudinal cracking • Typical cracks can be seen in the photo in Figure x • Some raveling but not as severe • Estimate IRI at 130 – 140 • Minimal rutting except before intersection • Estimate PSR 2.6 – 2.8
V	Dimond Center Rd to King St
	• Same transverse cracking pattern as previous section • Raveling • Estimate rutting up to .75" • Estimate IRI at 150 +/- • Estimate PSR to be near 2.5 or slightly better depending on exact location
VI	King St to C St
	• Same transverse crack pattern • Less raveling than previous sections • Estimate IRI 120 +/- • Estimate Rutting at .5" • Estimate PSR to be just below 3.0

The notes from table 5 show several sections being below 2.5 which occur in the first part of the section and improve while moving to the 1.0 mile point. This confirms the data in the graphs of the 120 ft intervals for IRI and rutting shown in figure 4 and figure 6.

According to AKDOT&PF a PSR rating below 2.5 is considered Poor .

CONCLUSIONS

The goal of this work was to develop a simple method to predict road distress so the predicted value could be used to help make decisions for road maintenance and rehabilitation in Alaska. As shown, there were differences between the different methods implying more data should be analyzed.

RECOMMENDATIONS

Recommendations are to perform analysis on more IRI and Rut data in the same manner for Alaskan roads to gain confidence in the methodology.

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