EVALUATION OF CRACK SEALING TECHNIQUES IN ALASKA'S ASPHALT CONCRETE PAVEMENTS

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Abstract

Thermal cracking is one of the most prevalent asphalt concrete (AC) pavement distresses in northern states and countries. Every year in Alaska, a substantial amount of funding is spent on sealing cracks according to the practices of the Alaska Department of Transportation and Public Facilities (ADOT&PF) Maintenance and Operations (M&O) division. However, to date there are no specific guidelines available that clearly outline the best timing for crack sealing or even what conditions necessitate crack sealing in a consistent manner. There is a need to evaluate the effectiveness and best practices for using the crack sealing techniques on AC pavements in Alaska.

In response to this research need, a pavement preservation project was conducted and found that although crack sealing is a very common practice in Alaska, it is unclear how and why M&O decides to seal cracks since some are sealed and some are not. This motivated further evaluation of 91 field sections that represent the various climate regions of Alaska. A new survey method, "special thermal crack evaluation (STCE) ", was developed to answer critical questions related to road thermal cracks and to provide guidance for crack sealing practices. The new STCE method was conducted along with two other field survey methods, the Long Term Pavement Performance (LTPP) program and the Pavement Surface and Evaluation Rating (PASER). Results between methods were then correlated.

Finally, regression analyses were conducted to determine factors that significantly influence crack development and crack sealing practices in Alaska. Significant influencing factors on crack development include pavement temperature, freezing index, and rut depth. Crack frequency, freezing index, pavement age, PASER rating, PASER transverse crack severity level, and certain STCE questions can significantly contribute to the decision making for current sealing practices.

It was found that the STCE method could generate direct recommendations on crack sealing practices. STCE, in combination with the LTPP and PASER methods, provides specific analysis about asphalt thermal cracking and sealing of these cracks so that informed decisions can be made for a positive impact on ADOT&PF's maintenance budget. It is recommended to use STCE along with the LTPP and PASER methods and to use the findings of influencing factors of this study to develop more specific plans for future crack sealing practices.

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Chapter 1 Introduction

1.1 Problem Statement

Thermal cracking is one of the most prevalent asphalt concrete (AC) pavement distresses in northern states and countries. Most state transportation agencies in the United States have developed various regional crack sealing practices. As with others, the Alaska Department of Transportation & Public Facilities (ADOT&PF) has promoted sealing cracks, which has cost the ADOT&PF's Northern Region $450,000 annually. If the Central and Southcoast Regions were included, the cost would be approximately $1,000,000 annually. To reduce this cost, either materials need to be developed that successfully resist cracking, or a study needs to prove that sealing cracks is not maintaining or enhancing the serviceability of the roads in question. However, to date, there are no guidelines available to outline clearly when the best timing is for crack sealing or under what condition crack sealing is necessary. Presently, crack sealing practices on Alaska's highway system vary. Some areas seal almost every visible crack, and some areas have very little crack sealant applied or none observable. Therefore, there is a need to evaluate the effectiveness of crack sealing techniques of AC pavements in Alaska. For this study, 91 road sections were selected from different climate regions in Alaska to obtain detailed crack survey data for further evaluation of the efficacy of crack sealing practices.

To provide direct recommendations for decision-makers on crack sealing practices for thermal cracking, this study developed a new method named "special thermal crack evaluation (STCE)". The STCE method serves a specific purpose, which is to provide guidance on the crack sealing practices, rather than just provide typical pavement surface condition data as the other two methods used for this study, the Long Term Pavement Performance (LTPP) program and the Pavement Surface and Evaluation Rating (PASER) system, do. By using STCE, the ADOT&PF and other agencies can make recommendations for crack sealing based on the answers to several critical questions that are important to Alaska's pavement maintenance. The answers to these questions are interpreted as ordinal data format and collected as the results of the STCE. However, no comparison or correlation between STCE and other commonly used pavement surveying methods has been accomplished. To fill this knowledge gap, this study also conducted preliminary comparison and correlation between the LTPP and PASER methods, and the newly developed STCE method.

The ultimate objective of developing effective and economical crack sealing practices is to provide durable and driver-friendly pavement. This objective requires knowledge of what factors cause thermal cracking in northern regions such as Alaska. The currently adopted crack sealing practices also suggest that the sealing decision may be affected by some key factors. However, these factors have not been fully identified, especially in Alaska. In addition, the abovementioned three crack survey methods have not been used in combination, and one of them, STCE, was developed especially for this study; therefore, the determined influencing factors will provide a unique insight to sealing practices on Alaskan asphalt roads, which can aid with decision making by state agencies. To understand current practices, this study obtained critical parameters of the surveyed sections such as pavement age, traffic data, and the freezing index. These parameters were then evaluated to determine their correlations with crack development in Alaska. Additionally, select data from the LTPP, PASER, and STCE survey methods were also evaluated for their effects on crack sealing practices. The influencing factors can be further used in the future for modeling of thermal cracks on Alaskan roads or used in other statistical methods for predictability of crack development and effectiveness of sealing practices.

1.2 Research Objectives

The objectives of this research are as follows:

1. Study thermal cracking, crack sealing practices, and factors that influence thermal cracking in asphalt roads through a thorough literature review.
2. Conduct a preliminary pavement preservation survey in Alaska to reveal the current crack sealing status of Alaskan roads, to help develop criteria for further field site selection.
3. Develop a new survey method to specifically answer critical questions related to thermal cracks on the road and directly guide crack sealing practice.
4. Select sites representing the entire state of Alaska and record measured data and observations through quantitative and qualitative data relative to thermal cracking using currently existing survey methods (LTPP and PASER) and the new method

developed in this study (STCE), which represent national, regional, and local evaluation methods.

5. Interpret and analyze field data collected using each evaluation method.
6. Find the correlation between the newly developed STCE method, and the LTPP and PASER methods, and investigate how best to combine the results for better decision making regarding crack sealing.
7. Evaluate which factors identified in this study affect the crack development and crack sealing practices.
8. Provide conclusions and recommendations related to the objectives and analysis.

1.3 Research Approach

Research approaches for each of the objectives listed in Section 1.2 are listed below:

1. For research objective 1, a thorough literature review for thermal cracking in asphalt was performed (presented in Chapter 2). First, in Section 2.1.1, references discuss influencing factors. This is followed by a discussion of thermal crack modeling in Section 2.1.2. Crack sealing practices are then introduced, followed by discussions of crack sealing methods, Section 2.2.1; and crack sealing materials, Section 2.2.2. The last section, 2.2.3, is about performance evaluation and concludes by asking the question whether crack sealing has maintained or enhanced the asphalt surface performance.
2. For research objective 2, Section 3.1 provides preliminary field surveys on eight crack sealing sections of Alaskan roadways as part of a set of guidelines for pavement preservation projects performed in Alaska.
3. For research objective 3, a new thermal crack evaluation method called the special thermal crack evaluation method (STCE) was developed, as described in Section 3.3.3. This method addresses specific questions related to thermal cracking.
4. For research objective 4, Section 3.2 addresses which road sections were selected for detailed evaluation of efficacy of cracking sealing techniques in Alaska and what the criteria were for the selection of these sections. Section 3.3 provides detailed descriptions of the field survey methods adopted in this study. These

include two established methods, LTPP and PASER, and the newly developed STCE method.

5. For research objective 5, field data were analyzed and interpreted (as presented in Section 4.1). Sections 4.1.1, 4.1.2, and 4.1.3 present the organized results according to LTPP, PASER, and STCE survey methods, respectively.
6. For research objective 6, STCE data were correlated with LTPP results and PASER results, respectively. The results of correlation are presented in Section 4.2. The same section discusses how to combine results of various survey methods to facilitate decision making of crack sealing.
7. For research objective 7, Section 4.3 lists influencing factors on crack development and sealing practice. These factors were identified according to the literature review and practitioner experience. Statistical analysis was performed to determine which factors significantly affect thermal crack development and sealing practice in Alaska.
8. For research objective 8, conclusions of this study and recommendations to state agencies and for further research are summarized in Chapter 5.

Chapter 2 Literature Review

2.1 Thermal Cracks in Asphalt

Thermal cracks appear as fairly linear openings in asphalt roads and are mostly perpendicular to the direction of travel, although this is not absolutely true for every thermal crack. Thermal cracks are also referred to as low-temperature cracking. Typically, thermal cracks start with spacing between cracks longer than the width of the road. In time, as the asphalt hardens, the new thermal cracks form parallel to the first ones. Then, as spacing becomes less than the width of the road, longitudinal thermal cracks form and interconnect with transverse cracks. This is termed "block cracking." Although thermal cracks are usually initiated in the asphalt layer, they can also be initiated in the underlying frozen pavement layers or subgrade (McHattie et al. 1980). This is caused by the binding effect of pore ice (Dore and Zubeck 2009). The effect of this can be seen in cold areas where cracks extend beyond just the pavement and into adjacent bike paths, sidewalks, and in between vegetated areas (Osterkamp et al. 1986). Thermal cracking can be further divided into low-temperature cracking and thermal fatigue cracking according to Dore and Zubeck (2009). Marasteanu et al. (2004) also stated that there is little research for looking at a road system as a whole in dealing with low-temperature cracking.

2.1.1 Influencing Factors on Thermal Crack Development

A review of the literature shows two major approaches to explain thermal cracking: a macro and a micro approach. The macro approach is an equating of major stresses and strengths. The micro approach is a more finite discussion of discontinuities and stress risers within fracture mechanics. According to Dore and Zubeck (2009), low-temperature cracking occurs when temperatures drop rapidly below -16 °C and -35 °C. The thermal contraction stress exceeds the tensile strength of the asphalt and a crack forms. Thermal fatigue cracking occurs in regions that are not as cold but form due to the diurnal temperature cycling. The authors stated that two conditions need to be met to have a thermal crack: cold and constraint. Without either one, a crack will not happen. They further defined "cold" as meaning that the temperature must drop enough in both magnitude and rate to cause cracking. Once the crack has occurred, then the constraint is the most influential parameter for crack spacing. They also stated that binder properties dictate cracking temperatures.

The aspect of the interaction of the granular base and how it affects thermal cracking was used in a Mohr-Coulomb equation to calculate the constraining force, as presented by Zubeck and Vinson (2007). This involved obtaining cohesion and friction angle of the granular base layer. Currently, there is not a test method mentioned in literature to measure the cohesion and friction angle between the granular base and lower surface of the asphalt, especially at temperatures experienced in cold regions such as Interior Alaska, which can experience temperatures below -45 °C.

Ponniah et al. (1996) used a fracture mechanics approach and state that asphalt binders are the controlling factor in thermal cracking. They explained that asphalt pavement layers had built-in flaws that act as stress concentrators. Micro cracks then developed at the asphalt – aggregate interface due to varying amounts of thermal contraction because asphalt cement and aggregates would contract different amounts since they are different materials. The thermal micro cracks created localized areas of stress concentration and occur at or near areas of discontinuity. The resulting stress caused premature failure in the asphalt binder. Ponniah et al. (1996) (Gardner et al. 1996) also stated that fracture mechanics suggests it is the rate of energy dissipation, or fracture energy, that controls the failure mode from crack initiation to crack propagation.

Wagoner et al. (2005) (Jensen and Hansen 2000) discussed that asphalt properties such as stiffness and fracture energy change with stress rate as well as temperature change. They stated fracture energy decreases as load rate increases. As temperature decreases, there is a transition from a quasi-brittle fracture with softening response to brittle fracture with minimal softening. They also witnessed that at low temperatures, the crack goes through the aggregate and mastic, but at higher temperatures tested, the crack goes around the aggregate and through the mastic. Test temperatures were 0, -10, and -20 °C. These observations are similar to those seen in the field by McHattie et al. (1980) and reported by Osterkamp et al. (1986).

The factors that influence thermal cracking differ depending on the type of testing methods and analysis being performed. There are certain fundamental variables such as temperature and coefficient of thermal expansion and contraction that are contained in most of the methodologies. In addition, geometry of samples for test methods, field conditions, and material conditions such as compaction of asphalt, densities, and air voids are all important variables.

Zubeck and Vinson (2007) stated the severity of low-temperature cracking is related to the spacing between cracks; therefore, the following factors need to be considered when using the Thermally Stress Restrained Specimen Test (TSRST): field aging of asphalt concrete based on laboratory aging procedure, effect of aging on the TSRST fracture temperature and fracture strength, relationship of the TSRST fracture temperature and actual fracture temperature measured in the field, relationship between TSRST fracture temperature and temperature dependent tensile strength of the asphalt, estimation of asphalt temperature with air temperature, and estimate of restraint conditions with asphalt and the base layer. McHattie, et al. (1980) and Osterkamp et al. (1986) mentioned the influence of base, sub-base, and subgrade layers on thermal cracking. He discussed the relation between air temperature magnitude and rates of change and found more rapid changes occurred in the winter than in the spring and summer. For the same magnitude in change of temperature, there were different measured openings in thermal cracks. This confers with Zubeck and Vinson (2007) that pavement should be calibrated for air temperature at a particular field site, and type of pavement used.

Geometry is another influencing factor stated by Zubeck and Vinson (2007). Different thicknesses of the same material will have different cooling and heating rates. This differential cooling/heating can cause development of stress and strain. The authors also mentioned that asphalt properties such as stiffness and tensile strength are temperature-dependent parameters. Geometry is also crucial to the development of the normal force to the base layer and therefore the amount of friction created between the bottom layer of the slab and top of the granular base coarse. This is the constraint or restraining force in Zubeck and Vinson's (2007) model of forces for thermal cracking and then the calculation of the spacing between cracks.

Along with geometry, specific weight of the asphalt is an influencing factor in the restraint probabilistic method by Zubeck and Vinson (2007). This parameter will provide data for the normal force as well and thus the amount of frictional restraint.

The main parameters influencing thermal cracks from a fracture mechanic's point of view are temperature, stiffness, fracture toughness, and fracture energy (Li and Marasteanu 2004). As mentioned above, tensile strength and stiffness of asphalt are temperature dependent (Zubeck and

Vinson 2007); therefore, the temperature at which fracture tests are conducted or modeling/analysis is computed for is important.

Stiffness is obtained from a load and displacement plot (Li and Marasteanu 2004) and is defined as the slope of the developed or measured curve in the linear or near linear portion. Fracture toughness, K_{IC}, characterizes the stress at the crack tip. It is a function of the load and geometry of the specimen and crack length. This stress intensity factor increases with increasing load until an unstable fracture occurs at what is called the "critical value" (Ponniah 1996; Lim et al. 1993) and defines fracture toughness for a particular specimen. The fracture toughness decreases as the width of the sample increases to a point at which it becomes a constant minimum value. Wagoner et al. (2005) mentioned that as thickness increased, in their study, the fracture energy increased and the variability remains constant. This was when a plane strain condition was met. Literature shows that since fracture toughness is dependent on specimen geometry, the calculation for K_{IC} depends on whether the specimen is beam shape or cylindrical. Fracture toughness is a reproducible parameter and allows the study of asphalt at low temperatures when it is most brittle.

Once the stiffness modulus and fracture toughness are determined, then fracture energy can be obtained. Ponniah et al. (1996) stated that fracture energy is a fundamental property of materials and provides the opportunity for fracture energy tests and analysis to evaluate asphalt and asphalt binders at low temperature. Marasteanu et al. (2007) stated that fracture energy is a better parameter than fracture toughness for differentiating performance of asphalts at low temperature since it is less dependent on linear elasticity and homogeneity of samples. Rosales et al. (2011) stated that fracture energy is unique to a particular material and indicates the resistance to crack propagation in asphalt binders at low temperatures. Wagoner et al. (2005) also stated that fracture energy is a better method for determining asphalts resistance to fracture than other test measures such as tensile strength. Tensile strength tests have shown to underestimate the tensile strength of more ductile materials.

As mentioned by Zubeck and Vinson (2007), aging causes material to stiffen and crack more easily. They reported on a regression analysis they performed between long-term oven aging (LTOA) and aging in terms of years, between LTOA and fracture temperature, and between LTOA and fracture strength. LTOA is an accelerated oven aging process performed on pavement samples at 85 °C. Ponniah, et al. (1996) found good correlation between fracture energy testing and TSRST testing but did not test the effects of aging. Testing for aging effects was their first recommendation since it directly affects creep stiffness.

Marasteanu et al. (2007) identified two distinct aging periods for pavements. The first was short term to represent what occurred at the time of production and construction of asphalt mixture and pavement. They simulated this process with a Rolling Thin Film Oven Test, American Association of State Highway and Transportation Officials (ASSHTO) T240. The second was long-term aging that represented what occurred over time after the pavement had been constructed. They simulated this aging for their study using a Pressure Aging Vessel, ASSHTO PP1, at 100 °C. Binders failed in warmer temperatures through a viscoelastic process, but as the temperature decreased or the material became stiffer as it aged and lost its elasticity, the failure was brittle, as mentioned earlier. The temperature where material failure goes from elastic to brittle is called the glass temperature, Tg. Marasteanu et al. (2007) provided a graph showing the result of dilatometer testing. The glass temperature could be seen where there was a change in the slope of the curve when measuring change in volume versus decreasing change in temperature. This then represented a change in the coefficient of thermal contraction. They concluded that the critical temperature increases as material stiffens.

Another influencing factor is the loading rate at various temperatures. According to Dore and Zubeck (2009), the stiffness of the asphalt binder is critical to low-temperature cracking, and binder stiffness is related not only to the temperature but the rate of cooling as well. They described it as a process where the asphalt having viscoelastic properties can relax to a given stress over a period of time. If the thermal loading happens at a rapid rate, the asphalt material might not be able to relax or become elastic, relieving the given stress and allowing strain without cracking. Wagoner et al. (2005) found that asphalt failure tended to be more brittle at increased loading rates, which for this situation means a faster cooling rate.

The last influencing factor mentioned for this literature review is the effect of polymers in hot mix asphalt (HMA) on thermal cracking. Dore and Zubeck (2009) stated that polymer-modified asphalts can offer good low-temperature cracking resistance and is recommended for high-traffic volume roads. Rosales et al. (2011) tested asphalt samples by using the Single Edge

Notched Beam (SENB) Test to compare materials that contained polymers with those that did not. They were looking for how the stiffness changed with the addition of polymers and its effect on low-temperature cracking. At a given temperature, -12 °C and -18 °C, those samples with the addition of polymers displayed higher fracture energy than those without the addition of polymers. In terms of fracture energy (and therefore thermal cracking resistance), the samples with polymer additives resulted in the highest fracture energy and the lowest fracture temperature.

2.1.2 Low-temperature Crack Modeling

Low-temperature crack modeling can be categorized as either empirical or mechanistic based, per Marasteanu et al. (2007). Empirical models use equations created from regression analysis performed on inputs important to the situation being studied. Mechanistic models rely on mechanics of materials theory to create the modeling equations used for predictions of failure. There are also probabilistic analyses that incorporate parameter variances along with inputs to the analysis being performed. Most of the models focus on the wear layer only and not the entire pavement structure. All models need valid parameters obtained from the field and laboratory testing as mentioned above.

Fromm and Phang (1972) performed research for the Ontario Department of Transportation by studying the extent of cracking on 33 pavement sections in Ontario, Canada. They developed three equations to predict the cracking index by performing multiple regression analysis using 11 parameters. The three prediction equations consisted of (1) a general crack index equation, (2) one for the northern area of Ontario, and (3) one for the southern area of Ontario. While the mentioned parameters cover a variety of conditions such as binder viscosity and percent of aggregate passing certain sieves, the freezing index, which is what was used in regression analysis for this study, was a key parameter. In addition, crack spacing was a variable used in the general crack index equation similar to data collected for a LTPP crack evaluation.

Haas et al. (1987) gathered data from 26 airports in Canada to develop a statistically derived predictive equation for thermal crack spacing. Asphalt cores were obtained along with evaluations of field conditions. Freezing index and age were not parameters used but minimum temperature was.

The mechanistic models are based on mechanics of materials, and some include the Mohr-Coulomb friction-cohesion principle between the surface asphalt layer and the granular base. Zubeck and Vinson (2007) created a deterministic as well as a probabilistic model that incorporates the estimated variances for the inputs. These models predict low-temperature crack spacing as a function of time, pavement thickness and bulk density, pavement restraint conditions calculated from the friction angle and cohesion of the granular base layer, air temperature, and results from the thermal stress restrained specimen test (TSRST). They also incorporated aging by predicting field aging using the long-term oven aging process on sample material in the laboratory.

In their probabilistic model, Zubeck and Vinson (2007) employed the Point Estimate Method (PEM). This method predicts crack spacing and its variation with time and yields the reliability of the design with regard to minimum crack spacing as defined by any road agency.

Hill and Brien (1966) method compares asphalt tensile strength to the thermal stress applied to it. Their method was created as a procedure to predict the temperature at which a thermally induced fracture will happen. A master curve is created for tensile strength versus temperature through laboratory methods. Then a stress curve is created and plotted concurrently with the tensile strength curve. Where the two intersect gives the predicted fracture temperature. Their primary governing principle is that an asphalt mix is elastic and isotropic. They used Hooke's law theory equations for a beam and slab and a linear coefficient of thermal contraction for the temperature-induced strain. They then substituted stiffness as a function of temperature and time for Young's modulus, knowing rate of temperature drop has an important implication on the resulting stress. They tested fully restrained beams at a cooling rate of 10 °C per hour. Marasteanu et al. (2007) stated that the method is valid if the asphalt being tested is reasonably pseudo-elastic. This only predicts the fracture temperature and not low-temperature crack spacing (Marasteanu et al. 2007; Dore and Zubeck 2009). The Hill and Brien (1966) method was implemented into a computer program by Finn et al. (1977). The developed thermal cracking prediction software, COLD, provides predicted temperatures at which certain asphalt mixes will fracture due to the thermal stresses. A thermal gradient was first derived that was then used to calculate thermal stresses (Hill and Brien 1966). A primary input was the tensile strength versus temperature. As described with Hill and Brien (1966) a fracture occurred where the stress curve crossed the tensile strength versus temperature relationship. COLD can account for the variability of strength versus temperature.

The Strategic Highway Research Program (SHRP), in its project SHRP A-005 Thermal Cracking model, asked engineers to develop a thermal cracking model to predict the amount of thermal cracking with time (Hiltunen and Roque 1994). The authors described that a thermal gradient was present and assumed micro cracks exist. The thermal stresses would then cause the micro cracks to propagate through the asphalt layer. The variation of material properties influenced the extent and placement of these cracks. This model was incorporated into the AASHTO Mechanistic-Empirical Design Guide for the thermal cracking consideration portion. The overall Thermal Crack Model has three components: calculation of thermal stress with time assuming asphalt has viscoelastic properties, crack depth fracture based on linear elastic fracture mechanics, and the amount of cracking using a probability based model. First, thermal stress is calculated based on a change in temperature and time, which is the applied load. A relaxation modulus curve is derived for a particular asphalt sample using an indirect tensile test (ASTM, 2012) procedure. The crack depth growth is then predicted using the Paris Law for crack propagation. A stress intensity factor is derived for the particular situation. The transverse cracking threshold for judging acceptable trial design is 500 ft/mi for an Interstate and 700 ft/mi for a primary or secondary road, according to the AASHTO Mechanistic-Empirical Design Guide (2008).

Hiltunen and Roque (1994) used the finite element program "CRACKTIP" to model a single crack. The probability based model assumes there is a maximum number of cracks that can exist, cracks only count when they are fully through the thickness of the asphalt layer, and the spatial distribution of crack spacing is normally distributed. They then calibrated this model to 23 sections of pavement. According to Marasteanu et al. (2004), although this model works well, it is limited because its empirical components are pertinent only to the data used to develop the parameters and variables used. This method is a numerical simulation for the distribution of thermal cracks in asphalt concrete pavements with frictional restraint between layers (Shen and Kirkner 1999). The method was first proposed by Hillerborg et al. (1976). It first assumed cracking and damage on a mesoscale, which redistributed the stress on a macroscale. The assumed damage or fictitious cracks represented the heterogeneity of asphalt material. The friction of the underlying layer was what allowed for redistribution of the stress and cracking. A nonlinear stability analysis was used to formulate a stepwise formation of the open cracks, which created a jump in stability. The model assumes that all damage within a mesoscale area, order of magnitude being the size of the aggregate 10 mm – 50 mm, is focused into a fictitious crack. The ability to carry stress is indirectly proportional to the opening width of the crack. All material outside this area is undamaged and behaves elastically. The distance between fictitious cracks is developed as a random variable that follows some type of assumed distribution. As the temperature drops some cracks dominate over others. The interface frictional forces act to distribute the major cracks. This situation was represented as a one dimensional thermal model with Mohr-Coulomb frictional forces at the interface. Marasteanu et al. (2004) stated that this model contributed much toward modeling low-temperature cracking by using frictional constrain along with fracture energy but it was over simplistic by not involving a thermal gradient and heat transfer effects from the underlying layers. They also mentioned how none of the models mentioned to this point had taken traffic loading into consideration.

The latest model for thermal cracking is an improved version of the TCMODEL, which was developed at the University of Illinois Urbana-Champaign called ILLI-TC (Dave et al. 2011; Marasteanu et al. 2012; Ahmed et al. 2012). Fracture is now determined with a 2D viscoelastic cohesive zone model instead of a 1D Paris Law based model. Marasteanu described the Paris Law approach as being an empirical approach whereas the cohesive zone model uses fundamental fracture mechanics. Also mentioned are the sometimes unique combinations of strength and fracture energy for asphalt mixes. Some can have high strength and low fracture energy such as for some recycled mixes and some have both high strength and high fracture energy as with some mixes with polymer additives. The ILLI-TC model can capture this directly as opposed to indirectly with the previous TCMODEL. A graphic user interface (GUI) called Visual-LTC provides a user friendly means to input parameters and data from which analysis is performed. The GUI collects input data such as location for climatic data, pavement structure, and viscoelastic and fracture material properties. Most parameters can also be preselected as well. The data are then used in the Input File Generator, which creates all the files necessary for the finite element analysis to produce and output file containing the critical events for thermal cracking, amount of dissipated fracture energy, and extent of pavement thickness damage and cracking (Dave et al. 2011).

After reviewing what others had used as variables for their modeling and this study was intended to be a one-time field evaluation study it was anticipated that low temperature, freezing index, and age of section would be important and pertinent parameters to regress against variables representing crack development, which is represented by crack frequency and crack sealing practices, which is represented by the sealed ratio.

2.2 Crack Sealing Practices

In performing a literature review, crack sealing is the most extensive pavement maintenance or preservation treatments performed for thermal cracking. In a survey conducted by Fang et al. (2000) more than half of the states responding claimed cracks were sealed because it was a long standing policy, unsure, or did not respond. Only 17% stated that the decision to seal was based on research. The reason for crack sealing was commonly stated to prevent water intrusion thus preventing further deterioration or secondary spalling of the crack edges. Hicks et al. (2000) provided a decision tree for pavement cracking treatments. The first criterion was to determine whether a crack was load associated or not. If it was load associated and was further determined to be fatigue cracking or alligator cracking no preventative treatment was recommended. If the crack was longitudinal or some other non-load associated cause such as a transverse crack then treatment was based on average daily traffic (ADT) and varied from crack sealing, to chip seals, and finally to thin HMA overlays. Other road agencies and researchers discussed whether to seal or not based on the width of the crack. Caltrans (2009) recommended that cracks should be greater than 1/4” in width before applying a treatment such as a seal or fill. Federal Highway Administration (FHWA) (1999) recommends crack widths of .2” or greater. Eaton and Ashcroft (1992) created a report for the Cold Regions Research Laboratory that cracks with widths greater than 1/8” should be treated.

One researcher from the Wisconsin DOT (Shober 1996) asked three questions related to crack sealing criteria. Does the joint sealing enhance pavement performance? If joint sealing does enhance pavement performance, then is it cost effective? If it is cost effective, then it is appropriate to determine the best sealant system to use? Although Shober’s approach was to evaluate cost-effective solutions, his study also discussed the criteria for sealing pavement cracks.

Within the State of Alaska, a variety of crack sealing practices have been used. With some sections of road, all cracks are sealed, and then on the same highway but in a different area of maintenance responsibility, no cracks are sealed and there are moderations of either extreme on yet different sections of responsibility. Therefore, the criteria are variable.

2.2.1 Crack Sealing Methods

Most literature concerning asphalt cracking states cracks that are sealed appropriately in terms of timeliness and material will extend the life of the pavement and maintain or improve the serviceability of the road being maintained (Chong and Phang 1988). The primary reason mentioned for the benefit of sealing a crack is to keep the water out; doing so will impede deterioration of any cracks (Eaton and Ashcroft 1992). About ten percent of asphalt roads in the United States have structures that will be unaffected by cracks because the base course and subgrade materials allow rapid water drainage (Ibid). Although it was not found in this literature review, this author assumes that along with good drainage, another factor in areas with few cracks could be low precipitation.

Crack treatments are most often defined with two methodologies: one is for crack sealing and the other is for crack filling. The difference is due to whether a crack or series of cracks are working or nonworking; the FHWA (1999) defines this parameter with the amount of horizontal movement a crack will display. Cracks with movement are sealed, and cracks with no movement are filled with the appropriate material for the climatic conditions and traffic levels. The minimum amount of movement is 3 mm or approximately 1/8." Thermal cracks are working cracks; therefore, it is recommended they are appropriately sealed and not filled. FHWA (1999) defines crack sealing as the placement of specialized treatment materials above or into working cracks using unique configurations to prevent the intrusion of water or incompressibles into the crack. Crack filling is defined as the placement of ordinary treatment materials into nonworking cracks to reduce the infiltration of water substantially, as well as to reinforce the adjacent pavement. If both working and nonworking cracks exist then treat for the more demanding type of crack. Crack sealing should occur in moderately cool temperatures, relative to the majority of the US (7 to 18°C). Cracks should be partially open at this time, which will minimize elongation and contraction of sealing materials. Table 2.1 displays an approach to any crack treatment method.

Table 2.1: Description of a general stepwise approach to any crack treatment program (FHWA 1999).

Step	Description
1	Obtain and review construction and maintenance records. Pavement age, design, repairs, etc.
2	Perform pavement/crack survey such as LTPP, PASER, Micro-PAVER, etc. Record distress types, amounts and severities.
3	Determine appropriate type of maintenance for cracked pavement based on density and condition of cracks. High density of cracks having moderate to no edge deterioration -perform pavement surface treatment. Moderate density of cracks having moderate to no edge deterioration - crack treatment.
4	For crack treatment, determine whether cracks should be sealed or filled. Cracks typically showing significant annual horizontal movement - crack sealing. Cracks typically showing very little annual horizontal movement - crack filling.
5	Select materials and procedures for crack treatment operation based on the following considerations: Climate (dry-freeze, dry nonfreeze, wet freeze, wet nonfreeze). Traffic (high, medium, low). Crack characteristics (width, deterioration). Available equipment. Available labor. Cost effectiveness (anticipated treatment cost and performance).
6	Acquire materials and equipment.
7	Conduct and inspect crack treatment operation.
8	Periodically evaluate crack treatment performance.

As stated in Table 2.2, if cracks are of moderate density with moderate to no edge deterioration, then a crack treatment is warranted. The FHWA (1999) also states that if cracks are of high density and/or severely deteriorated, the pavement is in advanced decay; therefore, a crack treatment is not economically practical and does not provide any benefit to the serviceability.

Per Eaton and Ashcroft (1992), few states were able to specify equipment and materials for their entire state since most were divided into districts, divisions, or counties, which act independently. Often each district, division, or county has its own budget, climate, geography, and past practices. They also state that a pavement management system with proper documentation would enable all districts, divisions, and counties to make accurate cost assessments. While parts of this statement are true for Alaska, the climate varies greatly according to what part of the state the roads are being evaluated. When planning for crack sealing or filling, Table 2.2 lists FHWA's primary considerations according to FHWA (1999) and table 2.3 shows the three primary crack treatment material families.

Table 2.2: Primary considerations for crack treatment procedures.

Step	Description
1	Climatic condition, at time of procedure in general.
2	Highway classification.
3	Traffic level and percent trucks.
4	Crack characteristics and density.
5	Materials.
6	Material placement configurations.
7	Procedures and equipment.
8	Safety.

Table 2.3: Three primary crack treatment families.

Number	Description
1	Cold applied thermoplastic bituminous materials. Liquid asphalt (emulsion). Polymer-modified liquid asphalt.
2	Hot applied thermoplastic bituminous materials. Asphalt cement. Fiberized asphalt. Asphalt rubber. Rubberized asphalt. Low-modulus rubberized asphalt.
3	Chemically cured thermosetting materials. Self-leveling silicone.

According to the FHWA (1999), there are four general categories of placement configurations: flush fill, reservoir, over-band, and a combination of reservoir and over-band. In a reservoir configuration, material is placed within the walls of the crack and filled flush with the road surface or slightly below. The over-band configuration is filled over an uncut crack and either squeegeed or not to shape the surface of the material. A combination configuration involves cutting or routing the crack in various widths and depths (called the shape factor) and then filling or overfilling that is both squeegeed and not squeegeed. Sometimes a polyethylene backer rod is placed into a crack prior to filling. Routed configurations with a larger shape factor, width to depth ratio, are better at resisting adhesion loss. During on-site research for this study, this author witnessed that Alaska roads are flush fill, over-band, and some routing of cracks. The procedure for crack treatments can be as few as two to five steps as listed in Table 2.4.

Table 2.4: Crack treatment procedure steps (FHWA 1999).

Step	**Description**
1	Crack cutting: Routing Sawing
2	Crack cleaning and drying: Backpack blowing Air compressor Hot-air lance Sandblaster Wire brush
3	Material preparation and application: Pour pots Asphalt distributor Melter-applicator Direct heat kettles Indirect heat kettles (double boiler) Backer rod installation tools Silicone pump and applicator
4	Material finishing and shaping: Squeegee – U or V shaped
5	Blotting: Sand Toilet paper

Steps 2 and 3 are most essential. In regions where there is much crack movement such as areas with large temperature differentials, a high shape factor can provide more material for elastic movement, thus reducing strain. Cleaning and drying cracks are the most important steps for successful crack treatments (FHWA 1999). Failure often occurs from lack of adhesion, which is caused by dirt or moisture. Hot compressed air lance is the most effective technique for preparing a crack for sealing. Not only are debris blown away and moisture removed, but also the heated surfaces enhance bonding with the sealant or filler. Sandblasting can be effective since it produces a roughened surface and removes loose asphalt but can require a second air compressor wand to remove the sand or blasting material.

The type of material decided upon and the availability of equipment and skill level will dictate the equipment used to heat and apply the material. Hot-applied thermoplastic bituminous materials are heated and applied with an asphalt distributor or kettle-melter, which typically burn propane in a direct manner. Rubber and fiber modified asphalt materials must be heated indirectly with agitator kettles. Heat is applied through combusting propane or diesel onto a kettle with oil that transfers the heat to a separate kettle in a double boil type setup equipped with a pressure applicator. Cold-applied thermosetting materials such as those that are silicon based are applied with a pump and Teflon®-lined pressure applicator. Teflon-lined hoses aid in the prevention of curing in the hose. FHWA (1999) provides goals for each step of a complete crack treatment process, which are listed in Table 2.5.

Table 2.5: Crack treatment stepwise procedure goals.

Step	Goal
Crack Cutting	To create a uniform, rectangular reservoir, centered as closely as possible over a particular crack, while inflicting as little damage as possible on the surrounding pavement.
Crack Cleaning and Drying	To provide a clean, dry crack channel, free of loosened AC fragments, in which the crack treatment material and any accessory materials can be placed.
Material Preparation and Application	To install any accessory materials into the crack channel, prepare the crack treatment material for recommended application, and place the proper amount of material into or over the crack channel to be treated.
Material Shaping and Finishing	To shape or mold the previously applied material to the desired configuration.
Material Blotting	To apply a sufficient amount of blotter material to protect the uncured crack treatment material from tracking.

Along with performing a proper procedure, traffic control and safety are paramount. Personal protective equipment and education on the appropriate Material Safety Data Sheets (MSDSs) should be provided.

2.2.2 Crack Sealing Materials

As listed in Table 2.6, there are three families of crack sealing materials: cold-applied thermoplastic bituminous materials, hot-applied thermoplastic bituminous materials, and chemically cured thermosetting materials. The FHWA (1999) provides a table relating crack treatment materials, their appropriate specifications, and recommended applications, included in this document as Table 2.6. The materials are also listed from the least costly to most expensive in terms of material. The FHWA (1999) also provides a table depicting various attributes for each category of material, shown in this document as Table 2.7. Actual field performance should always be trialed. No matter how appropriate the material, a treatment will only be successful with proper installation.

Table 2.6: Crack sealing materials, specifications, and applications.

Material Type	Specification	Application
Asphalt Emulsion	ASTM D 977, AASHTO M 140, ASTM D 2397, AASHTO M 208	Filling
Asphalt Cement	American Society for Testing and Materials (ASTM) D 3381, AASHTO M 20, AASHTO M 226	Filling
Fiberized Asphalt	Manufacturer's recommended specs	Filling
Polymer-Modified Emulsion	ASTM D 977, AASHTO M 140, ASTM D 2397, AASHTO M 208	Filling, possible sealing
Asphalt Rubber	State specs, ASTM D 5078	Sealing, possible filling
Rubberized Asphalt	ASTM D 1190, AASHTO M 173, Fed SS-S-164	Sealing
	ASTM D 3405, AASHTO M 301, Fed SS-S-1401	Sealing
Low-Modulus Rubberized Asphalt	State-modified ASTM D 3405 specs	Sealing
Self-Leveling Silicone	ASTM D 5893	Sealing

Table 2.7: Properties associated with various crack treatment materials.

Property	Material Type							
	Emulsion	**Asphalt Cement**	**Fiberized Asphalt**	**Polymer-Modified Emulsion**	**Asphalt Rubber**	**Rubberized Asphalt**	**Low-Modulus Rubberized Asphalt**	**Self – Leveling Silicone**
Short Prep	x			x				xx
Quick to Place	x	xx	xx	x	xx	xx	xx	
Short Cure Time		xx		xx	xx	xx	xx	x
Adhesion	xx	xx	x	x	x	x	x	x
Cohesion					x	x	xx	x
Softening and Flow				x	x	x	xx	xx
Flexibility				x	x	x	xx	xx
Elasticity				x	x	x	x	xx
Aging						x	x	xx
Abrasion					x	xx	x	

x – applicable, xx – very applicable

2.2.3 Performance Evaluation

It should be agreed upon ahead of time what will be the quality inspection procedure both during and after the treatment has been applied. The FHWA (1999) recommends that a crack survey of 150-meter (m) sections should take place post-procedure annually. This is similar to the evaluation schedule required by the LTPP crack evaluation procedure and what was used as part of this study but measured in US customary units. Items to evaluate and record are full depth adhesion loss, full depth cohesion loss, complete pull out of material, spalls or secondary cracks extending below treatment material to crack, and potholes. It should be documented in terms of length of percent of failure divided by total length of crack treated times 100. The effectiveness is then the percentage of failure subtracted from 100. The effectiveness can then be tracked and graphed over time, which could result in a regression analysis to produce a prediction equation.

There are several reports by state DOTs that list policies for sealing cracks to minimize water infiltration and keep incompressibles from getting into cracks. Johnson et al. (2000) performed a study in Montana on crack sealing methods and materials. Four sites were selected using nine crack sealing materials and six different sealing techniques. The stated goal was to determine what role crack sealing has in Montana's pavement management system (PvMS). ASTM D5329 was the primary testing specification. All nine materials displayed a cone penetration greater than 90. There were no substantial differences between materials. Routing of the transverse cracks showed greater success than the cracks that were just capped. Routing was determined to be unnecessary for longitudinal cracks. The operators preferred to produce shallow reservoirs versus square reservoirs. Many sealants displayed failure during the coldest months but would heal during the summer months.

Shober (1996) states that crack sealing has to somehow enhance pavement performance either by the quality of ride and/or longevity of pavement. The sealing should be cost effective, meaning the benefits outweigh the costs, and costs should also include user delays and safety issues when traffic patterns are changed to perform a sealing operation. Shober believes that road authority agencies should be customer driven and holistic. Customers might not have an opinion on water infiltration or incompressible material in a crack unless it affects the quality of their ride or the cost effective longevity of the pavement. If crack sealing does enhance a pavement, then the cost – benefit analysis should be a life cycle cost analysis. If crack sealing is determined to be cost effective, then the most effective material and procedure should be determined for the climate and traffic at hand. In Shober's view, too many agencies start and end with the most appropriate material and procedure and do not perform a life cycle cost analysis for crack sealing (1996).

Shober (1996) describes a situation in Wisconsin where two adjoining counties had jointed plain concrete pavement. One county routinely sealed joints while the adjoining county did not. After 11 years, the county that did not seal had better-performing pavement in terms of faulting, cracking, spalling, and patching. Although Shober says this is not true for every location, he noted that when sealing was conducted, it might be prudent to leave some sections alone and not seal the cracks. These early findings eventually led to a design of experiments approach in which 50 test sections were conducted from 1974 to 1988. These were both doweled and un-doweled Portland concrete cement (PCC) sections on subgrades varying from sand to silt to silty clay with different levels of traffic. These sections were in urban as well as rural areas, on two and four lane roadways, and on dense as well as open graded base materials. The Wisconsin DOT used a Pavement Distress Index (PDI) to measure the amount of distress in their pavements. A PDI measures the extent and severity of several distresses and compiles it into one figure, ranging from 0 to 100 with 100 being the most severe. PDI was used to evaluate and perform a statistical analysis at the 95% confidence interval level. There were differences depending on spacing openings sealed. There were no statistical differences between sealed and unsealed openings using PDI as the measurement. The Wisconsin DOT made it a policy not to seal joints in PCC, claiming to save $6,000,000 annually (Shober 1996).

Chapter 3 Field Survey and Data Collection

3.1 Crack Sealing Status in Alaska Asphalt Pavements

As part of this study, a preliminary cracking sealing survey was conducted as part of a pavement preservation guidelines project during the summer of 2011 on eight sections in Alaska (Hicks et al. 2012). This was done to give an overview of the status of cracking sealing practice in Alaska. Table 3.1 summarizes these eight sections with two sections in Anchorage and six in Fairbanks. One of the most significant observations out of this preservation project was that crack sealing is a very common practice in Alaska. These crack sealing sections demonstrated a variety of severity levels, and if there was cracking in the sealant, it was hard to determine when it might have occurred. Further information such as previous pavement records, construction history, etc. is needed to evaluate the effectiveness of crack sealing treatment but had not been recorded. Figures 3.1 through 3.8 show the crack sealing applications that were evaluated.

Table 3.1: Crack sealing projects monitored in 2011.

No	Town/City	Year	Road	From	To	Current conditions
1	Anchorage	2011	Abbott	Lake Otis Parkway	Hilltop Ski Area	Cracks went from low to medium going toward Lake Otis Parkway. Figure 3.1.
2	Anchorage	2011	Old Seward	36th	Dimond	Medium cracking for the whole length. New seal. Figure 3.2.
3	Fairbanks	2011	Wembly	Aurora	Danby	New. Medium transverse and longitudinal, and low block cracking. Figure 3.3.
4	Fairbanks	2011	Trainor	Steese Hwy	River Rd	New. Medium transverse and low longitudinal cracking. Figure 3.4.
5	Fairbanks	2011	South Cushman	Old Richardson	26th	New. Medium transverse and low longitudinal and low block cracking. Some permafrost distortion. Figure 3.5.
6	Fairbanks	2011	Lacey St	4th	Wendell	Medium transverse and longitudinal, and low alligator cracking. Figure 3.6.
7	Fairbanks	2011	2nd	Cushman	Nobel	Medium transverse and longitudinal cracking. Low block and alligator cracking. Figure 3.7.

8	Fairbanks	2011	3rd	Cushman	Lacey	Low transverse and longitudinal cracking, and a few potholes. Figure 3.8.

Figure 3.1: Abbott Road, Anchorage, crack seal, thermal crack and frost damage, 2011.

Figure 3.2: Old Seward Highway, Anchorage, crack seal, thermal and frost damage, 2011.

Figure 3.3: Wembley Ave, Fairbanks, crack seal, 2011.

Figure 3.4: Trainor Gate Road, Fairbanks, crack seal, 2011.

Figure 3.5: South Cushman Street, Fairbanks, crack seal, 2011.

Figure 3.6: Lacey Street, Fairbanks, crack seal, thermal cracking, and alligator cracking, 2011.

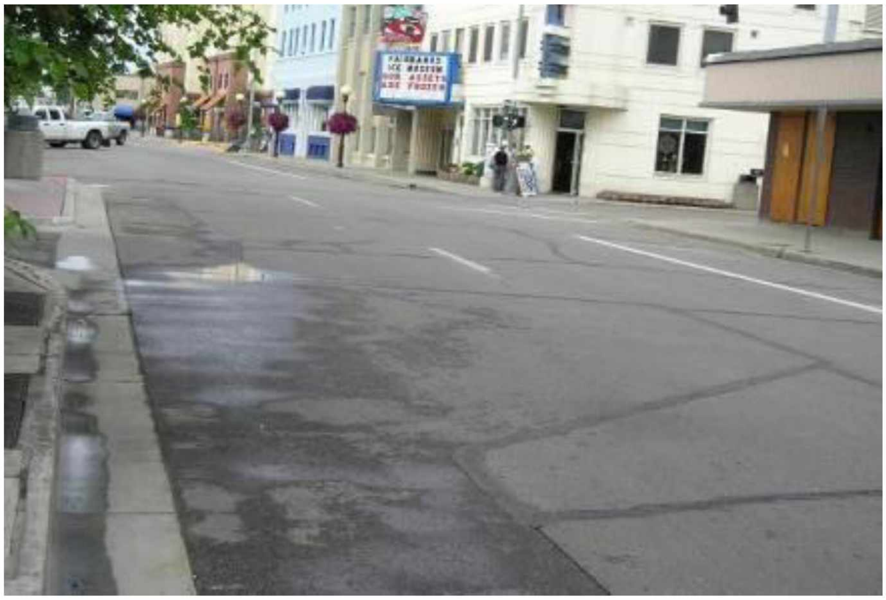


Figure 3.7: 2nd Avenue, Fairbanks, crack seal, thermal cracking, 2011.

Figure 3.8: 3rd Avenue, Fairbanks, crack seal, thermal cracking, 2011.

3.2 Field Site Selection and Data Collection

The preliminary preservation guidelines project motivated further evaluation of thermal cracking and crack sealing practices in Alaska. Therefore, one of the objectives of this study was to examine thermal cracking on a reasonably large sample of old Alaska AC pavement sections in a first attempt to evaluate the efficacy of sealing.

The following were considerations and actions taken in selecting pavement areas for study:

- Only standard “hot mix”-type asphalt concrete pavements were intended for study.
- The maximum sample size was limited due to time limitations of a single field season.
- Pavements were examined only during a single summer season.
- Urban areas were not studied due to safety reasons.
- Sample locations recognized as being paved with an asphalt surface treatment pavement (e.g., double-shot chip job or high-float pavement) were removed from the study.
- Sample locations recognized as including an asphalt surface treatment overlay (e.g., a “chip job” seal coat) were deleted from the study.
- Sample locations heavily damaged due to poor foundation conditions (e.g., permafrost) were not used in the study.

The ADOT&PF’s Pavement Management System (PMS) records indicated the existence of 52 sections of AC pavement that were 20 or more years old and spread reasonably throughout the contiguous nonurban road system of the department’s Northern and Central Regions. The minimum 20-year pavement surfacing age was selected because such pavements could be classified as old by normal standards. These pavements had reached or exceeded a normal pavement design life; therefore, they would be expected to exhibit well-developed evidence of the relationship between thermal cracking and any other aspects of long-term pavement performance. Additionally, the total number (52) of 20+-year-old pavement sections would provide more than enough individual sampling locations for examination during a single field season.

A sampling size of 120 locations was originally decided to be apportioned throughout the 52 old pavement sections. This practical sample size was selected based on workload considerations. The randomness of a selected sample location was modified only when deemed necessary to improve the quality of the sampling process, due to safety concerns, or because of uncertainty about pavement age evidenced in the field. It was eventually necessary to remove about 20% of the originally selected 120 locations from the sampling.

The total number of evaluated sections was pared down to 91 after several weeks of fieldwork, mostly due to encountering unexpected or problematic pavement types (e.g., newer than expected, recent maintenance overlay, very poor foundation conditions, surface treatment pavement type). A few sections were removed because of safety concerns, for example, to improve traffic visibility or because of unsafe parking conditions. Questions about the true age of the pavement surfacing layer at some locations remained throughout the project. For various reasons, including recognition of undocumented maintenance work, it was significantly more difficult to establish pavement age than had been originally assumed. Pavement ages were identified using the best available data. Sections were removed wherever age was obviously questionable. Although assigned ages may not be 100% accurate, the total sampling is considered large enough to compensate for the inclusion of a few new pavements.

All sample locations were 0.1 mile in length, and centered approximately at the milepost locations indicated in Appendix A. It is believed that the 91 sample locations eventually chosen during the course of the fieldwork are sufficient to meet the research objectives defined for the project. The final sampling size is considered large enough to reasonably represent the performance of old AC pavements throughout the area of Alaska's highway system being studied.

Urban pavement sections were not selected because of the inherent dangers of conducting fieldwork in urban areas and because the nonurban sampling was considered sufficiently large to provide a basis for valid conclusions. Figure 3.9 is a map of Alaska showing the general area of the state that was sampled. Locations of the 91 sample sites are indicated by the yellow pins. The exact location of each site is accurately identified by latitude and longitude coordinates (WGS 84). Sections shown on the map are located on the following highways (listed generally from north to south):

- Elliott Highway—within 50 miles of Fairbanks
- Steese Highway—within 40 miles of Fairbanks
- Richardson Highway—between Delta and Valdez
- Parks Highway—between Healy and Willow
- Alaska Highway—between Tok and Delta
- Tok Cutoff—Tok to 30 miles south of Tok
- Glenn Highway—Little Nelchina River to 15 miles west of Glennallen
- Sterling Highway—except for 30 miles at north end

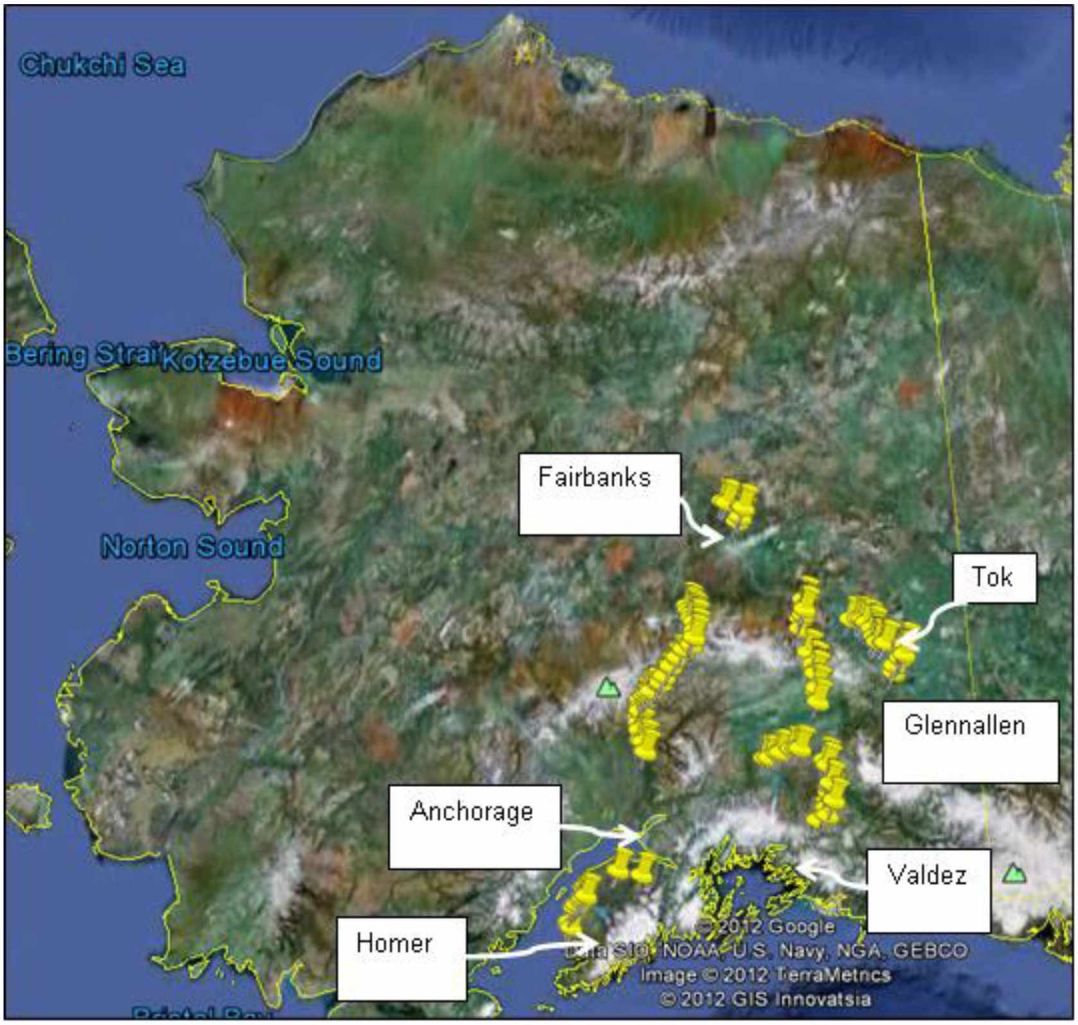


Figure 3.9: Google Maps locations of the 91 road sections evaluated.

3.3 Data Collection Methods

Each sample location was evaluated using three methods:

- The Long Term Pavement Performance (LTPP) program is the standard FHWA method for generally defining the surface condition of a pavement (FHWA 2003).
- Pavement Surface Evaluation and Rating (PASER) is the University of Wisconsin's simplified method for generally defining the surface condition of a pavement (Walker 2002).
- Special Thermal Crack Evaluation (STCE) was developed for this study to serve a specific purpose—it shares almost nothing in terms of data format or purpose with the LTPP and PASER methods and defines only thermal cracking aspects of a pavement.

The LTPP and PASER methods are standard and comprehensive ways of documenting the general condition of the paved surface—to provide an overall pavement condition "snapshot" at a single point in time. The STCE method provides data specifically used for evaluating thermal crack damage.

3.3.1 Long Term Pavement Performance (LTPP)

The LTPP program, which started in 1987, was conducted under the SHRP (Miller and Bellinger 2003). Though the SHRP ended in 1992 as planned, the LTPP continues under the FHWA. To date, 2,500 pavement sections have been evaluated in all of the United States, Puerto Rico, and 10 Canadian Provinces (FHWA 2010). The data consisted of surface condition, climate, and traffic volumes and loads. The data were intended for use in providing information for designing longer lasting, improved roads.

Normally, under a LTPP program measurements are recorded in the International System (IS) system but for this study measurements were recorded in United States customary (USC) system, 500 feet are surveyed, and the data are kept in two forms: mapping distresses in 50-foot increments and quantitative measured values. The LTPP manual states that photographs depicting certain distress or showing levels of severity are also acceptable. For this particular study, it was decided by the team that 1/10 of a mile (approximately 530 feet) would be the length for each evaluation. The milepost locations designated as the location of each of the 91 project field sites were used to define the center point for each 530-foot LTPP survey. This length was measured with a typical pavement measuring wheel; paint marks displayed the center point and both ends. It was decided that photographs showing either typical distresses for the section or some unique severe distress would be one form of documentation. Filling out the typical quantitative measurements would be the other form of documentation. The blank forms for quantitative measurements shown in the LTPP manual are shown on Figures 3.10 and 3.11. The FHWA manual *Distress Identification Manual for the Long Term Pavement Performance Program* describes how to identify surface distresses in AC pavements in five parts, A through E.

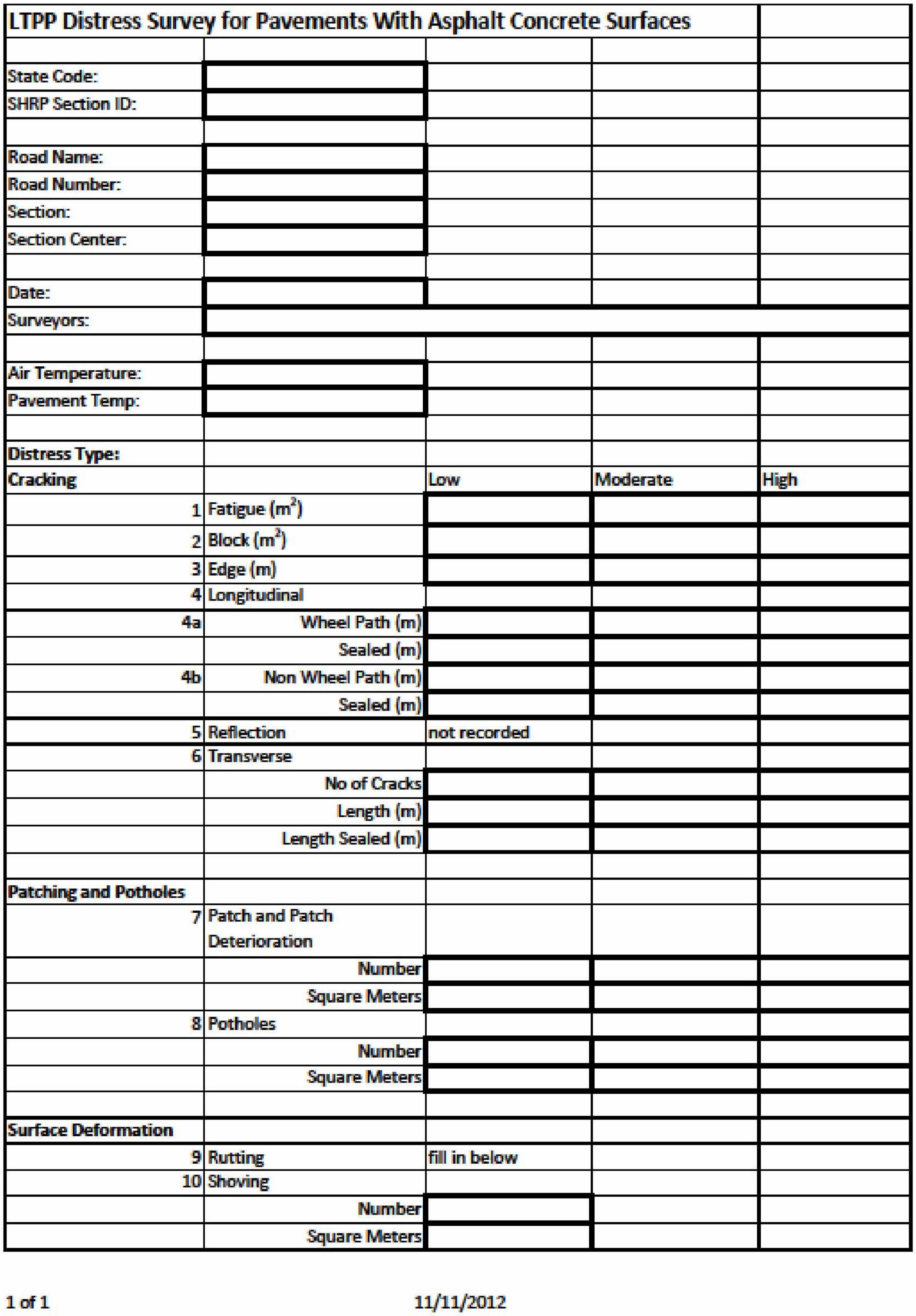
A. Cracking
B. Patching and Potholes
C. Surface Deformation
D. Surface Defects
E. Miscellaneous Defects

Crack types that were evaluated for a section are the following:

1. Fatigue
2. Block
3. Edge
4. Longitudinal
    a. Wheel Path
    b. Non-wheel path
5. Reflection
6. Transverse

Data were recorded for all crack types (items 1 through 6) listed above, but only transverse cracks (item 6) are discussed in this study. Transverse cracks run in a general perpendicular direction to that of traffic flow. The quantity of transverse cracks was recorded, as well as the total length in a given section at a certain level of severity. Although more than one severity level can exist in a given section, for the purpose of this study, the average was recorded. The total length of cracks that remain successfully sealed are recorded on a separate line as well as the total length of transverse cracks. The severity of cracks were categorized in the following three ways:

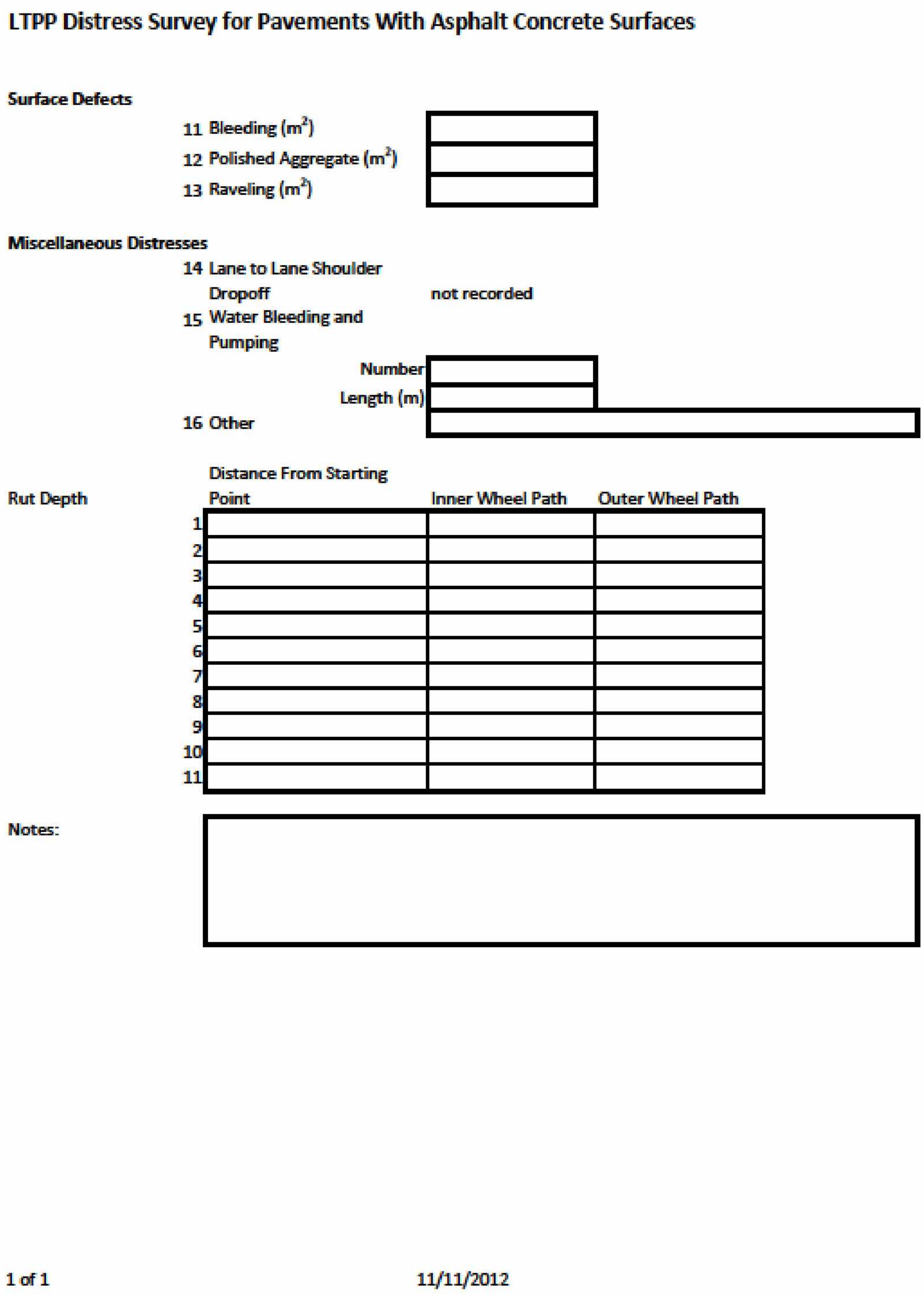
- Low severity cracks are tight, 1/4 inch or less, with no spalling or deterioration along the crack edge. Low severity cracking can also be described as a sealed crack where the opening cannot be determined.
- Medium severity cracks are open from 1/4 inch to 3/4 inch with little signs of secondary deterioration and little adjacent cracking.
- High severity cracks are open more than 3/4 inch with spalling along the crack edge, as well as much adjacent cracking.



LTPP Distress Survey for Pavements With Asphalt Concrete Surfaces				
State Code:				
SHRP Section ID:				
Road Name:				
Road Number:				
Section:				
Section Center:				
Date:				
Surveyors:				
Air Temperature:				
Pavement Temp:				
Distress Type:				
Cracking		Low	Moderate	High
1	Fatigue (m^2)			
2	Block (m^2)			
3	Edge (m)			
4	Longitudinal			
4a	Wheel Path (m)			
	Sealed (m)			
4b	Non Wheel Path (m)			
	Sealed (m)			
5	Reflection	not recorded		
6	Transverse			
	No of Cracks			
	Length (m)			
	Length Sealed (m)			
Patching and Potholes				
7	Patch and Patch Deterioration			
	Number			
	Square Meters			
8	Potholes			
	Number			
	Square Meters			
Surface Deformation				
9	Rutting	fill in below		
10	Shoving			
	Number			
	Square Meters			

1 of 1 11/11/2012

Figure 3.10: Printout of LTPP survey sheet page 1 used in this study.



LTPP Distress Survey for Pavements With Asphalt Concrete Surfaces

Surface Defects

11 Bleeding (m^2) ☐
12 Polished Aggregate (m^2) ☐
13 Raveling (m^2) ☐

Miscellaneous Distresses

14 Lane to Lane Shoulder Dropoff not recorded
15 Water Bleeding and Pumping
Number ☐
Length (m) ☐
16 Other ☐

Rut Depth

	Distance From Starting Point	Inner Wheel Path	Outer Wheel Path
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			

Notes: ☐

1 of 1 11/11/2012

Figure 3.11: Printout of LTPP survey sheet page 2 used in this study.

3.3.2 Pavement Surface and Evaluation Rating (PASER)

PASER for asphalt roads is a road surface condition rating system produced by the Wisconsin Transportation Information Center, a department at the University of Wisconsin-Extension program, which also maintains the rating system (Walker 2002). Various road surface distresses are discussed in the *PASER-Manual Asphalt Roads* (Ibid), along with possible treatments that could revitalize the condition providing improved serviceability to extend the life of the treated road. The PASER rating is a methodology whereby the observer takes into account the severity level of various road surface conditions and combines them into a single number as a result. The result ranges from 10 to 1, with 10 being a newly constructed roadway and 1 being a totally failed roadway. Compared to the LTPP survey, PASER is quicker to perform with less quantification.

The PASER manual suggests that when evaluating a road section, first look at the general condition of the road surface. Next, think about what treatments would correct the distresses or bring it back to an acceptable level of serviceability. Finally, compare what is being looked at to what pictures and descriptions are in the PASER asphalt manual. The manual also notes that not all distresses described for a particular rating need to actually exist on the pavement section being evaluated to have a particular rating. Surface defects, surface deformations, cracks, and patches and potholes comprise the four major categories of distresses. Raveling, flushing, and polishing are surface defects. Rutting, rippling and shoveling, settling, and frost heaves make up surface deformations. Transverse, longitudinal, block, alligator, reflection, and slippage are the various names for crack types.

For this particular study, PASER data were recorded for severity in the following manner in an Excel spreadsheet: n – none, l – low, m – medium, and s – severe. Categories are meant to be assigned by quick visual assessment (a “windshield” survey). The following definitions were used as a rough guide to assist with assigning a severity category to cracking during this study, and Table 3.2 shows the PASER ratings with accompanying description.

- n (none) = no cracking.
- l (low) = 1/4 inch or less.

- m (medium) = 1/4 inch to 1/2 inch and up to 3/4 inch if the edges are in good condition.
- s (severe) = more than 1/2 inch if there is much edge deterioration and secondary cracking, or more than 3/4 inch if the edges are in good condition.

Table 3.2: PASER ratings and descriptions.

Surface Rating	**Visible Distress**	**General Condition/ Treatment Measure**
10	None	New condition.
9	None	Recent overlay, like new.
8	No longitudinal cracks except reflection of paving joints. Occasional widely spaced transverse cracks, 40 ft. All cracks sealed or tight, opening 1/4″ or less.	Recent sealcoat or new cold mix. Little or no maintenance required.
7	Very slight or no raveling showing some traffic wear. Tight longitudinal cracks due to reflection of paving joints. Tight transverse cracks spaced 10 ft with slight crack spalling. None to a few patches in excellent condition.	First signs of aging. Maintain with routine crack filling.
6	Slight raveling and traffic wear. Longitudinal cracks opened 1/4″ – 1/2″ with some spaced less than 10 ft. First sign of block cracking. Slight to Moderate flushing and polishing. Occasional patching in good condition.	Shows signs of aging. Sound structural condition. Could extend life with a sealcoat.

Surface Rating	**Visible Distress**	**General Condition/ Treatment Measure**
5	Moderate to severe raveling, loss of fine and course aggregate. Longitudinal and transverse cracks opened to 1/2″ with slight crack spalling and secondary cracks. First sign of longitudinal cracks near pavement edge. Block cracking on 50% of the surface. Extensive to severe flushing or polishing. Some patching or edge wedging in good condition.	Surface aging. Sound structural condition. Needs sealcoat or thin nonstructural overlay of 2″ or less.
4	Severe surface raveling. Multiple longitudinal and transverse cracking with slight raveling. Longitudinal cracking in wheel path. Block cracking over 50% of the surface. Patching in fair condition. Slight rutting or distortions, 1/2″ deep or less.	Significant aging and first signs of need for strengthening. Would benefit from an overlay of 2″ or more.
3	Closely spaced longitudinal and transverse cracking with spalling and crack erosion. Severe block cracking. Some alligator cracking, 25% of surface or less. Patches in fair to poor condition. Moderate rutting or distortion at 1″ to 2″ deep. Occasional potholes.	Needs patching and repair prior to major overlay. Milling and removal of deterioration extends the life of the overlay.
2	Alligator cracking over 25% of the surface. Severe rutting and distortions over 2″ deep. Extensive patching in poor condition. Potholes.	Severe deterioration. Needs reconstruction with extensive base repair. Pulverization of old pavement is effective.
1	Severe distress with extensive loss of surface integrity.	Failed and needs total reconstruction.

Figure 3.12 (the PASER field data form) depicts the adaptation of the PASER rating system to an electronic spreadsheet with a few added parameters important to Alaska and other cold regions. The spreadsheet is constructed with check-off columns so that the observer can quickly rate distresses. The other added distresses are frost heave, permafrost, deformation, and drainage. These distress types are of great importance in a cold-region environment.

PASER FORM

Date		GPS
Evaluating Person		
Road Name		
Section ID		
Region		
Town/City		
Beginning Mileage		
Ending Mileage		
Last Treatment		
Date of Last Treatment		
Original Construction Type		
Date of Original Construction		
ADT		
Last IRI averaged over section		
Last Rut averaged over section		
Last PSR averaged over section		
Speed Limit		
Road Category		

	Distress Type	none	low	medium	severe
1	Raveling				
2	Flushing				
3	Polishing				
4	Rutting				
5	Transverse Cracks				
6	Reflection Cracks				
7	Slippage Cracks				
8	Longitudinal Cracks				
9	Block Cracks				
10	Alligator Cracks				
11	Patches				
12	Potholes				
13	Frost Heaves				
14	Permafrost				
15	Deformation				
16	Drainage				

Paser Number

Comments:

Figure 3.12: PASER form used in this study.

3.3.3 Special Thermal Crack Evaluation (STCE)

The STCE does not share data format or purpose with the LTPP and PASER methods described previously. It was developed for this study to serve a specific purpose and (as opposed to the LTPP and PASER methods) not just to provide a snapshot of general pavement condition. The STCE method collects data to help answer three basic questions that are important to Alaska's pavement maintenance: (1) To what degree does vehicle traffic affect thermal cracking? (2) Is the interaction between thermal cracking and traffic a significant contributing factor in producing additional forms of damage in AC pavements? (3) Does the maintenance practice of sealing thermal cracks significantly improve general pavement performance? These questions are expanded upon with brief commentary below:

1. Does the condition of the thermal cracks themselves tend to deteriorate with time?
   - Theory says they should be affected by repeated vehicle loading.
   - This question is addressed by comparing the condition of thermal cracks in wheel path versus non-wheel path areas on old pavements.
2. Do thermal cracks negatively influence other aspects of pavement performance?
   - This is the assumed case in all pavement preservation literature.
   - The question is addressed by examining the pavement for signs of fatigue cracking, potholing, excess rutting, or other signs of structural softening near thermal cracking on old pavements.
3. Is sealing of thermal cracks necessary?
   - Standard practice indicates that it is.
   - This question is addressed by comparing the condition of sealed cracks versus nonsealed cracks on old pavements.

The emphasis of the STCE method is on examining old pavements. It is common sense that careful examination of thermal cracking and sealing on old pavements in a given area is the most reliable basis for proposing good maintenance strategies for that same area in the future. With this empirical approach in mind, only pavements thought to be 20 years old or older were evaluated. The STCE method requires field personnel have experience recognizing and describing all aspects of pavement surface damage and maintenance techniques. Each field site was photographed and visually examined to obtain a general impression of the long-term value of crack sealant practices (i.e., sealed versus nonsealed) at that location. Photographs and miscellaneous notes were added to the field data sheets to document the observations.

Specifically, the STCE method evaluates the following:

A. What is the difference in the wheel path versus the non-wheel path condition of major transverse thermal cracks with the section?
   - No difference
   - Slightly different
   - Much different

B. What is the difference in the wheel path versus non-wheel path condition of lesser thermal cracks?
   - No difference
   - Slightly different
   - Much different

C. What is the maximum total width of the widest of major transverse cracks observed at the site (total width includes the damaged zone extending perpendicular to the edge of the crack)?
   - Less than 2 inches
   - 2 to 5 inches
   - More than 5 inches

D. What is the maximum total width of the widest of lesser thermal cracks observed at the site (total width includes the damaged zone extending perpendicular to the edge of the crack)?
   - Less than 1/8 inch
   - More than 1/8 inch

E. What is the extent of noticeable pavement deterioration due to major transverse thermal cracking?
   - None
   - Slightly noticeable
   - Very noticeable

F. What is the extent of noticeable pavement deterioration due to lesser thermal cracking?
  - None
  - Slightly noticeable
  - Very noticeable

G. Which thermal cracks received sealant?
  - No thermal cracks sealed (or sealant so old as to appear absent)
  - Major transverse thermal cracks sealed
  - Both types of thermal cracks sealed

H. What is the present condition of the existing sealant?
  - No sealant (or sealant so old as to appear absent)
  - Sealant failed and most or all sealed thermal cracks have opened (recracked)
  - Some sealant failure (some recracking)
  - Most sealant in good condition (limited or no recracking)

In general, recording data for the STCE method requires recognizing thermal cracks of two types: major thermal cracks and lesser thermal cracks. Major transverse thermal cracks are oriented perpendicular or nearly perpendicular to the road's centerline. They vary in appearance from hairline, extending nearly straight across the road (almost invisible to casual observation), to spalled, ragged zones, several inches wide that may extend crookedly across the road. Many of these cracks bifurcate between the two pavement edges and form two or more branches. The cracks are usually identified easily, even from vehicles at a speed of 60 mph. A zone of pavement along the crack is nearly always at least slightly depressed, and this produces the somewhat rhythmic bump felt by all vehicle occupants on all roads in colder areas of Alaska. These depressed zones can become quite deep and extremely annoying to those inside the vehicles, even possibly influencing user costs through accumulated vehicle damage. It is common knowledge among ADOT&PF engineers that these cracks extend below the bottom of the pavement to variable depths. Examples of major thermal cracks are shown on Figure 3.13.

Figure 3.13: Examples of major thermal cracks.

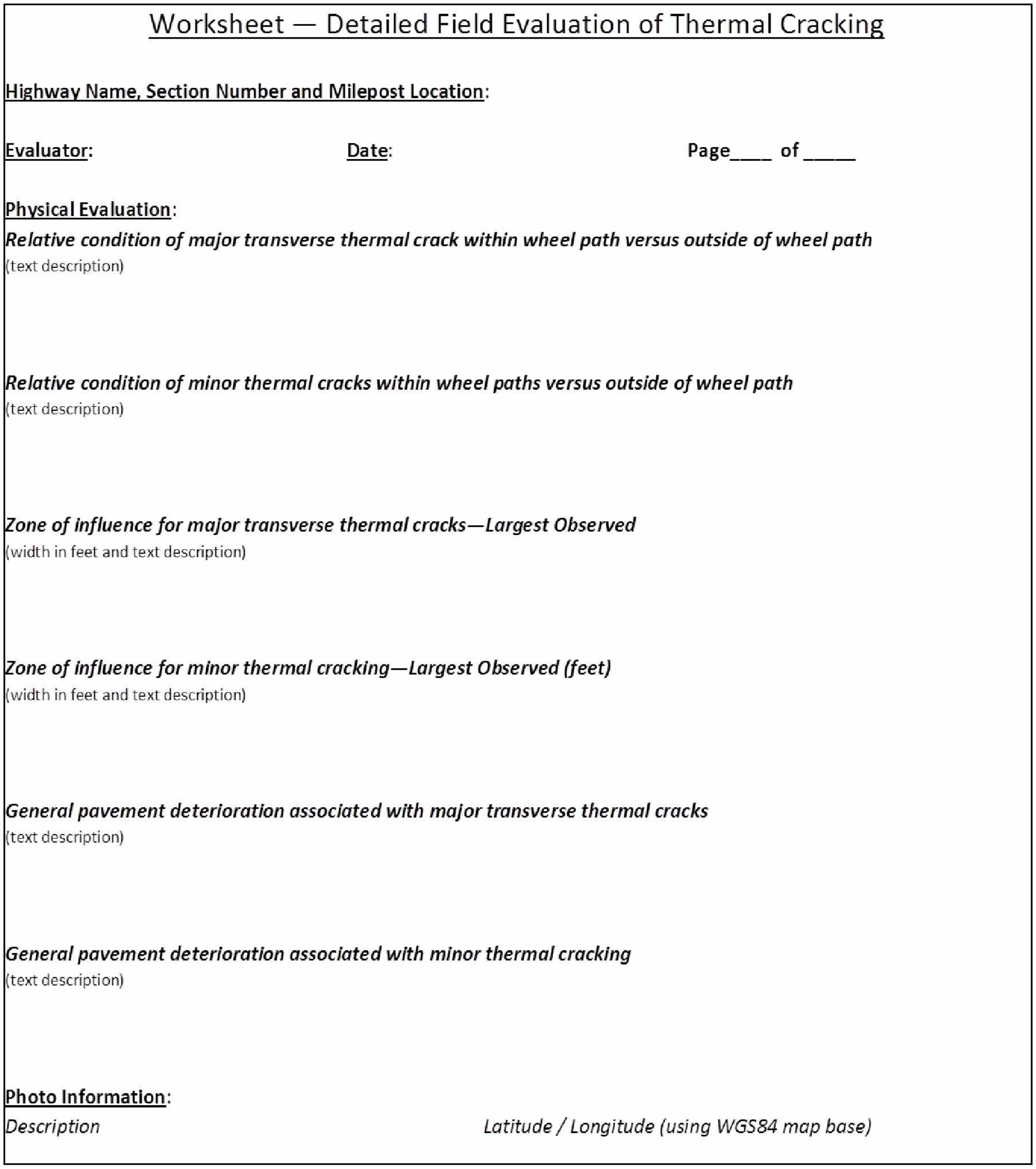
Lesser thermal cracks constitute all other thermally induced cracks that are not major transverse cracks. Their appearance ranges from short segments of hairline cracking to a very distinctive grid-like pattern. In newer pavements, short segments of this crack type are usually more or less perpendicular to the centerline and can be more or less parallel to the centerline. In older pavements, the maturing pattern often becomes grid-like, as the individual segments lengthen and intersect. These cracks are referred to as lesser thermal cracks because their width is nearly always less than 1/4 inch (they are also known as block cracking or grid cracking). It is believed that these cracks do not extend below the bottom of the pavement. Additional research is needed to confirm this belief. Examples of lesser thermal cracks are shown in Figure 3.14.

Figure 3.14: Examples of lesser thermal cracks.

The data recorded for the STCE method comprises evaluating eight questions and recording a ranking number for each. Table 3.3 shows each question and the meaning of the ranking number. There is also a letter assigned to each question so that the recorded data could be more easily and completely shown in Table 3.3. A value shown as “n/a” means there was no visible condition as described by the question at this particular section. Data collection at each of the field sites consisted of providing responses to the following questions using only the listed responses but with commentary as well. The field data sheets (two sheets) used for collecting STCE field data, developed for this research, are shown on Figure 3.15.

Table 3.3: STCE observation questions, letter assigned, and meaning of recorded ranking.

A	Condition of Major Transverse Cracks (wheel path [WP] vs. non-wheel path [non-WP]) 1 = no difference, 2 = slight difference, 3 = much difference
B	Condition of Lesser Thermal Cracks (WP vs non-WP) 1 = no difference, 2 = slight difference, 3 = much difference
C	Maximum Observed Width of Major Transverse Crack Zone 1= <2 inch, 2 = 2 to 5 inch, 3 = > 5 inch
D	Maximum Observed Width of Lesser Thermal Crack Zone 1 = <1/8 inch, 2 = ≥1/8 inch
E	General Pavement Deterioration Due to Major Transverse Cracking 1 = none, 2 = slightly noticeable, 3 = very noticeable
F	General Pavement Deterioration Due to Lesser Thermal Cracking 1 = none, 2 = slightly noticeable, 3 = very noticeable
G	Presence of Crack Sealant 1 = no/very old sealant, 2 = majors sealed, 3 = majors + lessers sealed
H	Present Condition of Sealant 1 = old and/or recracked, 2 = some recracking, 3 = mostly good condition, 4 = no sealant



Worksheet — Detailed Field Evaluation of Thermal Cracking

Highway Name, Section Number and Milepost Location:

Evaluator: **Date**: **Page____ of _____**

Physical Evaluation:

Relative condition of major transverse thermal crack within wheel path versus outside of wheel path

(text description)

Relative condition of minor thermal cracks within wheel paths versus outside of wheel path

(text description)

Zone of influence for major transverse thermal cracks—Largest Observed

(width in feet and text description)

Zone of influence for minor thermal cracking—Largest Observed (feet)

(width in feet and text description)

General pavement deterioration associated with major transverse thermal cracks

(text description)

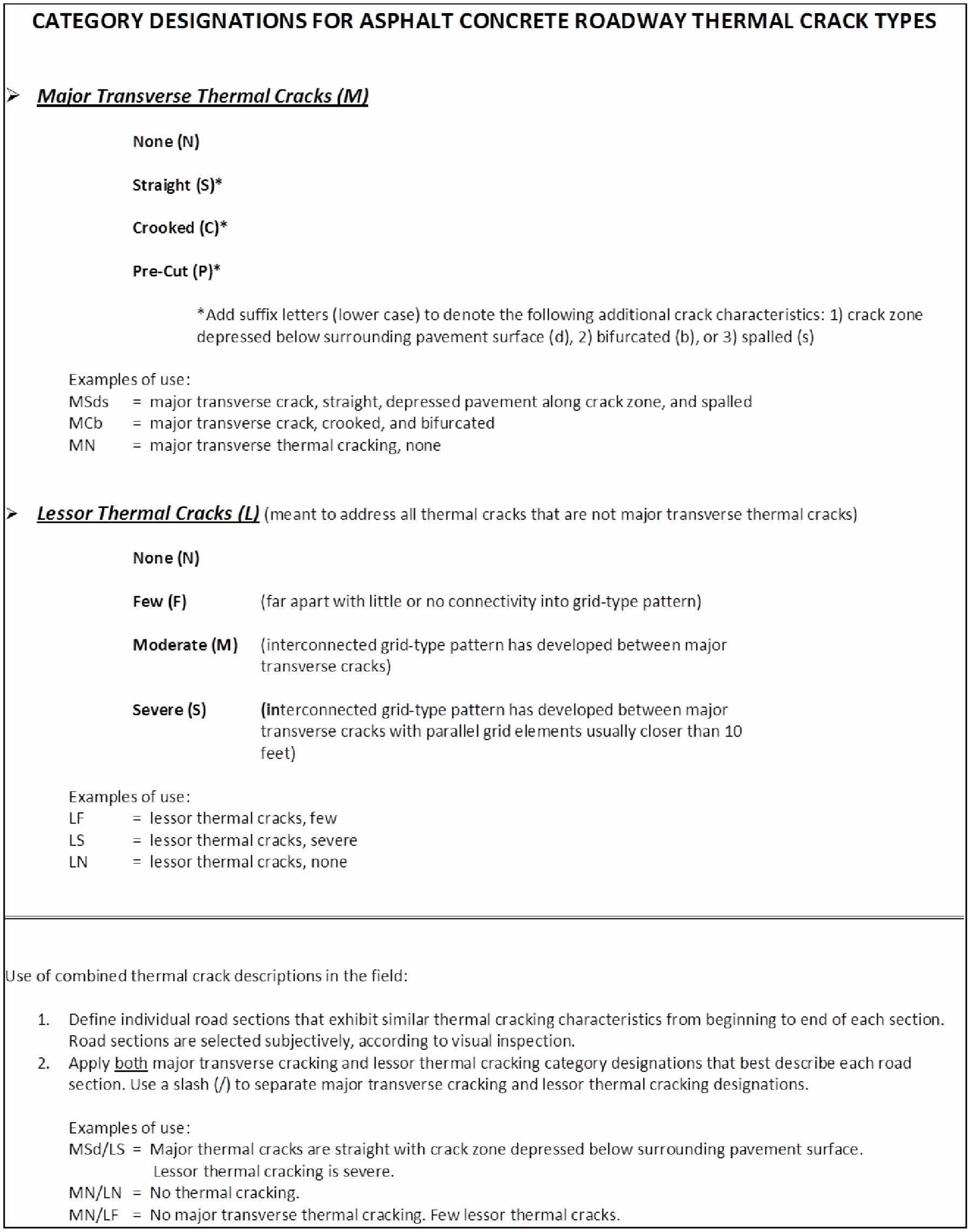
General pavement deterioration associated with minor thermal cracking

(text description)

Photo Information:

Description *Latitude / Longitude (using WGS84 map base)*

Figure 3.15: STCE recording sheets used in the field (page 1 of 2).



CATEGORY DESIGNATIONS FOR ASPHALT CONCRETE ROADWAY THERMAL CRACK TYPES

- ***Major Transverse Thermal Cracks (M)***

None (N)

Straight (S)*

Crooked (C)*

Pre-Cut (P)*

*Add suffix letters (lower case) to denote the following additional crack characteristics: 1) crack zone depressed below surrounding pavement surface (d), 2) bifurcated (b), or 3) spalled (s)

Examples of use:
MSds = major transverse crack, straight, depressed pavement along crack zone, and spalled
MCb = major transverse crack, crooked, and bifurcated
MN = major transverse thermal cracking, none

- ***Lessor Thermal Cracks (L)*** (meant to address all thermal cracks that are not major transverse thermal cracks)

None (N)	
Few (F)	(far apart with little or no connectivity into grid-type pattern)
Moderate (M)	(interconnected grid-type pattern has developed between major transverse cracks)
Severe (S)	(interconnected grid-type pattern has developed between major transverse cracks with parallel grid elements usually closer than 10 feet)

Examples of use:
LF = lessor thermal cracks, few
LS = lessor thermal cracks, severe
LN = lessor thermal cracks, none

Use of combined thermal crack descriptions in the field:

1. Define individual road sections that exhibit similar thermal cracking characteristics from beginning to end of each section. Road sections are selected subjectively, according to visual inspection.
2. Apply both major transverse cracking and lessor thermal cracking category designations that best describe each road section. Use a slash (/) to separate major transverse cracking and lessor thermal cracking designations.

Examples of use:
MSd/LS = Major thermal cracks are straight with crack zone depressed below surrounding pavement surface. Lessor thermal cracking is severe.
MN/LN = No thermal cracking.
MN/LF = No major transverse thermal cracking. Few lessor thermal cracks.

Figure 3.15: STCE recording sheets used in the field (page 2 of 2).

3.4 Data Collected

The LTPP method has the observer record data for thermal cracking for three attributes. The first attribute is the quantity of thermal cracks in a section being observed, 1/10 mile for this project, at low, medium, and high severity. The second attribute is the length of thermal cracks and the third being the length of effectively sealed thermal cracks at the three levels of severity previously mentioned. Appendix A displays the LTPP data recorded for the 91 sections.

PASER data were recorded for all 91 sections as well, as described in the previous section, 3.3.2. The intention of PASER is to provide a quick and simple means to determine this single rating while taking into account various pavement surface deficiencies of which thermal cracking is the focus of this study, or more aptly stated as the sealing of thermal cracks. Appendix B shows the recorded PASER values and final PASER rating for each section. The meaning of these ratings is discussed in section 3.3.

STCE data were recorded for all 91 sections as well and described in a previous section, 3.3.3. The intention of STCE is to provide a more detailed method for evaluating the effect of traffic on thermal crack deterioration, to determine whether there is a difference on the general pavement deterioration due to major thermal cracks and minor thermal cracks separately, to discover if crack sealant is present, and to evaluate the condition of the present sealant. Appendix C shows the recorded STCE values. The meaning of these ratings is discussed in section 3.3.

ADOT&PF data that were used for analysis for all 91 sections are shown in Appendix D. These data are the age for each section, milepost of ADOT&PF Road Weather Data Collection site, minimum air temperature (F°), minimum pavement temperature (F°), maximum air temperature (F°), maximum pavement temperature (F°), average daily traffic (ADT), International Roughness Index (IRI), Rut, and Present Serviceability Rating (PSR).

As described earlier, thermal cracking occurs due to temperatures low enough to cause contractive forces stronger than the tensile strength of the asphalt at those particular temperatures. Another engineering parameter used to account for low-temperature thermal stresses is the freezing index. The Western Regional Climate Center (WRCC) has many data collection sites in Alaska from which average daily temperatures can be obtained. For this study, the freezing index was calculated for all road sections evaluated. Average daily maximum and minimum temperatures are listed in the WRCC website for each data recording location. Average daily temperatures are calculated from the maximum and minimums and summed for all days that the average daily temperature falls below 32 °F. WRCC data recording stations were matched to the evaluated road sections, and the calculated freezing index for each is listed in Appendix E.

Chapter 4 Data Analysis

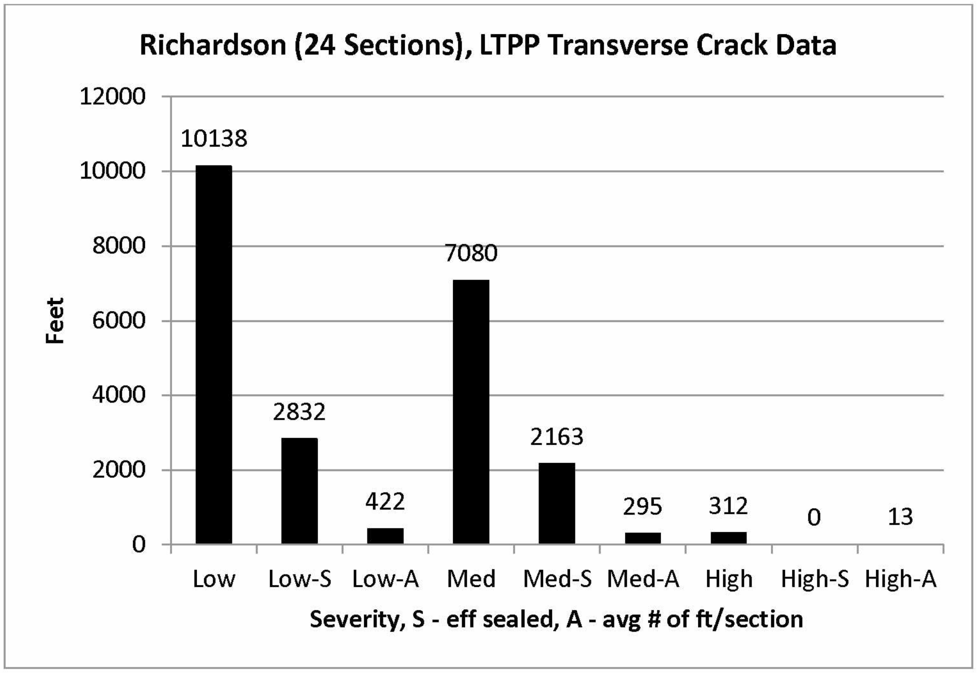
4.1 Field Data Interpretation

This section describes the results of three methods of data collection on the 91 sites selected for this study. Histograms are provided in each section that show the results of the particular data collection method used.

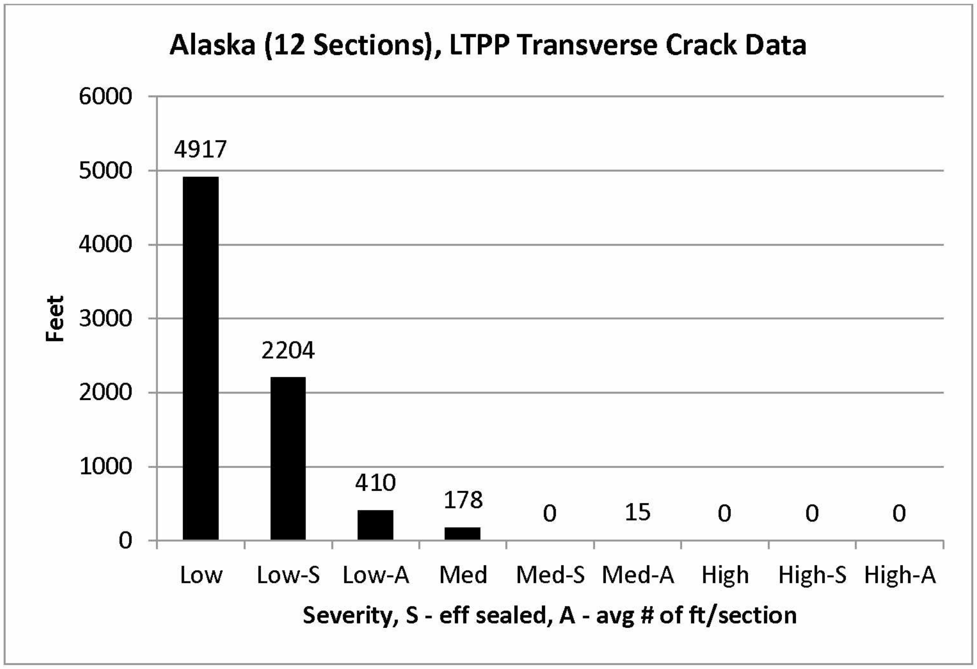
4.1.1 LTPP Results

The LTPP data are presented on Figure 4.1, which consists of nine histograms. The data, per the focus of this study, show only transverse crack measurements. The histograms included on Figure 4.1 depict information about LTPP's three levels of transverse crack severity, as well as the apparent effectiveness of sealants used on those cracks. The effectiveness of transverse crack sealants has played no major role in determining the present condition of old pavements. An interesting observation based on Figure 4.1 is that transverse cracking (according to the LTPP category) is not obviously more severe on the more northern sites. All sections on a given highway are represented by one histogram. Each histogram contains a maximum of 9 bars. From left to right, the bars represent:

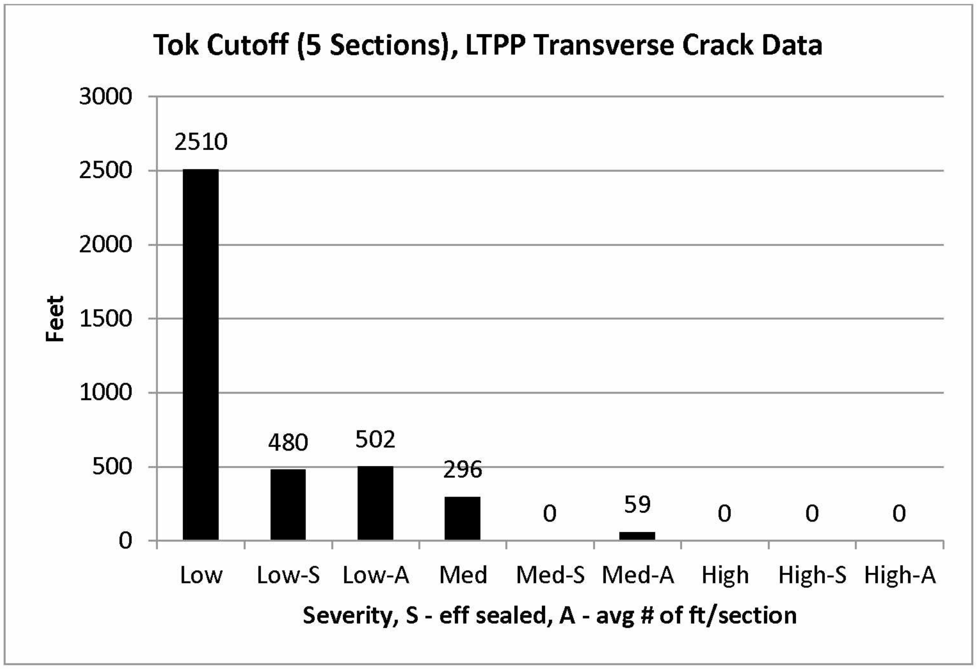
Low	Total linear feet of low-severity transverse cracking
Low-S	Total linear feet of effectively sealed transverse cracks of low severity
Low-A	Average linear feet of low-severity transverse cracking
Med	Total linear feet of medium-severity transverse cracking
Med-S	Total linear feet of effectively sealed transverse cracks of medium severity
Med-A	Average linear feet of medium-severity transverse cracking
High	Total linear feet of high-severity transverse cracking
High-S	Total linear feet of effectively sealed transverse cracks of high severity
High-A	Average linear feet of high-severity transverse cracking



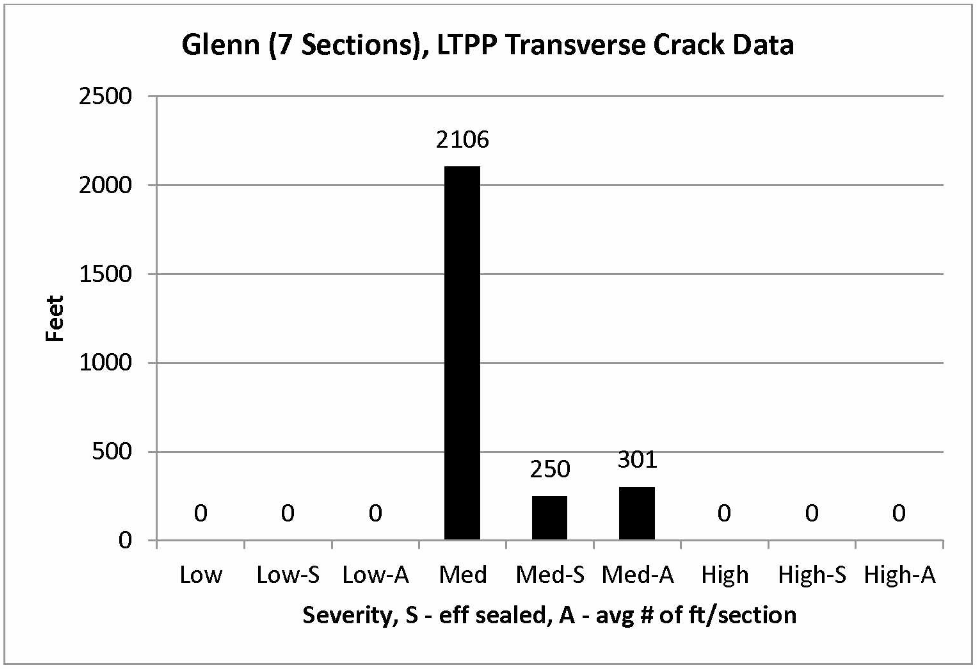
(a) The Richardson Highway



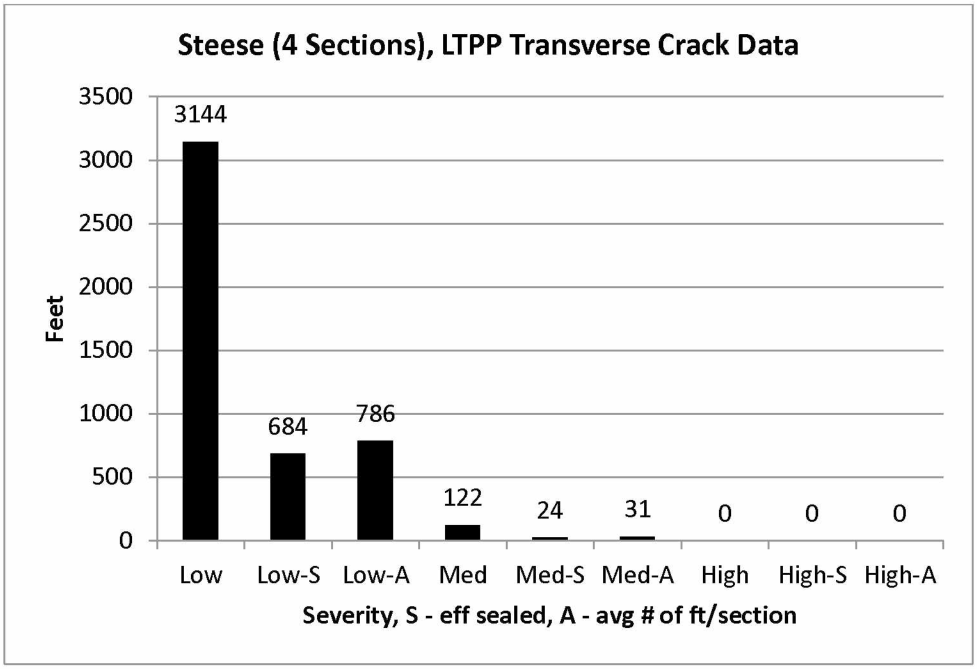
(b) The Alaska Highway



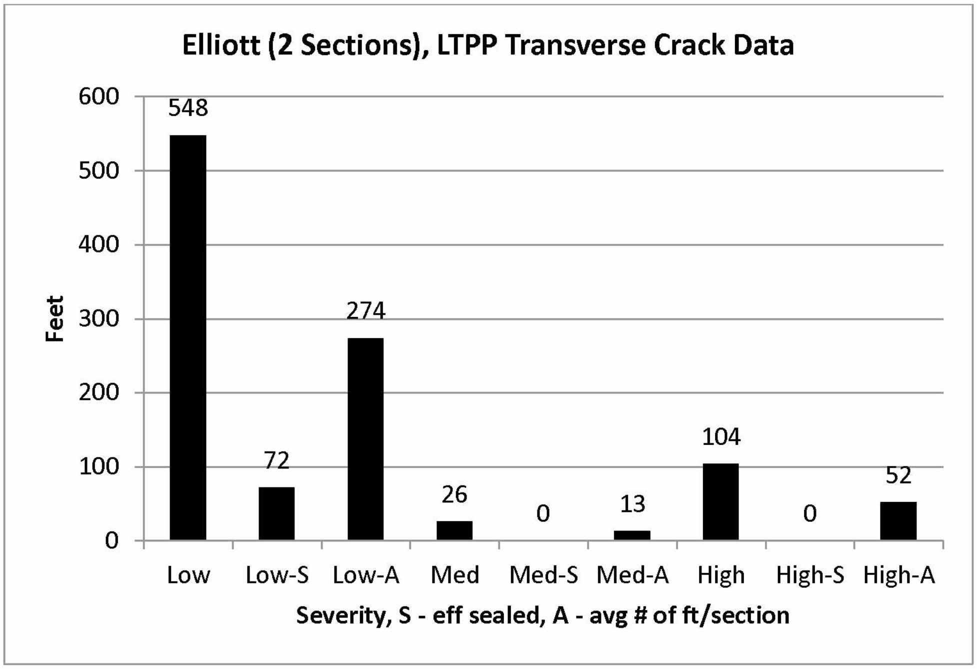
(c) The Tok Cutoff Highway



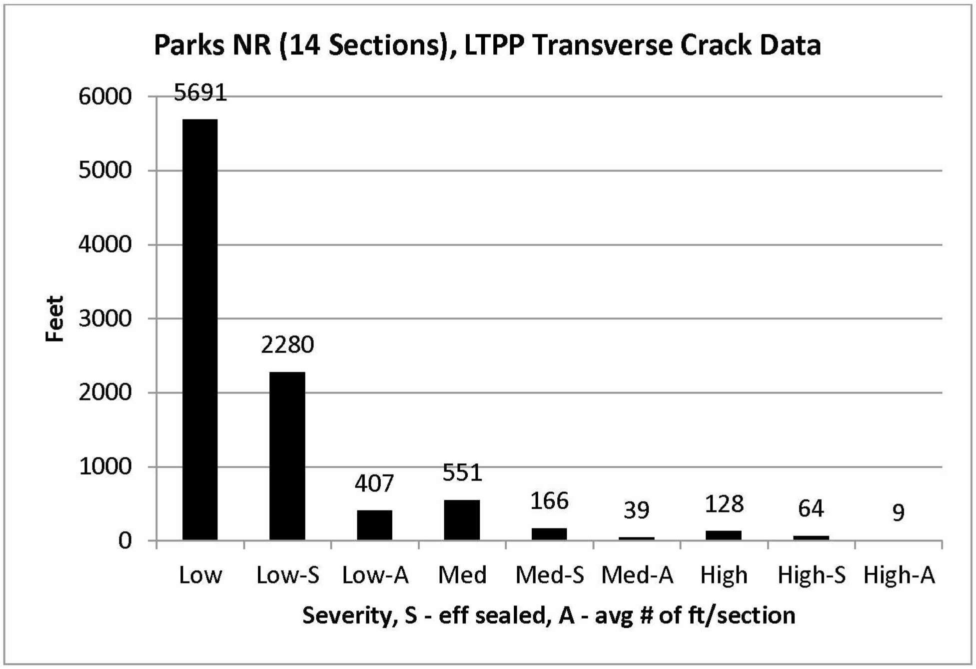
(d) The Glenn Highway



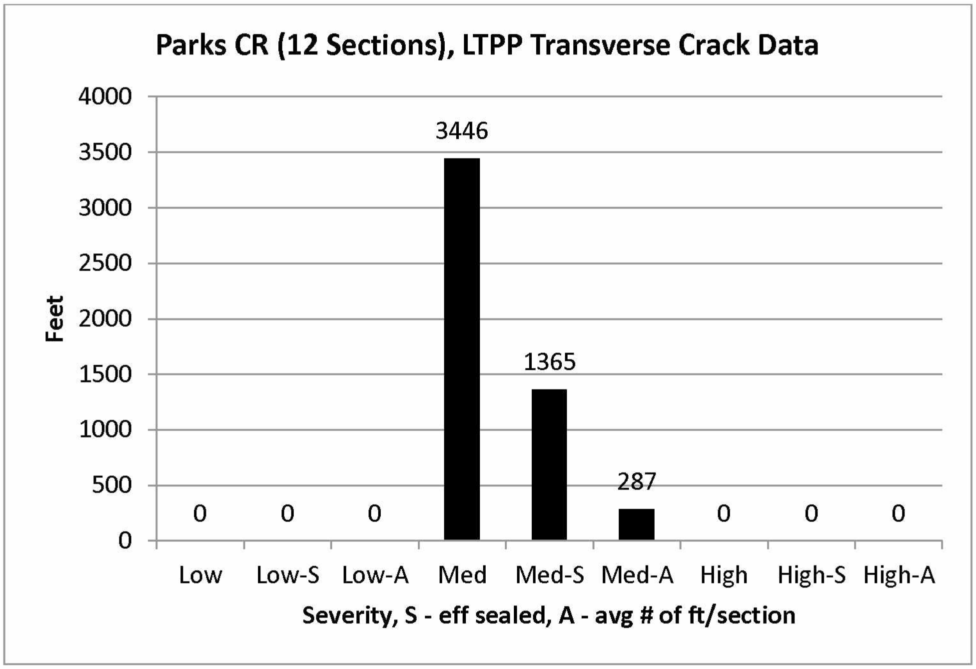
(e) The Steese Highway



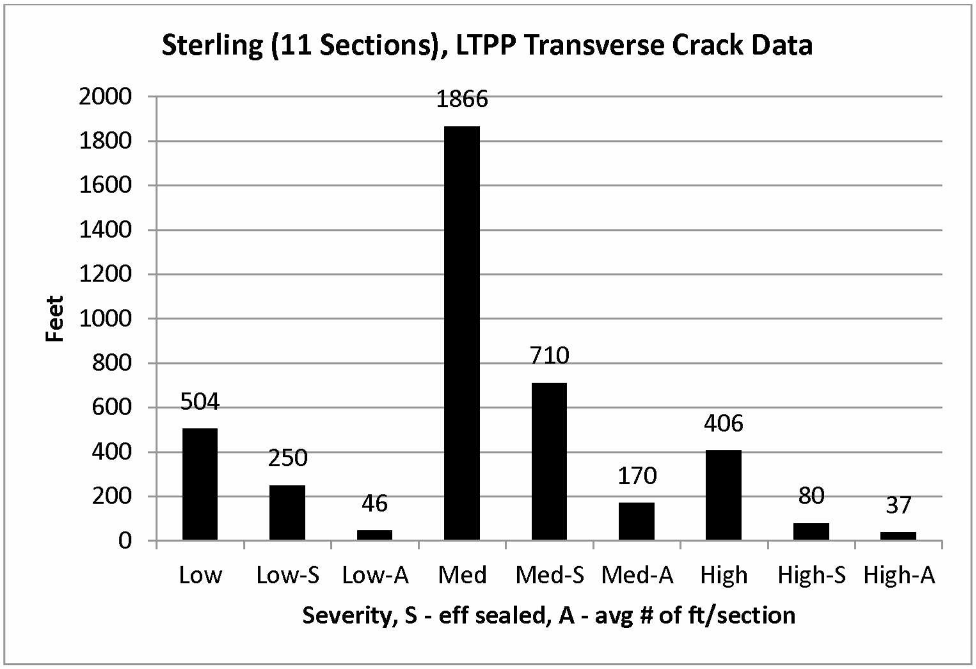
(f) The Elliott Highway



(g) The Parks NR Highway



(h) The Parks CR Highway



(i) The Sterling Highway

Figure 4.1: Length of transverse cracks at the different severity levels per LTPP method for: (a) The Richardson Highway, (b) The Alaska Highway, (c) The Tok Cutoff Highway, (d) The Glenn Highway, (e) The Steese Highway, (f) The Elliott Highway, (g) The Parks NR Highway, (h) The Parks CR Highway, (i) The Sterling Highway

Some significant points observed are:

- There is very little high-severity transverse cracking (> 3/4 inch width).
- Less than 1/3 of the total lengths of low-severity and medium-severity transverse cracking appeared to be effectively sealed.
- Less than 1/4 of the total length of high-severity transverse cracking appeared to be effectively sealed.

4.1.2 PASER Results

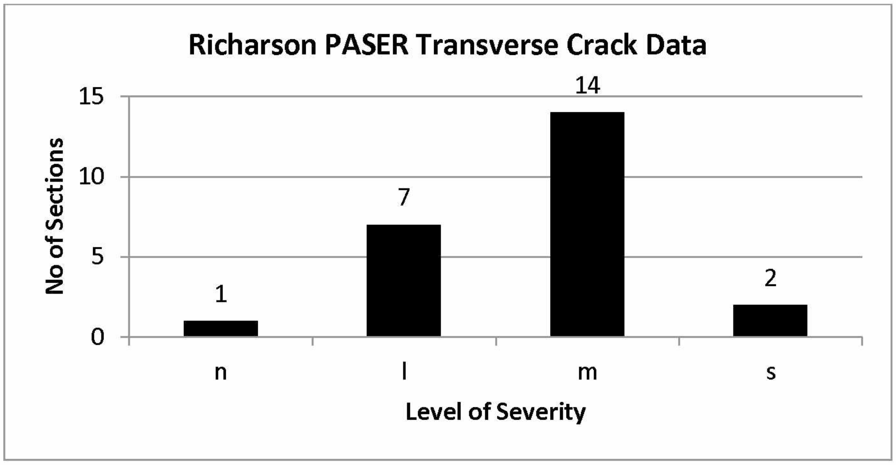
Figure 4.2 shows PASER data that focuses on transverse crack measurements. These data support other ways of characterizing thermal cracking used in this study. All sections on a given highway are represented on one histogram (for a total of nine histograms), and each bar indicates the number of sites on the highway that exhibit a specific transverse crack severity level:

n = none

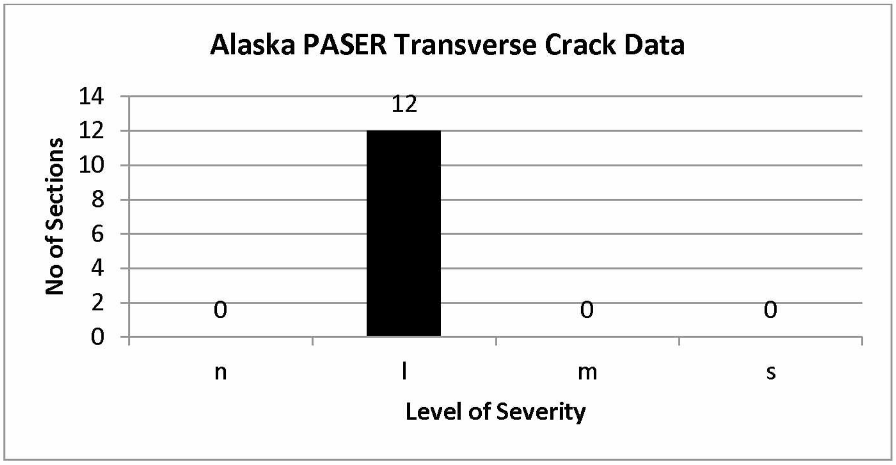
l = low

m = medium

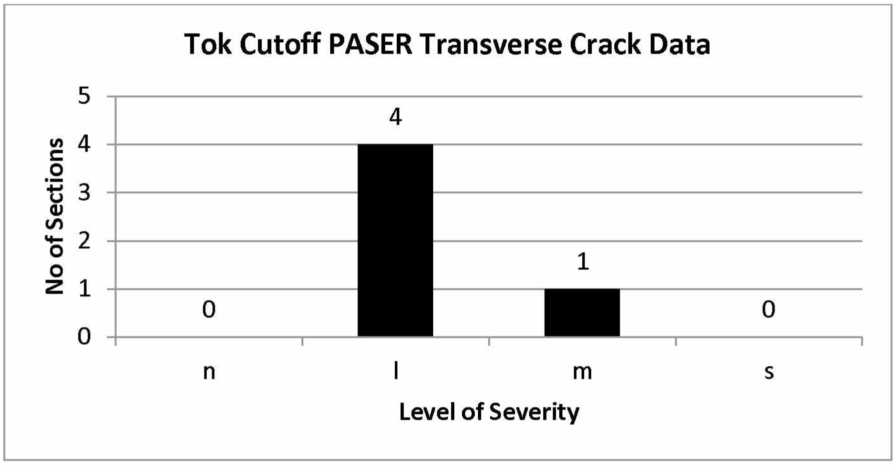
s = severe



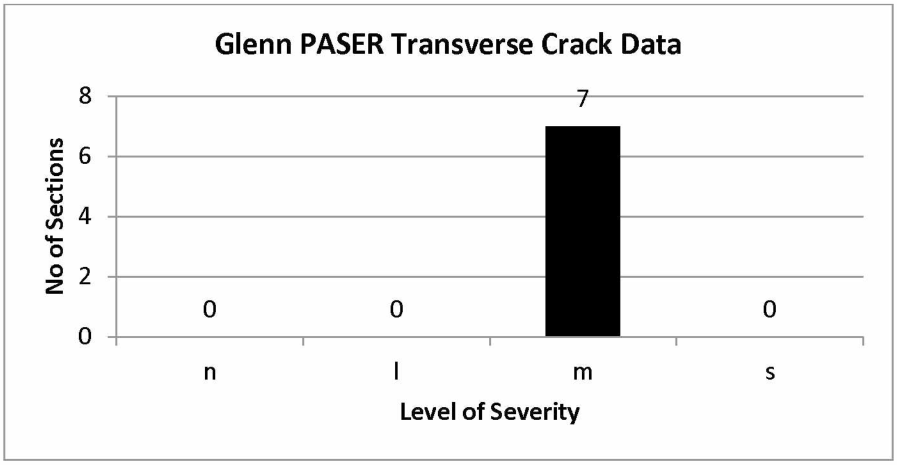
(a) The Richardson Highway



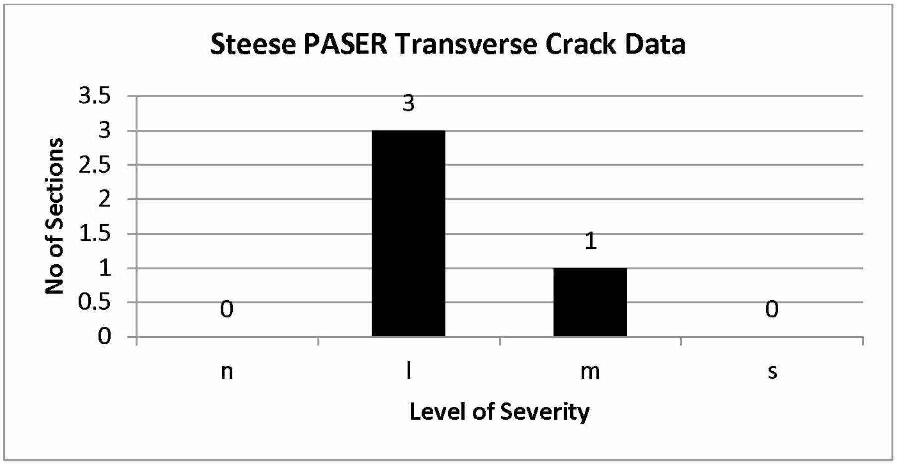
(b) The Alaska Highway



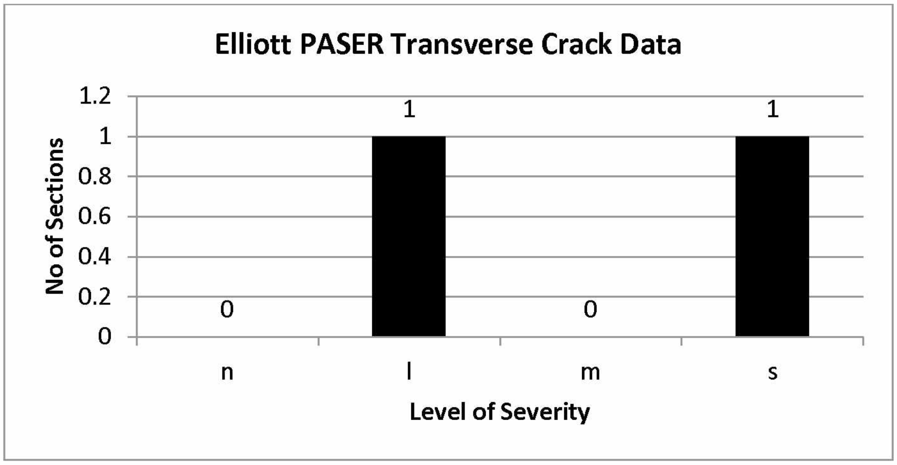
(c) The Tok Cutoff Highway



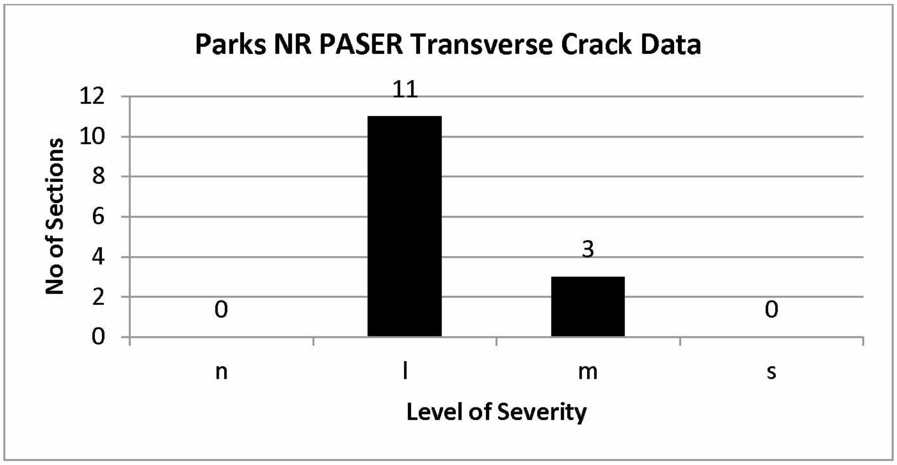
(d) The Glenn Highway



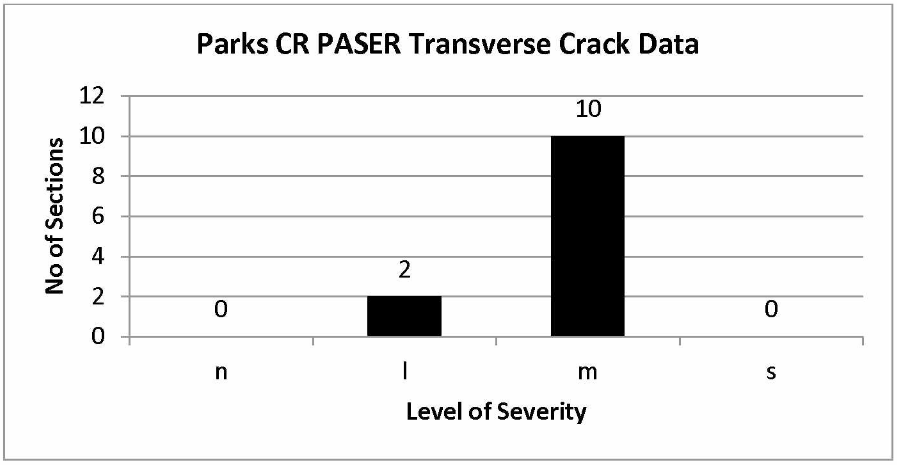
(e) The Steese Highway



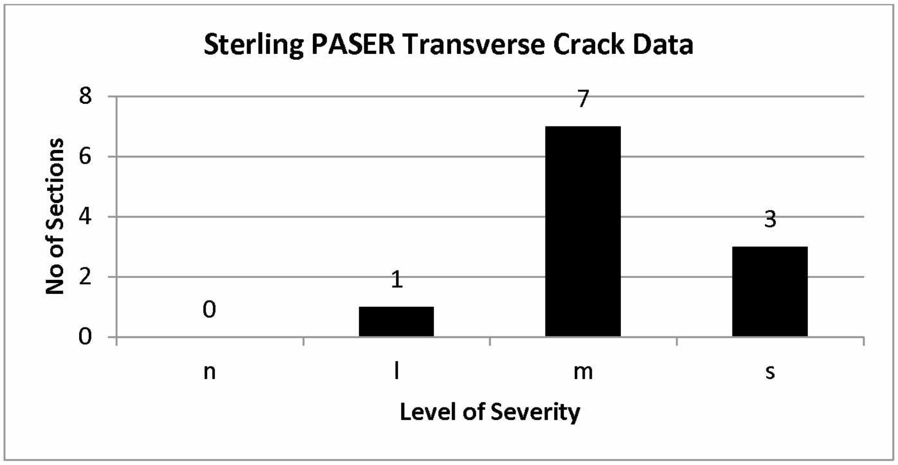
(f) The Elliott Highway



(g) The Parks NR Highway



(h) The Parks CR Highway



(i.) The Sterling highway

Figure 4.2. PASER method for the number of sections on the different highways at each level of severity for: (a) The Richardson Highway, (b) The Alaska Highway, (c) The Tok Cutoff Highway, (d) The Glenn Highway, (e) The Steese Highway, (f) The Elliott Highway, (g) The Parks NR Highway, (h) The Parks CR Highway, (i) The Sterling Highway

Significant observations are:

- Only 1 out of 91 sites exhibited no transverse cracking. This site was on the Richardson Highway.
- Only 6 out of 91 sites exhibited severe transverse cracking (crack width more than 1/2 inch to 3/4 inch depending on the amount of spalling along the crack edge)
- All other sites had either low or moderate transverse cracking (all crack widths less than about 3/4 inch).

These data indicate that almost all old AC pavement sections studied in ADOT&PF's Central and Northern Regions contain major transverse thermal cracks that are no more than moderately severe.

4.1.3 STCE Results

Figures 4.3 to 4.10 summarize STCE results in terms of frequencies of answers to the eight STCE questions shown in Table 3.3. The numbers of each histogram add up to 91, which is the total number of field sites. Note that not all sites fit the designed answers. For example, not all sites contained major transverse cracks; therefore, none of the answers would be suitable for such sites when it comes to Question A (Table 3.3). Therefore, the answer of "n/a" was allocated to these sites.

Figure 4.3 shows whether portions of major transverse cracks within wheel paths are performing worse than portions outside the wheel paths. Consistent, large differences in performance between the two locations would indicate that traffic loading plays an important part in degrading pavement near the cracks themselves. Theory indicates that the difference between wheel path and non-wheel path damage should be rather substantial. Such a difference should occur if the combination of wheel loads plus the softening influence of water intruding beneath the AC pavement combines to amplify damage in the wheel paths. Assuming that the wheel loading/water theory is correct, one could assume that fairly large areas of the pavement are affected within the wheel path and not just the pavement immediately adjacent to the edge of the crack. What Figure 4.3 reveals is that differences were observed only 35% of the time (no of "2's"), and large differences, only 11% of the time (no of "3's"). This finding suggests that there is often no marked softening of the pavement structure in the wheel path concerning major thermal cracks.

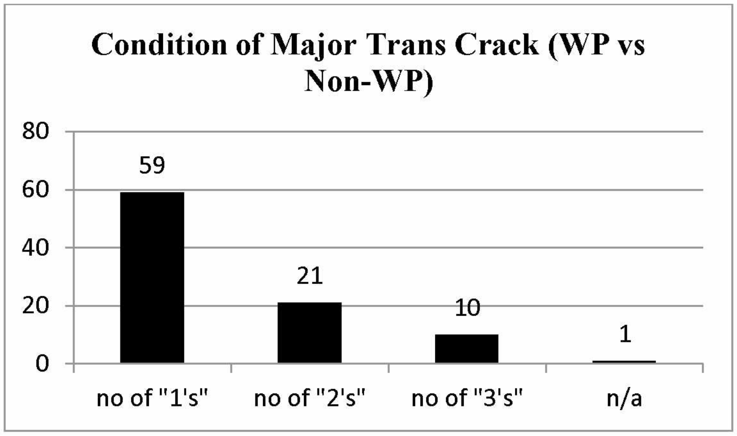


Figure 4.3: Condition of major transverse cracks (wheel path vs. non-wheel path). 1 = no difference, 2 = slight difference, 3 = much difference

Figure 4.4 shows whether portions of lesser thermal cracks within wheel paths show more damage than outside the wheel paths. Again, differences in performance between the two locations would indicate that traffic loading plus water was working in combination to more heavily damage pavement near the cracks. Theory certainly suggests that a noticeable difference should exist. Figure 4.4 indicates that, for lesser thermal cracks, there is almost no difference between wheel paths and non-wheel path areas. Only at 1 site out of 84 total was a difference seen (no of "2's"), or just over 1%. Figure 4.4 shows that in one case the difference was slight. Therefore, based on the project data, lesser thermal cracking seems unaffected by softening of the pavement structure.

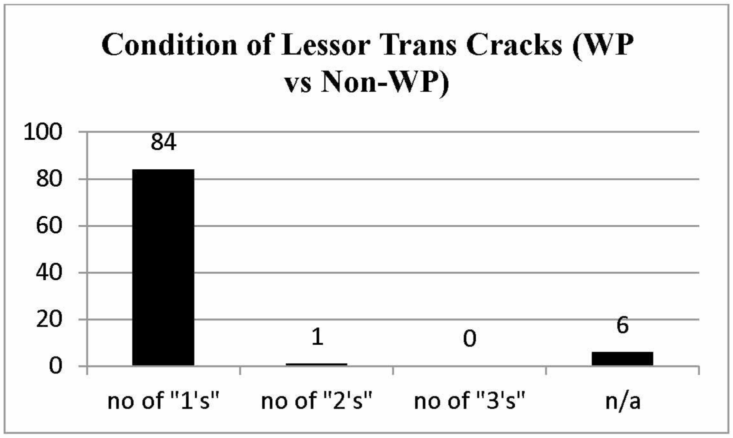


Figure 4.4: Condition of lesser thermal cracks (wheel path vs. non-wheel path). 1 = no difference, 2 = slight difference, 3 = much difference

Figure 4.5 supports Figure 4.3 for transverse cracks by showing not only is there usually little damage difference between wheel path and non-wheel path locations (Figure 4.1), but also usually no marked softening much beyond the edges of the cracks themselves. The crack zone width indicated in Figure 4.5 includes the combined total width including both sides of the crack.

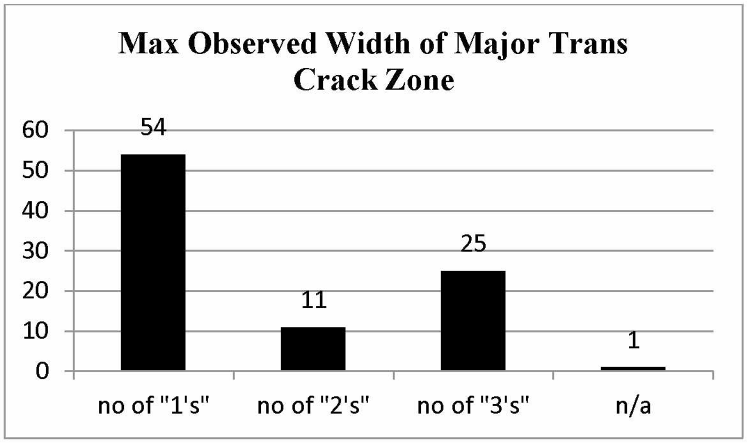


Figure 4.5: Maximum observed width of major transverse crack zone. 1= <2 inch, 2 = 2 to 5 inch, 3 = > 5 inch

The histogram on Figure 4.6 indicates that most lesser thermal cracks are no wider than 1/8 inch (94%) (no of "1's"). Important in this finding is that vehicle action, water, and time (20 years or more) did not combine to widen lesser thermal cracks or noticeably degrade/damage pavement adjacent to those cracks.

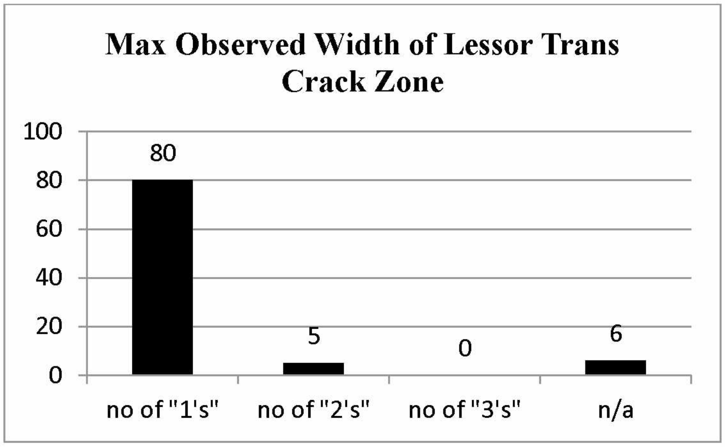


Figure 4.6: Maximum observed width of lesser thermal crack zone. 1 = <1/8 inch, 2 = ≥1/8 inch

Figure 4.7 shows that 8% of the examined pavements showed signs of major transverse cracks affecting pavement performance. There were only two field sites that the relationship between transverse cracks and more general pavement performance were obvious. It is important to note that all of the 8% indicated were in areas where multiple layers of pavement were present and in the process of delaminating. Field data collected to produce Figure 4.7 required careful assessment of the road surface as a whole. At each field site, the evaluator had to address the question of whether there were obvious signs that rutting, alligator cracking, raveling, or potholes were associated more with the near vicinity of major transverse thermal cracks than all other areas of the road.

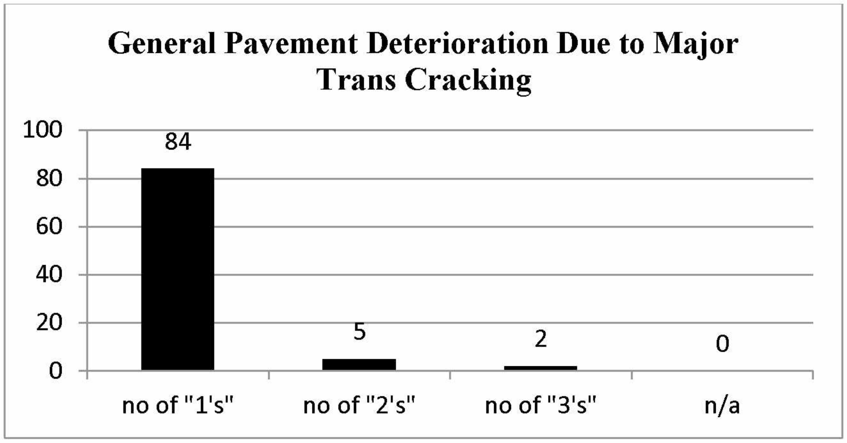


Figure 4.7: General pavement deterioration due to major transverse cracking. 1 = none, 2 = slightly noticeable, 3 = very noticeable

Figure 4.8 indicates that no sites could be found where lesser thermal cracks appeared to influence other aspects of pavement performance. Very few exceptions were found where minor potholing occurred at intersections of lesser crack segments. This observation also holds true for most of the delaminating pavements viewed during the study.

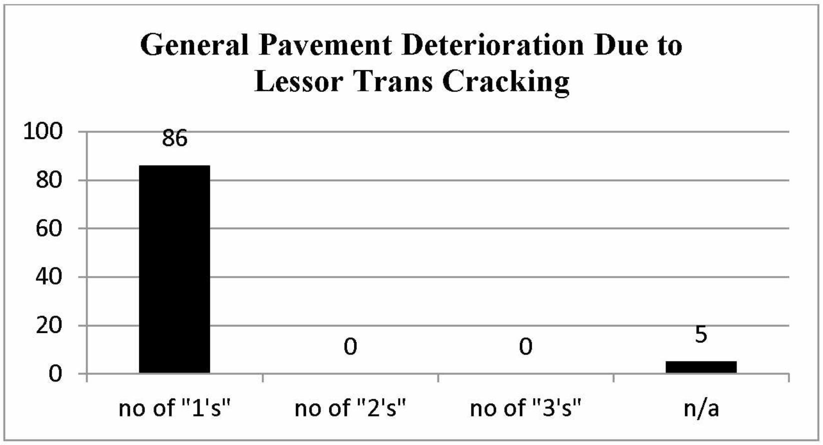


Figure 4.8: General pavement deterioration due to lesser thermal cracking. 1 = none, 2 = slightly noticeable, 3 = very noticeable

Prior to fieldwork for this project, it was hoped that many of the old rural pavement sites selected for study would have received little or no sealing. The fact that more than anticipated sites had received sealant and patching maintenance obscured interpretation of the pavement aging process with respect to all crack types although much newer seals had cracked. In the end, it was found that several of the older pavements were sealed but cracked and appeared to have been so for a long time. It was decided that the original assumption that old, cracked pavements were good candidates for study remained valid. Figure 4.9 indicates that approximately half the sites contained major transverse cracks that had been sealed at some time (48 sites). There had been an attempt to seal all thermal cracks at only 29 sites. At 14 additional sites the sealant was so old that it appeared not to be useful.

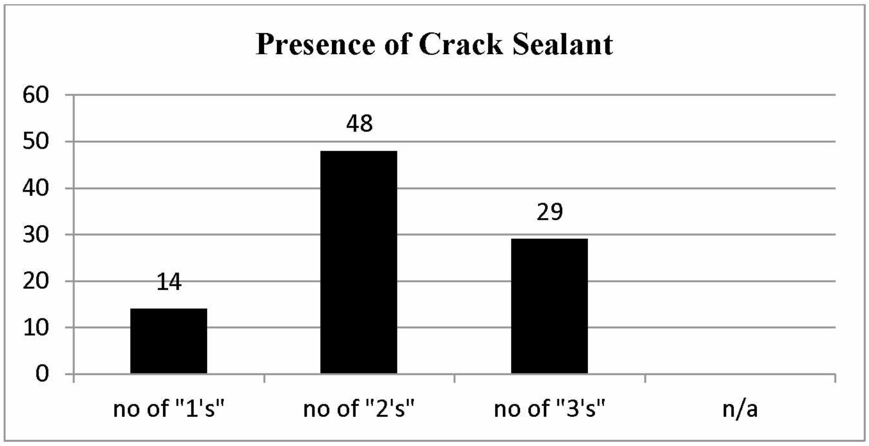


Figure 4.9: Presence of crack sealant. 1 = no/very old sealant, 2 = majors sealed, 3 = majors + lessers sealed

Figure 4.10 shows that 84 sites where sealants were recognized (some old sealants were very difficult to recognize). Only about 13% of those sites still exhibited effective sealants. Even sites that generally contained effectively sealed thermal cracks also offered unsealed cracks.

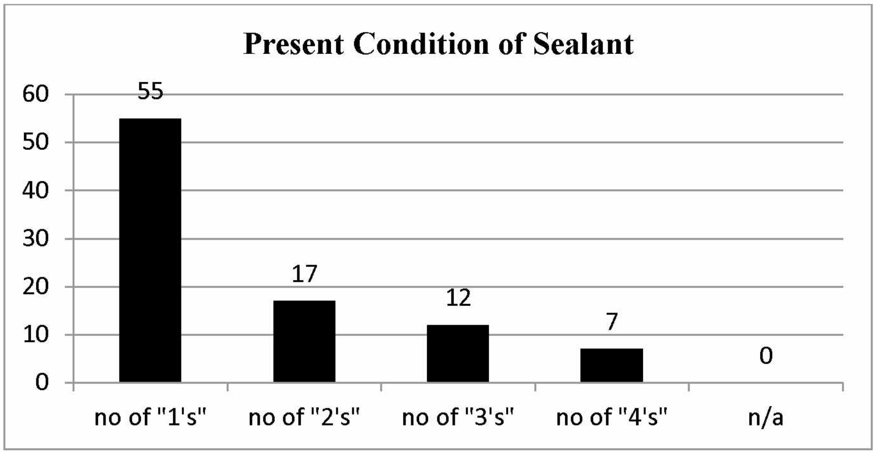


Figure 4.10: Present condition of sealant. 1 = old and/or recracked, 2 = some recracking, 3 = mostly good condition, 4 = no sealant

4.1.4 Interpretation of the Influencing Factors

Pavement age and freezing index are some of the important influencing factors when analyzing thermal cracking and are regressed with crack spacing and the sealed ratio later in this chapter. A synergy of asphalt cement weathering and low temperatures has produced thermal cracking in almost every old AC pavement in colder areas of Alaska. These data are illustrated in the figures that follow to provide a detailed picture of the range of pavement age and temperature environment that helped produce the large amount of thermal cracking seen on Alaska roads.

Are temperature regime and pavement age significant in this age of new paving materials, for example, polymer-rich asphalt cements? The ADOT&PF now uses performance graded (PG) asphalt cements for all AC paving in Alaska. This new material is supposed to modify the long-term temperature susceptibility of AC pavements and may someday prove to minimize or even eliminate thermal cracking. Such benefits have not been field-verified in Alaska. Until then, this study of old pavements provides insight into thermal cracking versus other pavement performance issues in Alaska. Figure 4.11 shows the minimum and maximum age for the road sections evaluated on each of the indicated highways.

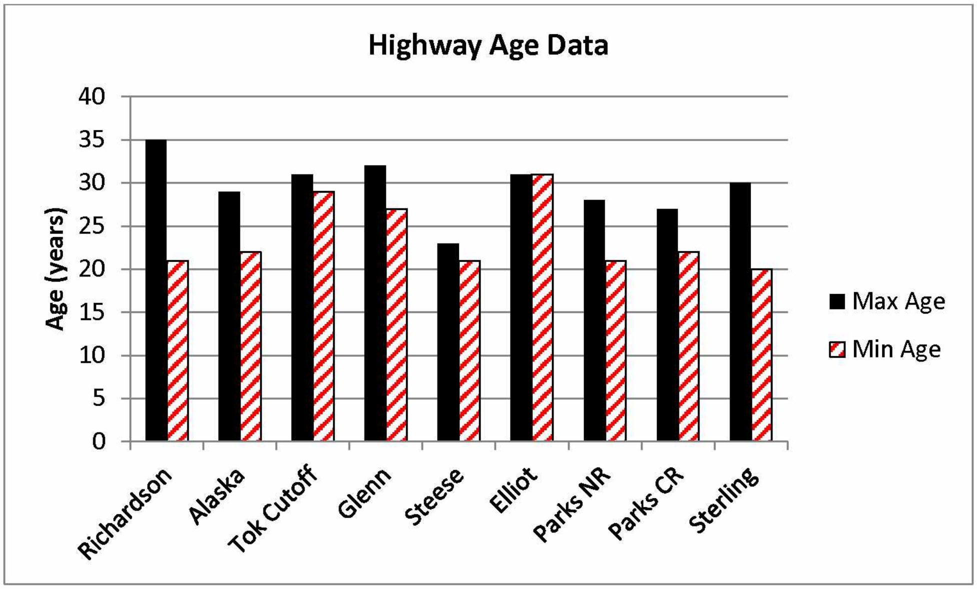
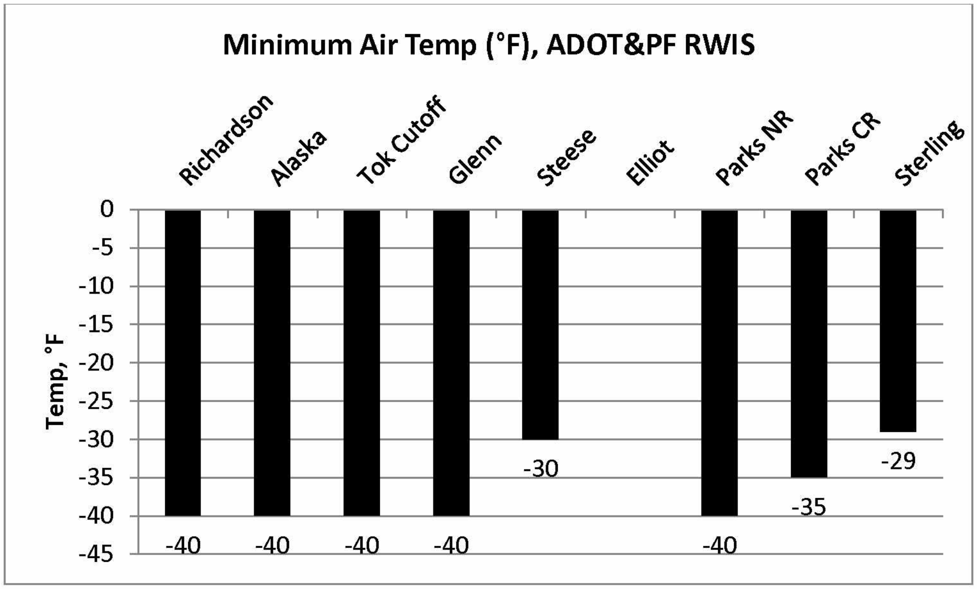


Figure 4.11: Maximum and minimum age for the different highways evaluated.

Figure 4.12 shows the extreme temperatures for minimum and maximum air temperatures as per ADOT&PF'S Road Weather Information System (RWIS) website data. Data were extracted from the temperature data probe information that can be found at http://www.dot.state.ak.us/iways/roadweather/forms/AreaSelectForm.html. At this URL, temperature probe data are obtained via the "RWIS – Camera – TDP Area & Corridor Maps" tab.



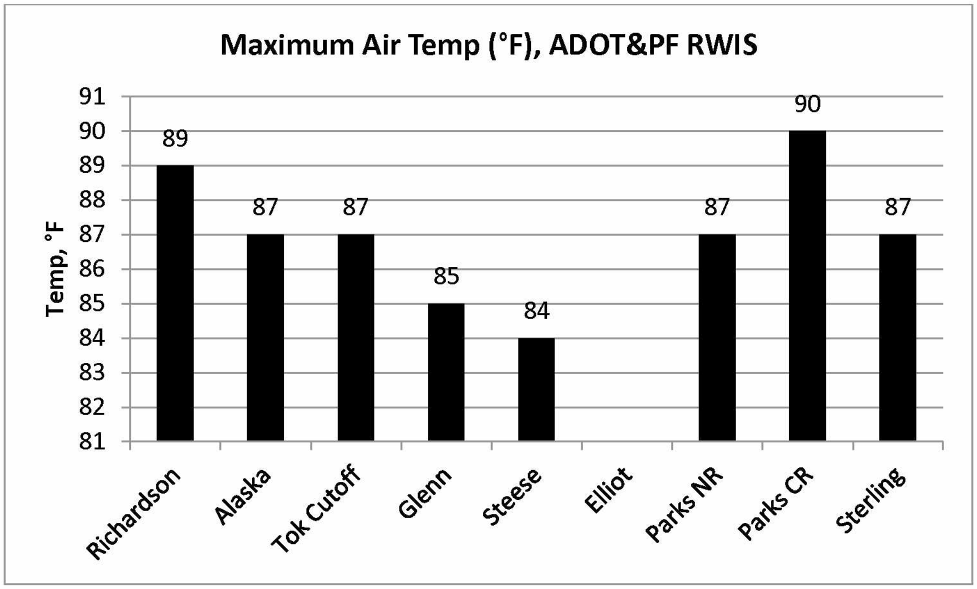


Figure 4.12: Minimum and maximum air temperature for RWIS sites on the various roads in proximity to the sites evaluated (approximately past 5–6 years).

Note the largest extreme minimum/maximum air temperature range of 125 °F for the Northern Region end of the Parks Highway. The smallest extreme minimum/maximum air temperature range shown is 114 °F for the Steese Highway. The minimum air temperature recorded was -40 °F for five different sites: one on the Richardson, one on the Alaska, one on the Tok Cutoff, one on the Glenn, and one on the Parks Northern Region (NR). The lowest pavement surface temperature was -39 °F, which occurred on the Alaska Highway. The maximum air temperature was 90 °F, which occurred on the Parks Central Region (CR), and the maximum pavement surface temperature was 129 °F, which occurred on the Richardson Highway. Figure 4.13 shows the extreme temperatures for minimum and maximum pavement surface temperatures according to RWIS data. The largest minimum/maximum pavement surface-temperature range is 161 °F for the Richardson Highway. The smallest maximum/minimum pavement surface-temperature range is 146 °F indicated on both the Steese and Sterling Highways.

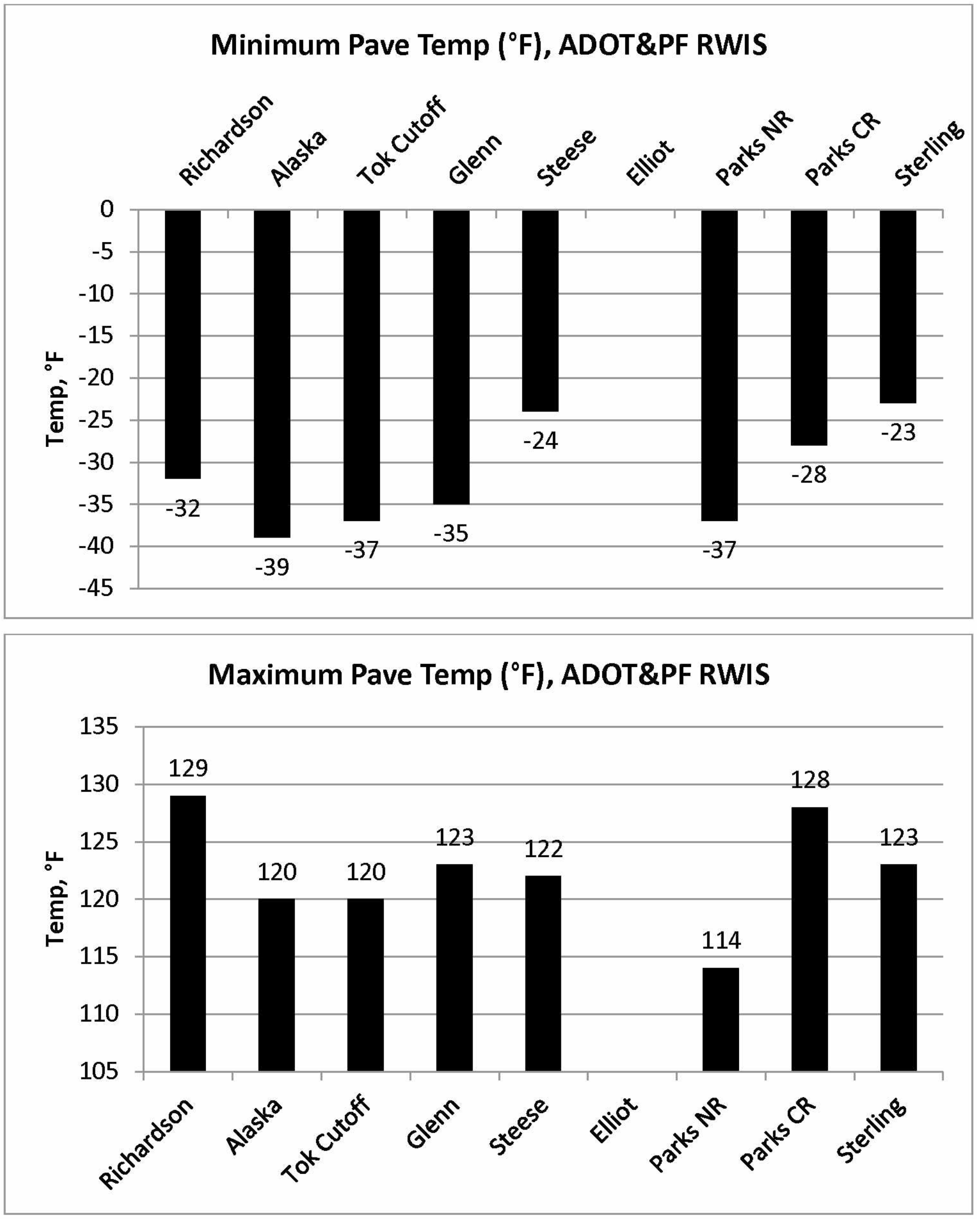


Figure 4.13: Minimum and maximum pavement surface temperature for RWIS sites on the various roads in proximity to the sites evaluated (approximately past 5–6 years).

A couple of interesting details are clearly shown on Figures 4.12 and 4.13:

- The pavement surface is subjected to temperature cycling much larger than would be indicated by air temperatures.

- Summertime temperatures of the pavement surface may run as much as 30 to 40 °F above the air temperature.

Maximum temperature differences between air and pavement surface would be expected on cloudless, dry, summer days with no wind. Minimum air/surface temperature differences would be expected (1) on rainy, windy summer days, (2) during spring/fall nights with cloud cover, and (3) during the darker winter months. Historical precipitation data were not as readily available as temperature data. However, an isopleth data "map" of precipitation from the Environmental Atlas of Alaska (Hartman and Johnson 1978) indicates that mean annual precipitation for most of the evaluated sites has been between about 15 and 40 inches. Most sections appear to fall at the lower end of these precipitation averages. Recent climate changes would not have significantly influenced these averages.

4.2 Correlation of Methods

As discussed above, LTPP, PASER and STCE are developed with different purposes and focuses. However, the information revealed by each surveying method may be correlated or complemented by one another, which may lead to more reasonable conclusions or recommendations. This motivated the following research based on a preliminary statistical analysis.

4.2.1 LTPP versus STCE

LTPP versus STCE data results in responses to questions E, F and A, B were used to correlate with in this study since E and F represent general pavement deterioration or sealing effectiveness and A and B represent tire loading and crack deterioration related to that. It can be seen that tire loading has an effect in the pictures for previous pavement preservation projects. Table 4.1 presents the arranged results by combining responses to STCE question E and LTPP data. In order for potential correlation with STCE, each crack recorded in LTPP was marked as either lesser or major cracks, defined in chapter 3.3.3, by the surveyor. The table itself does not impart useful information rather than quantified total and sealed lengths of major transverse cracks. A better analysis can be accomplished by calculating the major crack sealing ratio conditioned on each category of STCE responses, which is displayed as histogram on Figure 4.14. The major crack sealing ratio can be calculated as the ratio of sealed length of major cracks over total major crack length displayed in Table 4.1. It can be seen from Figure 4.14 that a lowest average major crack sealing ratio was found on locations where major transverse cracks were not considered as a significant factor of pavement deterioration. This finding may contradict to the common sense that more sealants placed on the major cracks will result in less pavement deterioration due to major transverse cracks. A reassessment of necessity of crack sealing on major cracks is recommended based on this finding. However, it should be noted that only 5 and 2 sites were characterized as "slightly noticeable" and "very noticeable" for STCE question E, respectively. The small sample size may have affected the analysis.

Table 4.1: STCE data of question E vs. LTPP transverse cracking data.

Responses to STCE question E	1	2	3
No. of sections	84	5	2
LTPP total length of major transverse cracks (ft)	6607	276	163
LTPP sealed length of major transverse cracks (ft)	2126	118	96

Note: STCE questions E - General pavement deterioration due to major transverse cracking (1 = none, 2 = slightly noticeable, 3 = very noticeable). (1 ft = 0.3 m.)

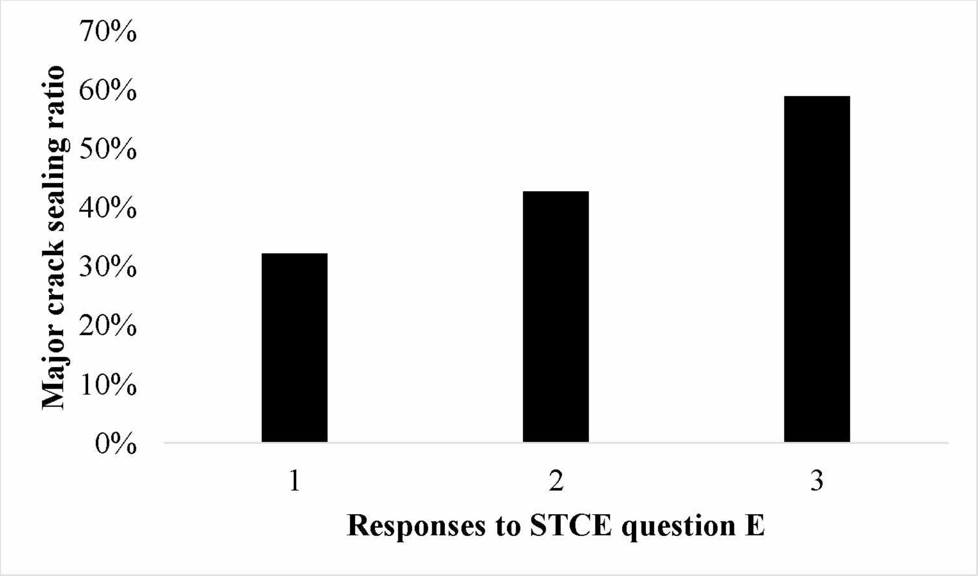


Figure 4.14: Major crack sealing ratio conditioned on STCE question E.

The sealed ratio appears to not necessarily follow what might be thought of logically. Logic might say that a high sealed ratio would provide protection for the crack in question and therefore no deterioration of the surrounding pavement would be present. What is just as telling is many more sections and length ratios calculated as [84/(84+5=2)] = 92% and [6607/(6607+276+163)] = 94% respectively have a STCE value of 1, meaning no pavement deterioration. So regardless of whether these cracks are sealed or not most of the sections do not exhibit deterioration where major thermal cracks are concerned.

While STCE question E deals with major thermal cracks and how they affect pavement deterioration STCE question F deals with minor thermal cracks. Table 4.2 shows STCE question F data conditioned on LTPP sections, lengths, and sealed lengths. Due to the small number "2" and "3" responses they were combined in Table 4.2. Figure 4.15 shows the sealed ratio for STCE question F.

Table 4.2: STCE data of question F vs. LTPP transverse cracking data.

Responses to STCE question F	1	2 & 3
No. of sections	84	5
LTPP total length of major transverse cracks (ft)	44125	664
LTPP sealed length of major transverse cracks (ft)	12500	200

Note: STCE questions F - General pavement deterioration due to minor transverse cracking (1 = none, 2 = slightly noticeable, 3 = very noticeable). (1 ft = 0.3 m.)

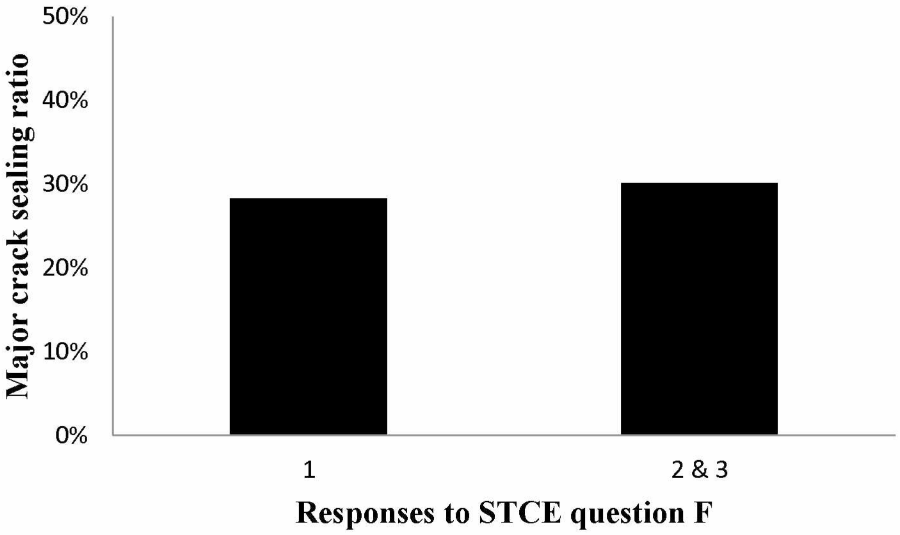


Figure 4.15: Major crack sealing ratio conditioned on STCE question F.

Here the sealed ratio is the same despite the STCE question F rating. For STCE question F conditioned on sections and lengths the percentages conditioned to a "1" are calculated as [84/(84+5)] = 94% for sections and [44125/(44125+664)] = 99% for lengths. This supports that regardless of whether the minor cracks are sealed or not they did not contribute to the deterioration of surrounding pavement. This agrees with recommendations given by McHattie et al. (2013).

Similar correlation can be conducted between STCE data of question A and LTPP transverse cracking data. Table 4.3 presents the combined data while Figure 4.16 shows the results of major crack sealing ratio. The two categories of STCE responses "slight difference" and "much difference" were added up due to small size of samples. According to Figure 4.16, the major crack sealing ratio was found to be much higher at STCE response "no difference" than at "slight difference" and "much difference." This indicates that sealing on major transverse cracks may improve the condition of the cracks and make it more consistent at either the wheel path or non-wheel path.

Table 4.3: Combination of STCE data of question A and LTPP transverse cracking data.

Responses to STCE question A	1	2 & 3
No. of sections	59	31
LTPP total length of major transverse cracks (ft)	4664	2337
LTPP sealed length of major transverse cracks (ft)	2118	443

Note: STCE questions A - Condition of major transverse cracks comparing at the wheel path versus non wheel path (1 = no difference, 2 = slight difference, 3 = much difference). (1 ft = 0.3 m.)

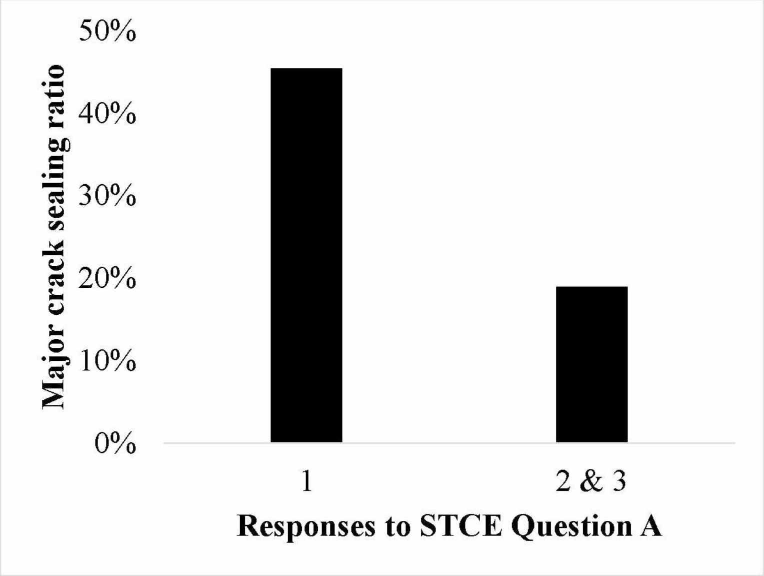


Figure 4.16: Major crack sealing ratio conditioned on STCE question A.

As with STCE questions E and F, which ask about pavement deterioration due to either major or minor thermal cracks, respectively, the same is performed for wheel path and non-wheel path for major and minor cracks. Therefore, Table 4.4 shows STCE question B conditioned on number of sections, length of thermal cracks, and sealed length. Figure 4.17 shows the respective sealed ratios.

Table 4.4: Combination of STCE data of question B and LTPP transverse cracking data.

Responses to STCE question B	1	2 & 3
No. of sections	82	7
LTPP total length of major transverse cracks (ft)	42189	2600
LTPP sealed length of major transverse cracks (ft)	11978	722

Note: STCE questions B - Condition of minor transverse cracks comparing at the wheel path versus non wheel path (1 = no difference, 2 = slight difference, 3 = much difference). (1 ft = 0.3 m.)

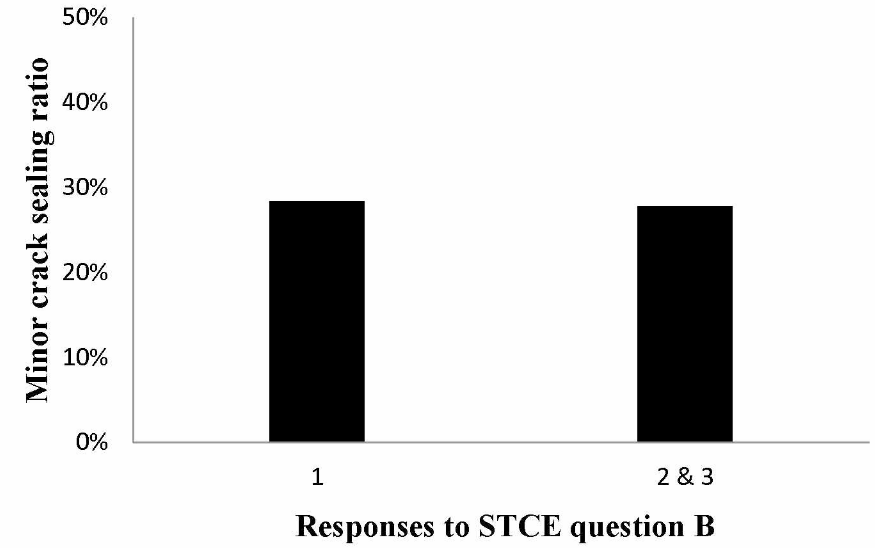


Figure 4.17: Major crack sealing ratio conditioned on STCE question B.

Figure 4.17 shows the same sealed ratio at both STCE B levels again showing that the sealed ratio is not affecting whether there is no difference in or out of the wheel path. Again for minor cracks a high percentage of the sections show no difference, calculated as [82/(82+7)] = 92%. Traffic does not have an effect on minor thermal cracking according to STCE B and minor thermal cracks do not affect the deterioration of the surrounding pavement, which further supports the recommendation not to seal minor thermal cracks according to Mullin et al. (2015).

The findings drawn from Figures 4.14 and 4.16 appear to contradict to each other, since the former questions the effectiveness of sealing major cracks while the latter supports the same type of crack sealing. This is caused by the different evaluating aspects of each STCE question. Recommendation based on Figure 4.14 focused on the effects of sealing major transverse cracks in terms of the general pavement performance, while the one made by Figure 4.16 highlighted the differences of pavement conditions at wheel or non-wheel paths. Actually, a combination of these findings may lead to a more complete conclusion. It can be interpreted as sealing major transverse cracks upgrades crack conditions but may not improve the general pavement performance. However, tables and graphs related to minor thermal cracks support the recommendation to not seal them (Mullin et al. 2015). Findings like this may help to make better decision on crack sealing practice, and cannot be obtained by a single method mentioned above.

4.2.2 PASER versus STCE

Different from LTPP, PASER gives a general severity level of each distress: n – none, l – low, m – medium, and s – severe. Tables 4.5 thru 4.8 organize the combined PASER cracking data and responses to the same two STCE questions used in "LTPP vs. STCE" section, respectively, in terms of PASER severity frequencies conditioned on each STCE question.

Table 4.5: PASER severity frequencies conditioned on STCE question E.

PASER cracking	**Responses to STCE question E**		
	1	**2**	**3**
n	1	0	0
l	31	7	2
m	26	10	7
s	1	4	1

Table 4.6: PASER severity frequencies conditioned on STCE question F.

PASER cracking	Responses to STCE question F		
	1	**2**	**3**
n	0	0	0
l	40	0	0
m	40	0	0
s	4	0	0

Table 4.7: PASER severity frequencies conditioned on STCE question A.

PASER cracking	Responses to STCE question A		
	1	**2**	**3**
n	1	0	0
l	39	1	1
m	38	4	1
s	6	0	0

Table 4.8: PASER severity frequencies conditioned on STCE question B.

PASER cracking	Responses to STCE question B		
	1	**2**	**3**
n	0	0	0
l	38	1	0
m	40	0	0
s	4	0	0

Similarly, a better analysis can be achieved by calculating the frequency ratio of each severity level. Due to limited size of sample, lower levels of crack severity was used to represent the summation of "n" ("none") and "l" (low") levels, while the STCE response "2" ("slight difference") and "3" ("much difference") are added up. Therefore, the ratio of lower levels of crack severity conditioned on response "1" of STCE question E can be calculated as: (1+31) / (1+31+26+1) * 100% = 54%.

Figure 4.18 presents the ratios of lower levels of PASER crack severity conditioned on STCE questions E and A, major thermal cracks. It can be seen that both ratios decreased significantly when the response changed from "1" to "2 & 3" regardless of the STCE question. According to the definitions of questions E and A in Table 3.4, this finding indicates that: a higher possibility of cracks falling on lower severity levels may occur, if in a STCE survey general pavement deterioration is found not to be related to major transverse cracking, or if condition of major transverse cracks comparing at the wheel path versus non wheel path is found to be no difference. This finding may not directly help to make decisions on crack sealing practices. However, it may strengthen and complement the STCE survey results.

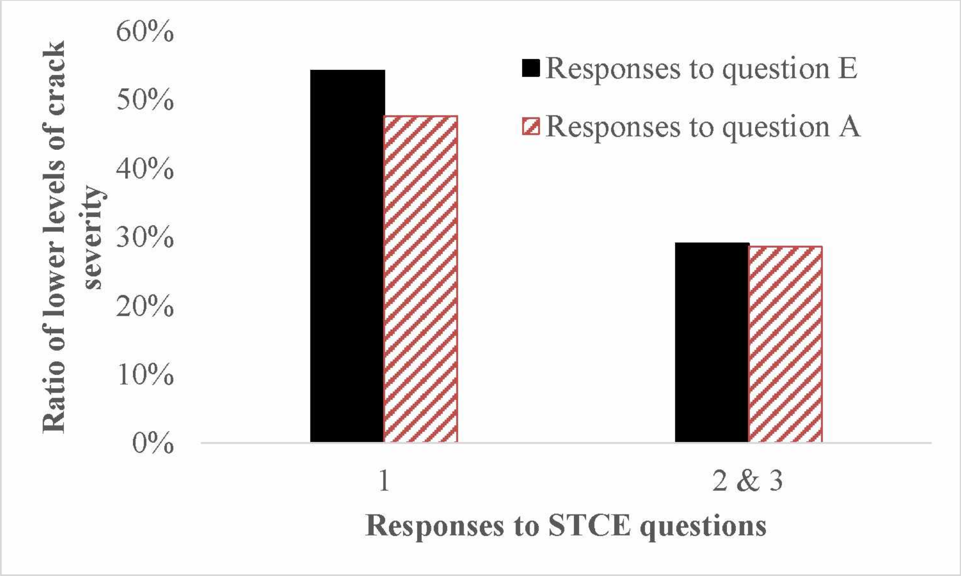


Figure 4.18: Ratio of lower levels of PASER crack severity conditioned on STCE questions E and A.

The ratio of lower PASER cracking, [(n+l)/(n+l+m+s)], as shown on Figure 4.18 for major thermal cracking yields about the same ratio for minor thermal cracking of STCE F and STCE B but since there are so few sections that fall into a STCE rating of “2” and “3” that it has no value. This simply states that PASER yielded an equal amount of low severity thermal cracking compared to medium and severe but it had no effect from traffic patterns, STCE B, nor did they contribute to pavement deterioration, STCE F. This also supports the recommendation of not sealing minor thermal cracks regardless of their severity (Mullin et al. 2015). Therefore, PASER coupled with STCE questions provided support for decision making about sealing thermal cracks where minor thermal cracks are concerned.

4.3 Influencing Factors

Previously it was shown that any one method used to evaluate thermal cracks and sealed thermal cracks did not necessarily show conclusively that thermal cracks provided a means for the surrounding pavement to deteriorate due to thermal cracks themselves. Methods were then combined in a manner as one method conditioned on another such as with LTPP and STCE E/F and STCE A/B as well as PASER and STCE E/F and STCE A/B. Subsequently, this section provides further analysis using linear regression analysis to produce significance values to identify which factors display influence. Crack frequency and the sealed ratio are initially regressed against freezing index, ADOT&PF obtained values, LTPP, PASER, and STCE values. Crack frequency is used since it represents thermal crack propagation. The sealed ratio is used because it represents crack sealing practice. Crack frequency as the dependent variable is documented in section 4.3.1 and results using the sealed ratio as the dependent variable is documented in section 4.3.2.

As explained in chapter 3 freezing index is a value calculated from the average daily temperature subtracted from the freezing temperature (32°F) added up annually and then averaged over the years daily annual temperatures were recorded. The ADOT&PF variables regressed against were Age, Min Air (°F), Min Pav (°F), Max Air (°F), Max Pav (°F), ADT, IRI, Rut, PSR. Here the Min and Max temperatures are minimum and maximum temperatures obtained from the Alaska Department of Transportation and Public Facilities Road Weather Information Web Page as stated in chapter 3. The average daily traffic, international roughness index, rut, and present serviceability rating are obtained directly from ADOT&PF data and averaged for each road section. Again, these are regressed to determine whether a significance level of 0.05 is obtained and therefore show importance for this data set for crack frequency (crack propagation) and the sealed ratio (crack sealing practice). Sealed ratio is regressed against crack frequency, which is the LTPP variable. The PASER values are also regressed against crack frequency and the sealed ratio showing significance when regressed against the sealed ratio but not crack frequency. All eight STCE question results are regressed by separating the data into different regions: Interior, Southcentral, and Southcentral coastal with comments about the results.

Significance at a 0.05 level is displayed by several variables meaning they show significance in a commonly accepted statistical sense and vary proportionally or inversely proportionally with the dependent variable, this case being crack frequency and the sealed ratio.

4.3.1 Influencing Factors on Thermal Crack Development

The lengths of the sections surveyed in this study were the same, so crack frequency was selected as the response variable to evaluate the influencing factors on thermal crack development. Table 4.9 shows the significance values when LTPP crack frequency was used as the dependent variable in a multilinear regression with the independent variables mentioned above and Table 4.10 shows the significance values when the independent variables were regressed linearly in a singular fashion. Table 4.9 shows Min Air, Min Pav, Max Air, and Max Pav as significant at a 0.05 level. As mentioned above the Min Air and Min Pav make sense as varying proportionately with crack frequency because one would expect the crack frequency to increase as temperatures became lower. But the Max Air and Max Pav do not make sense since asphalt thermal cracking is not caused by warmer temperatures, if anything warmer temperatures cause asphalt to relieve applied stresses by becoming more plastic, which can cause some rutting depending on the mix. Table 4.10 displays the single linear regression results. Freezing index is the only variable that makes sense to be related to thermal cracking frequency and therefore would warrant further investigation, but it did not show significance in the multilinear regression model. The influence of other factors decreases the significance of the freezing index in the multilinear model and therefore vary more in proportion to the dependent variable. It was noticed that the minimum temperatures provided by the RWIS, at that time, from ADOT&PF bottomed out at -40 °F; this appears to be an error since at times temperatures of -50 °F or lower are reported for the Alaska Interior during the winter months.

Table 4.9: Multilinear regression showing significance factors using crack frequency as the dependent variable.

Factor	**p - value**
Freezing Index	0.749962942
Age	0.680616404
Min Air (°F)	1.85861E-06
Min Pav (°F)	6.07713E-05
Max Air (°F)	3.36173E-07
Max Pav (°F)	0.000322318
ADT	0.266950563
IRI	0.079372799
Rut	0.863124472
PSR	0.895431116

Table 4.10: Single linear regression p-values using crack frequency as the dependent value.

Factor	**p - value**
Freezing Index	0.018484364
Age	0.320235823
Min Air (°F)	0.212160214
Min Pav (°F)	0.166283694
Max Air (°F)	0.001488769
Max Pav (°F)	0.0008612
ADT	0.98863188
IRI	0.200852265

Factor	p - value
Rut	0.004604846
PSR	0.00340075

Since the freezing index changed its p-value significantly when the regression was performed as a multilinear regression versus a single variable regression another regression was performed using freezing index and age together as shown in Table 4.11. Age was chosen since it is considered as an important decision factor when applying treatments such as crack sealing. Freezing index is still significant. It is interesting that these two factors reverse when the sealed ratio is regressed against freezing index and age, shown in section 4.3.2 below.

Table 4.11: Multilinear regression p-values using crack frequency as the dependent value and freezing index and age as the independent variables.

Factor	p - value
Freezing Index	0.032914217
Age	0.83886886

A regression model was also run on the data grouped by region such as Interior, Southcentral, and Southcentral coastal. The majority of sections evaluated can be regarded as Interior so Southcentral and Southcentral Coastal did not provide meaningful results since there were few temperature recording stations from the ADOT&PF RWIS website on these road sections. The results for the Interior are shown in Table 4.12 and the freezing index and age results are shown in Table 4.13. As with regressions performed on all of the data with crack frequency as the dependent variable and freezing index and age regressed in a multilinear manner the freezing index is almost significant at a 0.05 level in Table 4.13. Again, much of the data is from the Interior and has a strong influence on the regression models as a whole.

Table 4.12: Single linear regression p-values using crack frequency as the dependent value for Interior Alaska.

Factor	p - value
Freezing Index	0.270722977
Age	0.8422721
Min Air (°F)	0.000377308
Min Pav (°F)	0.00231021
Max Air (°F)	2.90858E-06
Max Pav (°F)	0.007560323
ADT	0.094480907
IRI	0.14693051
Rut	0.202109849
PSR	0.988205951

Table 4.13: Multilinear regression with freezing index and age as independent variables showing significance factors for the Interior where crack frequency is the dependent variable.

Factor	p - value
Freezing Index	0.063196
Age	0.454359

The freezing index showed significance most often when thermal crack frequency is the dependent variable. Since crack frequency is related to crack development and caused by cold thermal stress of which the freezing index indicates this seems reasonable. Min Air and Min Pavement does show significance when regressed multilinear, which seems reasonable and related to the Freezing Index. On another note Max Air and Max Pavement showed significance as well but as stated above these values are not shown in any literature review or seem reasonable to be causation factors for cold temperature cracking. Rut and PSR, of which Rut is part of the calculation, show significance as well but asphalt concrete ruts are caused by plasticity such as in warmer temperatures or sheared off from studded tires, which also does not seem reasonable to be a causation of thermal cracking, unless to cause a stress concentration where the asphalt might be more thinned out from the rut.

4.3.2 Influencing Factors on Sealing Practice

The sealed ratio is defined as the effective sealed length at any one section divided by the total length of thermal crack. This section discusses which influencing factors potentially affect the decision to seal a section, which can be reflected by the sealed ratio. Table 4.14 shows that when the sealed ratio is the dependent variable and crack frequency the independent variable there is significance in the model. Since the value is below the 0.05 level and directly related to crack sealing a graph was created to see if there is any obvious relationship shown in a plot of sealed ratio versus thermal crack frequency as shown on Figure 4.14. This plot does show that a higher sealed ratio is directly proportional to lower crack frequency meaning more effective sealing with less thermal cracks per mile, more effort is needed when sealing more cracks.

Table 4.14: Sealed ratio versus thermal crack frequency p-value.

Factor	**p-value**
Crack Frequency	0.031402

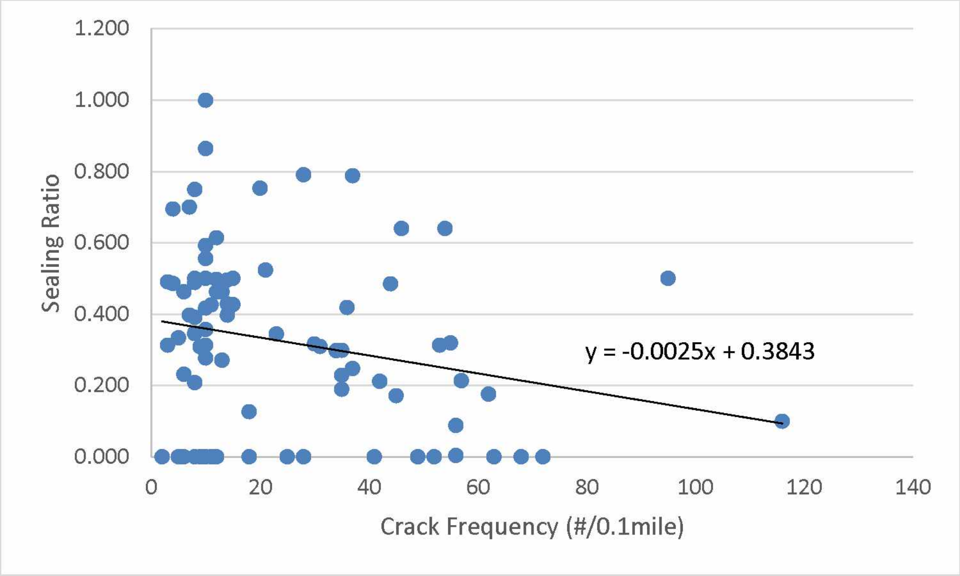


Figure 4.19: Plot of sealed ratio versus crack frequency.

Just as crack frequency was regressed in a multilinear and single linear fashion and the significance results shown in Tables 4.9 and 4.10 now the same independent variables are regressed against the sealed ratio and shown in Tables 4.15 and 4.16. Table 4.15 shows significance with the freezing index possibly when influenced by the other factors when regressed as a multilinear model but not when regressed singularly. Age shows just the opposite, not significant when regressed in a multilinear fashion but significant when done singularly. The freezing index would seem to be more of a causation for the propagation of cracks where it makes more sense that Age would show more of a relationship with sealing practice. Table 4.17 shows results when the freezing index and age are regressed as a multilinear regression. The freezing index does not show significance, but age does, which is the opposite of when crack frequency is the dependent variable where the freezing index was significant, which is more of what would be anticipated for this study.

Table 4.15: Multi-linear Regression showing significance factors using the sealed ratio as the dependent variable.

Factor	**p-value**
Freezing Index	0.051548755
Age	0.106689229
Min Air (°F)	0.826529736
Min Pav (°F)	0.80743348
Max Air (°F)	0.349400535
Max Pav (°F)	0.172648997
ADT	0.256371279
IRI	0.93442458
Rut	0.403647569
PSR	0.620932399

Table 4.16: Single linear regression p-values using the sealed ratio as the dependent value.

Factor	**p-value**
Freezing Index	0.769550545
Age	0.013492094
Min Air (°F)	0.789137387
Min Pav (°F)	0.399129819
Max Air (°F)	0.076135927
Max Pav (°F)	0.128925828
ADT	0.397927653
IRI	0.281715546
Rut	0.555731268
PSR	0.404563033

Table 4.17: Multilinear regression p-values using the sealed ratio as the dependent variable and freezing index and age as independent variables.

Factor	**p - value**
F.I.	0.545052564
Age	0.011976809

Table 4.18 displays the results linear regression results when the sealed ratio is the dependent variable and the final PASER rating is the dependent variable. Since many factors go into a PASER Rating another regression was performed for the transverse crack component of the PASER Rating only, which was recorded as a l – low, m – medium, or s – severe. But to be regressed the l, m, and s were converted to 1, 2, 3 respectively. Table 4.19 shows the p-value for this regression. This p-value shows very good significance; therefore, a plot was created as shown on Figure 4.18. There are 40 points of PASER at the low severity level and 44 points at the medium severity level. The low severity level is spread over a larger range of Sealed Ratios, as compared to the medium severity level, and is going all the way to a sealed ration of 1.0, meaning the entire crack was effectively sealed. This shows that a PASER Rating could prove to be useful not only for an overall rating but possibly indicating meaning for good or not good crack sealing for thermal cracks when the crack is at low severity.

Table 4.18: Sealed Ratio regressed against PASER Ratings p-value.

Factor	**p-Value**
PASER Rating	0.051759

Table 4.19: Sealed Ratio regressed against PASER trans crack severity level p-value.

Factor	**p-Value**
PASER trans crack severity level	0.004216

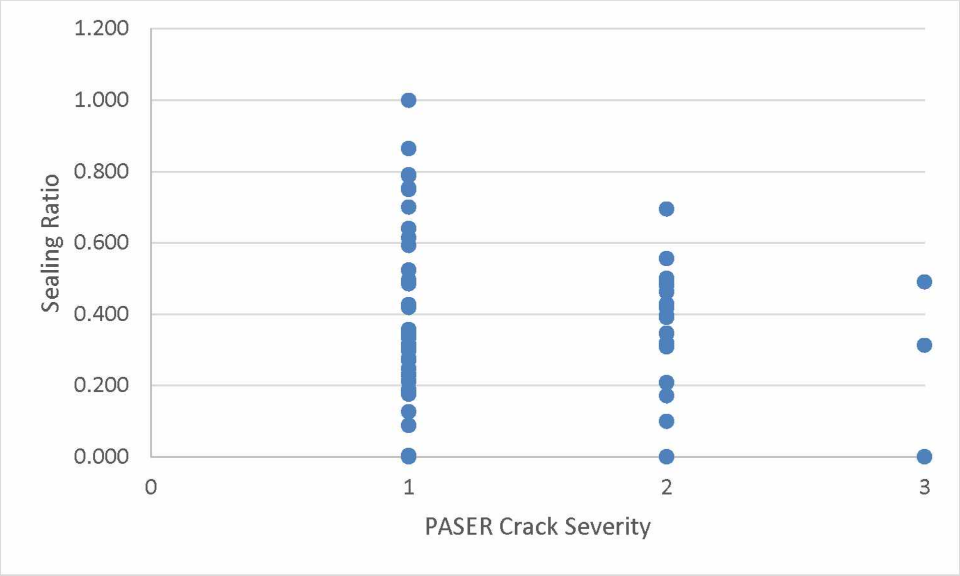


Figure 4.20: Plot of Sealed Ratio versus PASER (trans crack) Rating.

STCE was developed particularly for evaluating thermal cracks on Alaskan roads and determining if sealing them maintained or enhanced pavement performance so the Sealed Ratio was regressed first as a multilinear regression against each of the 8 STCE questions individually showing results in Table 4.20 and singularly against STCE questions A, B, E, F since these were the values analyzed in section 4.2.1 with results shown in Table 4.21. Table 4.20 shows significance with STCE questions E and G in which E is asking if major thermal cracks contribute to the surrounding pavement deterioration and G asks about the presence of crack sealant. This shows there is a relation of this data with major thermal cracks and the presence of crack sealant, which has been displayed in previous discussion with question STCE E when it was conditioned on LTPP and PASER data in chapter 4.2. Table 4.21 shows significance with STCE E again done in a singular fashion, which would suggest the importance of sealing practice and pavement deterioration due to major thermal cracks and should be further researched.

Table 4.20: Sealed Ratio multilinear regression against all eight STCE questions and p-values.

Factor	p-value
STCE A	0.686995398
STCE B	0.286452319
STCE C	0.147643683
STCE D	0.673282479
STCE E	0.009152639
STCE F	0.115816876
STCE G	0.032783691
STCE H	0.17161207

Table 4.21: Sealed Ratio single linear regression against STCE questions A, B, E, F questions and p-values.

Factor	p-value
A	0.821450079
B	0.451764531
E	0.020670318
F	0.804460396

Another question to ask is whether other data is useful even if it does not display variation either directly proportional or indirectly proportional to each other. STCE F asks whether minor thermal cracks contribute to the surrounding pavement deterioration with responses of 1, 2, or 3 meaning not at all, slightly, or contributing. When looking at this plot on Figure 4.21, it can be seen that almost all responses are a “1” or not contributing. So no matter what the sealed ratio is, all of the sections show that minor cracks do not contribute to pavement deterioration. This supports the recommendation of not sealing minor thermal cracks as recommended by McHattie, et al. (2013).

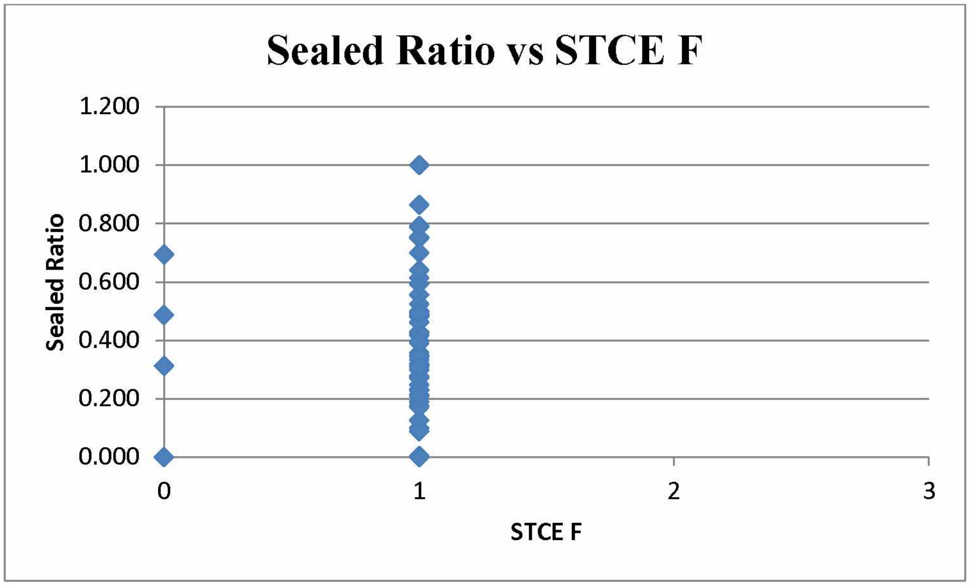


Figure 4.21: Plot of Sealed Ratio versus STCE question F.

When the sealed ratio is the dependent variable Age shows significance as a single independent variable as well as when regressed with the Freezing Index. It would seem reasonable that with Age the effectiveness of the crack seal would be affected. The final PASER rating as well as the PASER thermal crack rating of low, medium, and severe also show significance. As stated in section 4.2 these ratings conditioned on LTPP quantities could prove useful for decision making on crack sealing practice. STCE question E asks if major thermal cracks add to the general pavement deterioration and shows significance for both the multilinear and singular linear regression. As stated in Mullin et al. (2015), it is suggested that major thermal cracks be studied in a manner that includes a control, meaning no sealing next to thermal cracks that are sealed, to better answer their effect on pavement deterioration. STCE question F, minor thermal cracks contributing to general pavement deterioration, did not show significance but as stated above when looked at more closely the STCE F data still offers good insight about minor thermal cracks by being at a “1” no matter what the sealed ratio is. A “1” means the minor thermal crack did not contribute to general pavement deterioration, which supports Mullin et al. (2015) recommendation not to seal minor thermal cracks.

4.3.3 Summary of Influencing Factors

To summarize the results for crack frequency and sealed ratio that are significant are placed in Tables 4.22 and 4.23 respectively.

Table 4.22: Crack Frequency as the dependent variable with all independent variables showing significance.

Factor	Linear Regression Type	p-value
Min Air (°F)	Multi	1.85861E-06
Min Pav (°F)	Multi	6.07713E-05
Max Air (°F)	Multi	3.36173E-07
Max Pav (°F)	Multi	0.000322318
Freezing Index	Single	0.018484364
Max Air (°F)	Single	0.001488769
Max Pav (°F)	Single	0.0008612
Rut	Single	0.004604846
PSR	Single	0.00340075
Freezing Index	Multi with Age only	0.032914217
Min Air (°F)	Multi for Interior	0.000377308
Min Pav (°F)	Multi for Interior	0.00231021
Max Air (°F)	Multi for Interior	2.90858E-06
Max Pav (°F)	Multi for Interior	0.007560323
Freezing Index	Multi with Age for Interior	0.063196

Table 4.23: Sealed Ratio as the dependent variable with all independent variables showing significance.

Factor	Linear Regression Type	p-value
Crack Frequency	Single	0.031402
Freezing Index	Multi	0.051548755
Age	Single	0.013492094
Age	Multi with Freezing Index	0.011976809
PASER Rating	Single	0.051759
PASER trans crack severity level	Single	0.004216
STCE E	Multi	0.009152639
STCE G	Multi	0.032783691
STCE E	Single	0.020670318

To find which factor has the most influence on thermal cracking, various factors were regressed against thermal crack frequency and thermal crack sealed ratio as the dependent variables. Thermal crack frequency represents the development of thermal cracks, and the sealed ratio represents sealing practice, both of which were used as the dependent variable. While many factors were tried in a single as well as a multi regression as the independent variables they all are as recorded numbers. The freezing index is a calculated factor that represents the degree to which temperature at a particular location is below freezing per day for every day this condition exists in a year. This value is used in many different structurally related situations.

Finally, Freezing Index seems to be more related to thermal crack frequency, thermal crack propagation, and age seems to be more related to the sealed ratio, thermal crack sealing practice. The locally developed evaluation method used in collaboration with more regionally and nationally recognized methods can offer support for more informed decision making about sealing thermal cracks on Alaskan roads.

Research, experience, and common sense sometimes need to be applied to reason whether a variable showing significance makes sense for the situation being evaluated. For this research there are variables that seem obvious to be related to thermal cracking and some that do not. Min temperature would be one of those obvious variables and max temperature does not seem like it should show significance but it does in some of the regression models, unless it relates based on a temperature difference. Perhaps the volatile components of the asphalt are driven off more with warmer temperatures, which might cause the asphalt to become more brittle as cold temperatures are experienced but that is research that was not part of this study. Also, another explanation could be that the equipment measuring temperature is more sensitive at the high end and bottoms out at the low end leaving less variation of low temperature related to crack frequency and sealed ratio.

Chapter 5 Summary and Conclusions

Since the mid-1980s, it has been strongly suggested that a much more economical and sustainable approach be developed to address the thermal cracking issues in Alaska (McHattie et al. 2013). This study started with a literature review of thermal cracking, its causes, sealing practices, and factors that influence thermal cracking in asphalt. This was followed by a preliminary survey on status of crack sealing maintenance on Alaska's asphalt roads. Then 91 sites were selected to evaluate road sections in Alaska and the reasons for their selection were given. A new STCE method was developed to specifically answer critical questions related to thermal cracks on the road and directly guide crack sealing practice. Field survey on the 91 sites were conducted using the newly developed STCE method and two traditional field survey methods LTPP and PASER. The STCE results were then correlated with the LTPP and PASER results to investigate how to combine the survey methods to give more insightful information for better decision making of crack sealing. Finally, regression analysis was conducted to determine factors that influence thermal crack frequency which represents thermal crack propagation, and the sealed ratio which represents crack sealing practice so that more informed decisions can be made in the future regarding crack sealing practices of thermal cracks on Alaskan roads.

5.1 Conclusions

The following are the conclusions drawn from this preliminary study.

- According to the preliminary survey results of the pavement preservation guidelines project completed in 2011, it was found that crack sealing is the most common pavement preservation technique used to maintain asphalt road integrity in Alaska.
- The STCE evaluation method was developed including eight questions an evaluator asks. These questions pertain to the comparison of areas of the pavement where there is wheel loading and where there is not, width of thermal crack zones, general pavement deterioration near the thermal crack zones, presence of crack sealant, and condition of crack sealant. These are asked of major thermal cracks as well as minor thermal cracks. The STCE method was found to directly address the critical causes of pavement distress and could generate direct recommendations on crack sealing

practice. This method would be of great value to state agencies since the LTPP, PASER, or other evaluation methods do not address thermal cracking of asphalt directly.

- For LTPP surveying of transverse cracks, three categories were taken into account including total count of cracks, total linear length of cracks and total linear length of effectively sealed cracks. Each category was subdivided into three levels of crack severity: low, medium and high. The results of LTPP method show that LTPP allows for the current condition of thermal cracking to be known and a way to compare to other agencies that use LTPP. This allows comparisons to be made with other road agencies across the USA or any other country that uses the LTPP format for recording road distress conditions to include cracking.
- According to the PASER results, it can be found that this method provided an overall rating for a pavement surface condition and for this study. Different distress conditions were recorded so that a more consistent rating would be obtained, which included a simplified severity rating for thermal cracking. PASER allows the level of severity to be known with a quick use method that was intentionally modified in a way to focus on thermal cracking. Although not as widely used this data can also be used in comparison with those agencies that also use PASER.
- The results of correlation between methods show that STCE in combination with LTPP and PASER provides more specific analysis about asphalt thermal cracking and sealing of these cracks so that more informed decisions can be made for a positive impact on ADOT&PF's maintenance budget. This was carried out by conditioning general pavement deterioration on LTPP and PASER data so that severity levels of cracking are related to general pavement deterioration. Also, since loading is a factor as evident in the high traffic through the pictures of sealing projects in cities areas where wheel path versus non wheel path were conditioned or related to LTPP and PASER severity levels to provide more complete information on the situation.
- STCE questions related to major transverse cracks (questions A and E) combining with LTPP and PASER indicate sealing is probably not needed for major thermal cracks. It is confirmed that sealing is not needed for lesser thermal cracks with

answers to STCE questions about the condition and impact of lesser thermal cracks (questions B and F). The data shows that no matter what level of severity the LTPP or PASER showed the STCE questions B and F, about wheel path versus non wheel path and general pavement deterioration form minor thermal cracks, always showed no difference in the wheel path versus non wheel path and no or little pavement deterioration.

- Caution needs to be exercised for the evaluators for STCE method. They should have training or be experienced at evaluating thermal cracks and their influence on the surrounding pavement as well as the effect traffic could possibly have on them and the combined influence on pavement deterioration. At the start of the field study the evaluators met and the senior person explained what to look for when documenting and evaluating for the STCE method. This is recommended whenever this method is to be used.
- Influencing factors on crack development were found to include Min Air (°F), Min Pav (°F), Max Air (°F), Max Pav (°F), freezing index, and rut. However, these factors may affect the crack development in different climatic zones in different ways. The data shows that the quantity of thermal cracks for road sections in the warmer areas such as the Sterling in the Southcentral coastal area is much less for both major and minor thermal cracks. This could change the decision of sealing for both major and minor thermal cracks.
- Influencing factors on sealing practice were found to include crack frequency, freezing index, age, PASER rating, PASER transverse crack severity level, STCE Question E, STCE Question G. This finding will help ADOT&PF to develop more specific plans for crack sealing practice. A lower freezing index could relate to more thermal cracks and therefore possibly more pavement deterioration, but such deterioration is also related to the amount of traffic a certain road section experiences.

5.2 Recommendations

According to the conclusions drawn from this study, it is recommended for ADOT&PF to conduct STCE along with LTPP and PASER methods for further crack sealing surveys in Alaska. LTPP and/or PASER could be adopted by the various maintenance areas of responsibility for a quick evaluation and also a method that is recorded and can be trended over time to provide a basis for decision making of what preventative measure could be used as well as be compared to LTPP data from other agencies. STCE questions should be used in conjunction with a recorded crack evaluation method so that pavement surface condition can be trended over time and the appropriate treatment can be performed at the appropriate time.

Additional STCE questions should be developed to specifically address cracking sealing practices. After performing this study it has been learned that other questions could be developed to add to or replace some of the existing STCE questions that include other asphalt cracking that is currently being sealed. It is much easier to either seal all cracks in a section or none instead of just separating the thermal cracks out and treating them differently when sealing is concerned. This was evident in the sealing practice observed: mostly either all were sealed or none.

It should be noted that most of the data came from Interior sections suggested to acquire more data for the other regions such as Southcentral, Southcentral Coastal, and Southeast. As can be seen by the data recorded the warmer areas displayed fewer of thermal cracks.

5.3 Future Research

For future research, it is suggested to report the data collection at a predetermined time starting at the time of construction. This would allow for the use of control sections and the creation of predictive curves. The amount of time it takes for the cracking pattern to mature could be learned as well. Other statistical methods should be tried to gain further understanding of what the data collected in this study reveal, such as logistic regression and Bayesian methods. Logistic regression is related to data that is ordinal and Bayesian allows one to compare the probabilities of conditions to happen. This is useful since sometimes it is difficult to relate absolute measurements with each other.

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Appendix A – LTPP Data

Table A1: LTPP recorded data for the Richardson Highway.

Highway	No.	Transverse Qty.			Tot	Transverse (ft)			Tot	Transverse Sealed (ft)			Tot
		L	M	H		L	M	H		L	M	H	
Richardson	1	100	16	0	116	60	384	0	444	6	38	0	44
	2	87	8	0	95	522	192	0	714	261	96	0	357
	3	0	6	0	6	0	216	0	216	0	0	0	0
	4	0	15	0	15	0	540	0	540	0	270	0	270
	5	29	6	0	35	1740	1440	0	3180	850	100	0	950
	6	0	6	0	6	0	2160	0	2160	0	1000	0	1000
	7	0	12	0	12	0	432	0	432	0	215	0	215
	8	10	0	0	10	360	0	0	360	200	0	0	200
	9	0	12	0	12	0	432	0	432	0	200	0	200
	10	0	6	0	6	0	216	0	216	0	100	0	100
	11	0	8	0	8	0	288	0	288	0	144	0	144
	12	14	0	0	14	504	0	0	504	250	0	0	250
	13	7	1	0	8	252	36	0	288	216	0	0	216
	14	10	4	0	14	360	144	0	504	216	0	0	216
	15	5	2	0	7	240	0	0	240	168	0	0	168
	16	55	1	0	56	1320	24	0	1344	5	0	0	5
	17	36	0	0	36	716	0	0	716	300	0	0	300
	18	48	1	3	52	495	24	72	591	0	0	0	0
	19	63	3	2	68	1200	72	48	1320	0	0	0	0
	20	16	5	4	25	384	120	96	600	0	0	0	0
	21	60	8	4	72	1345	192	96	1633	0	0	0	0
	23	35	0	0	35	760	0	0	760	144	0	0	144
	24	0	5	0	5	0	120	0	120	0	0	0	0

Table A2: LTPP recorded data for the Alaska Highway.

Highway	No.	Transverse Qty.			Total	Transverse (ft)			Total	Transverse Sealed (ft)			Total
		L	M	H		L	M	H		L	M	H	
Alaska	25	31	0	0	31	620	0	0	620	192	0	0	192
	26	60	2	0	62	1575	64	0	1639	288	0	0	288
	27	10	0	0	10	540	0	0	540	320	0	0	320
	28	10	0	0	10	280	0	0	280	280	0	0	280
	29	8	2	0	10	160	50	0	210	0	0	0	0
	31	27	1	0	28	432	32	0	464	0	0	0	0
	32	18	0	0	18	476	0	0	476	60	0	0	60
	33	21	0	0	21	256	0	0	256	134	0	0	134
	34	20	0	0	20	340	0	0	340	256	0	0	256
	35	15	0	0	15	300	0	0	300	128	0	0	128
	36	12	0	0	12	280	0	0	280	172	0	0	172

Table A3: LTPP recorded data for the Tok Cutoff Highway.

Highway	No.	Transverse Qty.			Total	Transverse (ft)			Total	Transverse Sealed (ft)			Total
		L	M	H		L	M	H		L	M	H	
Tok Cutoff	37	7	5	0	12	224	160	0	384	0	0	0	0
	38	12	6	0	18	288	72	0	360	0	0	0	0
	39	23	0	0	23	186	0	0	186	64	0	0	64
	40	42	0	0	42	756	0	0	756	160	0	0	160
	41	33	2	0	35	1056	64	0	1120	256	0	0	256

Table A4: LTPP recorded data for the Glenn Highway.

Highway	No.	Transverse Qty.			Total	Transverse (ft)			Total	Transverse Sealed (ft)			Total
		L	M	H		L	M	H		L	M	H	
Glenn	42	0	8	0	8	0	288	0	288	0	0	0	0
	43	0	6	0	6	0	210	0	210	0	0	0	0
	44	0	9	0	9	0	324	0	324	0	0	0	0
	45	0	9	0	9	0	324	0	324	0	0	0	0
	46	0	11	0	11	0	280	0	280	0	0	0	0
	47	0	10	0	10	0	360	0	360	0	150	0	150
	48	0	10	0	10	0	320	0	320	0	100	0	100

Table A5: LTPP recorded data for the Steese Highway.

Highway	No.	Transverse Qty.			Total	Transverse (ft)			Total	Transverse Sealed (ft)			Total
		L	M	H		L	M	H		L	M	H	
Steese	49	53	1	0	54	376	24	0	400	256	0	0	256
	50	46	3	0	49	1058	72	0	1130	0	0	0	0
	51	10	0	0	10	324	0	0	324	280	0	0	280
	52	55	1	0	56	1430	26	0	1456	104	24	0	128

Table A6: LTPP recorded data for the Elliot Highway.

Highway	No.	Transverse Qty.			Total	Transverse (ft)			Total	Transverse Sealed (ft)			Total
		L	M	H		L	M	H		L	M	H	
Elliott	53	10	0	0	10	260	0	0	260	72	0	0	72
	54	36	1	4	41	288	26	104	418	0	0	0	0

Table A7: LTPP recorded data for the Parks NR Highway.

Highway	No.	Transverse Qty.			Total	Transverse (ft)			Total	Transverse Sealed (ft)			Total
		L	M	H		L	M	H		L	M	H	
Parks NR	55	10	0	0	10	224	0	0	224	80	0	0	80
	56	44	0	0	44	396	0	0	396	192	0	0	192
	57	13	0	0	13	288	0	0	288	78	0	0	78
	58	52	1	0	53	520	24	0	544	136	34	0	170
	59	28	0	0	28	364	0	0	364	288	0	0	288
	60	37	0	0	37	297	0	0	297	234	0	0	234
	61	45	1	0	46	360	15	0	375	240	0	0	240
	62	37	0	0	37	654	0	0	654	162	0	0	162
	63	33	1	0	34	520	24	0	544	162	0	0	162
	64	53	9	1	63	371	216	32	619	0	0	0	0
	65	51	4	0	55	357	144	0	501	160	0	0	160
	66	41	3	1	45	246	96	32	374	64	0	0	64
	67	56	1	0	57	728	32	0	760	162	0	0	162
	68	30	0	0	30	720	0	0	720	0	132	96	228

Table A8: LTPP recorded data for the Parks CR Highway.

Highway	No.	Transverse Qty.			Total	Transverse (ft)			Total	Transverse Sealed (ft)			Total
		L	**M**	**H**		**L**	**M**	**H**		**L**	**M**	**H**	
Parks CR	69	0	11	0	11	0	352	0	352	0	150	0	150
	70	0	13	0	13	0	416	0	416	0	200	0	200
	71	0	8	0	8	0	256	0	256	0	125	0	125
	72	0	8	0	8	0	256	0	256	0	100	0	100
	73	0	9	0	9	0	324	0	324	0	100	0	100
	74	0	10	0	10	0	360	0	360	0	180	0	180
	75	0	5	0	5	0	180	0	180	0	60	0	60
	76	0	8	0	8	0	290	0	290	0	100	0	100
	77	0	6	0	6	0	216	0	216	0	50	0	50
	78	0	8	0	8	0	256	0	256	0	100	0	100
	79	0	8	0	8	0	288	0	288	0	100	0	100
	80	0	7	0	7	0	252	0	252	0	100	0	100

Table A9: LTPP recorded data for the Sterling Highway.

Highway	No.	Transverse Qty.			Total	Transverse (ft)			Total	Transverse Sealed (ft)			Total
		L	**M**	**H**		**L**	**M**	**H**		**L**	**M**	**H**	
Sterling	81	0	0	8	8	0	0	208	208	0	0	0	0
	82	0	13	0	13	0	390	0	390	0	180	0	180
	83	14	0	0	14	504	0	0	504	250	0	0	250
	84	0	9	0	9	0	324	0	324	0	100	0	100
	85	0	8	0	8	0	288	0	288	0	60	0	60
	86	0	14	0	14	0	504	0	504	0	200	0	200
	87	0	0	3	3	0	0	102	102	0	0	50	50
	88	0	4	0	4	0	144	0	144	0	100	0	100
	89	0	4	0	4	0	144	0	144	0	70	0	70
	90	0	2	0	2	0	72	0	72	0	0	0	0
	91	0	0	3	3	0	0	96	96	0	0	30	30

Appendix B – PASER Data

Table B1: PASER recorded values for the Richardson Highway

Highway	**No.**	**Transverse Cracks**	**Rating**
Richardson	1	m	6
	2	m	7
	3	m	6
	4	m	7
	5	l	7
	6	m	7
	7	m	6
	8	m	7
	9	m	7
	10	m	6
	11	m	7
	12	l	8
	13	l	6
	14	m	6
	15	l	5
	16	l	7
	17	l	7
	18	s	5
	19	m	6
	20	s	6
	21	m	6
	23	l	7
	24	m	4

Table B2: PASER recorded values for the Alaska Highway

Highway	No.	Transverse Cracks	Rating
Alaska	25	1	5
	26	1	7
	27	1	7
	28	1	6
	29	1	6
	31	1	6
	32	1	6
	33	1	8
	34	1	7
	35	1	7
	36	1	7

Table B3: PASER recorded values for the Tok Cutoff

Highway	NoNo.	Transverse Cracks	Rating
Tok Cutoff	37	m	5
	38	1	4
	39	1	7
	40	1	7
	41	1	7

Table B4: PASER recorded values for the Glenn Highway

Highway	No.	Transverse Cracks	Rating
Glenn	42	m	8
	43	m	8
	44	m	7
	45	m	8
	46	m	7
	47	m	8
	48	m	7

Table B5: PASER recorded values for the Steese Highway

Highway	No.	Transverse Cracks	Rating
Steese	49	l	7
	50	m	7
	51	l	8
	52	l	6

Table B6: PASER recorded values for the Elliott Highway

Highway	No.	Transverse Cracks	Rating
Elliott	53	l	5
	54	s	5

Table B7: PASER recorded values for the Parks NR Highway

Highway	No.	Transverse Cracks	Rating
Parks NR	55	l	7
	56	l	7
	57	l	7
	58	l	7
	59	l	5
	60	l	8
	61	l	7
	62	l	7
	63	l	7
	64	m	7
	65	m	7
	66	m	5
	67	l	5
	68	l	4

Table B8: PASER recorded values for the Parks CR Highway

Highway	No.	Transverse Cracks	Rating
Parks CR	69	m	7
	70	m	8
	71	m	6
	72	m	6
	73	m	6
	74	m	7
	75	l	5
	76	m	5
	77	l	7
	78	m	6
	79	m	4
	80	m	5

Table B9: PASER recorded values for the Sterling Highway

Highway	No.	Transverse Cracks	Rating
Sterling	81	s	3
	82	m	6
	83	l	7
	84	m	6
	85	m	7
	86	m	6
	87	s	4
	88	m	6
	89	m	5
	90	m	4
	91	s	5

Appendix C – STEE Data

Table C1: STCE recorded values for the Richardson Highway.

Highway	No.	A	B	C	D	E	F	G	H
Richardson	1	1	1	1	1	1	1	3	3
	2	1	1	1	1	1	1	3	3
	3	1	1	1	1	1	1	3	1
	4	1	1	1	1	1	1	3	2
	5	1	1	3	1	1	1	3	1
	6	1	1	1	1	1	1	2	1
	7	1	1	1	2	1	1	2	1
	8	1	1	1	1	1	1	2	3
	9	1	1	1	1	1	1	2	3
	10	1	1	1	1	1	1	2	1
	11	1	1	1	1	1	1	3	2
	12	1	1	1	1	1	1	1	1
	13	2	1	1	1	1	1	1	1
	14	2	1	2	1	1	1	2	1
	15	2	1	2	1	2	1	2	1
	16	1	1	1	1	1	1	2	2
	17	2	1	1	1	1	1	3	1
	18	2	1	1	1	1	1	1	4
	19	1	1	1	1	1	1	1	4
	20	1	1	1	1	1	1	1	4
	21	1	1	3	1	1	1	1	4
	23	1	1	1	1	1	1	1	1
	24	2	1	1	1	1	1	1	4

Table C2: STCE recorded values for the Alaska Highway.

Highway	**No.**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Alaska	25	1	1	1	1	1	1	2	1
	26	1	2	1	2	1	1	2	1
	27	1	1	1	1	1	1	2	2
	28	1	1	1	1	1	1	2	3
	29	1	1	1	1	1	1	2	2
	31	1	1	1	1	1	1	2	1
	32	1	1	1	1	1	1	2	1
	33	1	1	1	1	1	1	2	2
	34	1	1	1	1	1	1	2	2
	35	1	1	1	1	1	1	2	2
	36	1	1	1	1	1	1	2	1

Table C3: STCE recorded values for the Tok Cutoff Highway.

Highway	**No.**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Tok Cutoff	37	1	1	2	1	1	1	1	1
	38	1	1	1	1	1	1	1	4
	39	1	1	1	1	1	1	2	2
	40	1	1	1	1	1	1	2	2
	41	1	1	1	1	1	1	2	3

Table C4: STCE recorded values for the Glenn Highway.

Highway	**No.**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Glenn	42	1	1	1	1	1	1	3	2
	43	2	1	3	1	1	1	2	1
	44	1	1	3	1	1	1	2	1
	45	2	1	2	1	1	1	1	1
	46	2	1	2	2	1	1	1	1
	47	1	1	1	1	1	1	3	2
	48	2	1	3	1	1	1	3	2

Table C5: STCE recorded values for the Steese Highway.

Highway	**No.**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Steese	49	1	1	1	1	1	1	2	2
	50	1	1	1	1	1	1	2	1
	51	1	1	1	1	1	1	2	1
	52	1	1	1	1	1	1	2	1

Table C6: STCE recorded values for the Elliott Highway.

Highway	**No.**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Elliott	53	2	1	3	1	1	1	2	1
	54	2	1	2	2	1	1	1	1

Table C7: STCE recorded values for the Parks NR Highway.

Highway	No.	A	B	C	D	E	F	G	H
Parks NR	55	1	1	1	1	1	1	2	3
	56	1	1	1	1	1	1	3	3
	57	1	1	1	1	1	1	3	1
	58	1	1	3	1	1	1	2	1
	59	3	1	3	1	3	1	2	1
	60	0	0	0	0	1	1	3	3
	61	1	1	3	1	1	1	2	1
	62	2	1	2	1	1	1	2	1
	63	1	1	2	1	1	1	2	1
	64	1	1	3	1	1	1	1	4
	65	1	1	2	1	1	1	2	1
	66	1	1	3	1	1	1	2	3
	67	1	1	1	1	1	1	2	1
	68	2	1	3	2	1	1	2	1

Table C8: STCE recorded values for the Parks CR Highway.

Highway	No.	A	B	C	D	E	F	G	H
Parks CR	69	2	1	3	1	1	1	3	1
	70	1	1	1	1	1	1	2	3
	71	3	1	3	1	2	1	3	1
	72	3	1	3	1	1	1	3	1
	73	3	1	3	1	1	1	3	1
	74	3	1	3	1	1	1	3	1
	75	3	1	3	1	1	1	3	1
	76	1	1	1	1	1	1	2	1
	77	2	1	1	1	1	1	3	2
	78	2	1	3	1	2	1	3	2
	79	3	1	3	1	2	1	3	1
	80	3	1	3	1	2	1	3	3

Table C9: STCE recorded values for the Sterling Highway.

Highway	No.	A	B	C	D	E	F	G	H
Sterling	81	2	0	2	0	1	0	2	1
	82	2	1	1	1	1	1	3	2
	83	1	1	3	1	1	1	3	1
	84	1	1	1	1	1	1	3	1
	85	1	1	1	1	1	1	3	1
	86	1	1	1	1	1	1	3	1
	87	2	1	3	1	1	1	3	1
	88	1	0	1	0	1	0	2	1
	89	3	0	3	0	3	0	2	1
	90	2	0	2	0	1	0	2	1
	91	3	0	3	0	1	0	2	1

Appendix D – ADOT&PF Data

Table D1: ADOT&PF data for road sections evaluated for the Richardson Highway

Highway	No.	Age	Mile Post for Temp	Min Air (°F)	Min Pav (°F)	Max Air (°F)	Max Pav (°F)	ADT	IRI	Rut	PSR
Richardson	1	26	25.7	-25	-24	74	120	532	112	0.24	3.5
	2	28	25.7	-25	-24	74	120	532	142	0.23	3.2
	3	30	45.7	-30	-24	81	128	532	174	0.27	2.9
	4	34	45.7	-30	-24	81	128	532	157	0.2	3.1
	5	30	45.7	-30	-24	81	128	532	168	0.43	3
	6	30	45.7	-30	-24	81	128	532	200	0.27	2.7
	7	35	45.7	-30	-24	81	128	598	234	0.31	2.4
	8	35	45.7	-30	-24	81	128	598	151	0.3	3.1
	9	21	45.7	-30	-24	81	128	598	136	0.31	3.3
	10	21	83	-38	-27	88	129	598	136	0.31	3.3
	11	21	83	-38	-27	88	129	875	109	0.25	3.6
	12	24	83	-38	-27	88	129	875	107	0.14	3.6
	13	28	83	-38	-27	88	129	456	221	0.42	2.5
	14	28	83	-38	-27	88	129	456	141	0.07	3.2
	15	28	83	-38	-27	88	129	456	210	0.27	2.6
	16	28	83	-38	-27	88	129	380	124	0.14	3.4
	17	30	83	-38	-27	88	129	380	111	0.15	3.6
	18	28	83	-38	-27	88	129	380	149	0.19	3.2
	19	31	218.2	-37	-31	81	118	618	125	0.23	3.4
	20	31	218.2	-37	-31	81	118	618	165	0.11	3
	21	31	218.2	-37	-31	81	118	618	156	0.13	3.1
	23	31	218.2	-37	-31	81	118	618	154	0.21	3.1
	24	31	292.6	-40	-32	89	120	618	109	0.22	3.6

Table D2: ADOT&PF data for road sections evaluated for the Alaska Highway

Highway	No.	Age	Mile Post for Temp	Min Air (°F)	Min Pav (°F)	Max Air (°F)	Max Pav (°F)	ADT	IRI	Rut	PSR
Alaska	25	29	1360.4	-40	-39	87	120	860	68	0.23	4.1
	26	29	1360.4	-40	-39	87	120	860	69	0.2	3.8
	27	29	1360.4	-40	-39	87	120	312	118	0.13	3.1
	28	26	1360.4	-40	-39	87	120	312	112	0.18	3.2
	29	26	1360.4	-40	-39	87	120	312	145	0.23	2.8
	31	26	1360.4	-40	-39	87	120	312	101	0.25	3.3
	32	26	1360.4	-40	-39	87	120	312	99	0.11	3.3
	33	26	1360.4	-40	-39	87	120	312	71	0.21	3.7
	34	22	1360.4	-40	-39	87	120	312	112	0.14	3.2
	35	22	1360.4	-40	-39	87	120	312	99	0.23	3.3
	36	22	1360.4	-40	-39	87	120	312	89	0.19	3.5

Table D3: ADOT&PF data for road sections evaluated for the Tok Cutoff Highway

Highway	No.	Age	Mile Post for Temp	Min Air (°F)	Min Pav (°F)	Max Air (°F)	Max Pav (°F)	ADT	IRI	Rut	PSR
Tok Cutoff	37	31	79.2	-40	-37	87	120	360	133	0.17	2.9
	38	31	79.2	-40	-37	87	120	380	90	0.17	3.5
	39	31	79.2	-40	-37	87	120	380	68	0.17	3.8
	40	31	79.2	-40	-37	87	120	380	57	0.06	4
	41	29	79.2	-40	-37	87	120	577	50	0.09	4.9

Table D4: ADOT&PF data for road sections evaluated for the Glenn Highway

Highway	No.	Age	Mile Post for Temp	Min Air (°F)	Min Pav (°F)	Max Air (°F)	Max Pav (°F)	ADT	IRI	Rut	PSR
Glenn	42	27	117	-24	-25	80	121	753	180	0.21	2.4
	43	27	117	-24	-25	80	121	901	141	0.16	2.8
	44	27	117	-24	-25	80	121	901	186	0.17	2.3
	45	32	117	-24	-25	80	121	901	110	0.18	3.2
	46	32	176.6	-40	-35	85	123	867	159	0.19	2.6
	47	32	176.6	-40	-35	85	123	867	148	0.15	2.7
	48	32	176.6	-40	-35	85	123	915	193	0.25	2.3

Table D5: ADOT&PF data for road sections evaluated for the Steese Highway

Highway	No.	Age	Mile Post for Temp	Min Air (°F)	Min Pav (°F)	Max Air (°F)	Max Pav (°F)	ADT	IRI	Rut	PSR
Steese	49	23	20.9	-30	-24	84	122	4870	146	0.22	3.2
	50	21	20.9	-30	-24	84	122	1563	160	0.23	3
	51	21	20.9	-30	-24	84	122	209	87	0.11	3.8
	52	21	20.9	-30	-24	84	122	209	67	0.1	4.1

Table D6: ADOT&PF data for road sections evaluated for the Elliott Highway

Highway	No.	Age	Mile Post for Temp	Min Air (°F)	Min Pav (°F)	Max Air (°F)	Max Pav (°F)	ADT	IRI	Rut	PSR
Elliott	53	31	20.9	-30	-24	84	122	595	209	0.54	1.8
	54	31	20.9	-30	-24	84	122	595	236	0.55	1.6

Table D7: ADOT&PF data for road sections evaluated for the Parks NR Highway

Highway	No.	Age	Mile Post for Temp	Min Air (°F)	Min Pav (°F)	Max Air (°F)	Max Pav (°F)	ADT	IRI	Rut	PSR
Parks NR	55	25	163.2	-25	-22	86	114	1639	151	0.35	3.1
	56	27	163.2	-25	-22	86	114	1680	108	0.36	3.2
	57	27	163.2	-25	-22	86	114	1680	104	0.48	3.3
	58	27	163.2	-25	-22	86	114	1680	120	0.24	3.1
	59	26	163.2	-25	-22	86	114	1644	98	0.29	3.3
	60	26	201.4	-34	-26	87	126	1644	70	0.1	3.8
	61	26	244	-40	-37	86	114	2193	66	0.12	3.8
	62	21	244	-40	-37	86	114	2193	103	0.09	3.3
	63	21	244	-40	-37	86	114	2193	93	0.1	3.8
	64	25	244	-40	-37	86	114	2193	70	0.21	3.8
	65	25	244	-40	-37	86	114	2193	84	0.19	3.5
	66	25	244	-40	-37	86	114	3094	161	0.27	3
	67	28	244	-40	-37	86	114	3094	192	0.35	2.3
	68	28	244	-40	-37	86	114	1932	134	0.28	3.3

Table D8: ADOT&PF data for road sections evaluated for the Parks CR Highway

Highway	No.	Age	Mile Post for Temp	Min Air (°F)	Min Pav (°F)	Max Air (°F)	Max Pav (°F)	ADT	IRI	Rut	PSR
Parks CR	69	27	98.7	-35	-28	90	128	2670	129	0.39	3
	70	27	98.7	-35	-28	90	128	1570	133	0.35	2.9
	71	22	98.7	-35	-28	90	128	1442	109	0.24	3.2
	72	22	98.7	-35	-28	90	128	1410	92	0.28	3.4
	73	22	98.7	-35	-28	90	128	1123	118	0.36	3.1
	74	22	98.7	-35	-28	90	128	1123	123	0.42	3
	75	22	98.7	-35	-28	90	128	1123	137	0.31	2.9
	76	25	98.7	-35	-28	90	128	987	135	0.21	2.9
	77	25	98.7	-35	-28	90	128	987	101	0.28	3.3
	78	25	98.7	-35	-28	90	128	1150	141	0.3	2.8
	79	25	98.7	-35	-28	90	128	1150	118	0.26	3.1
	80	25	98.7	-35	-28	90	128	1150	99	0.27	3.3

Table D9: ADOT&PF data for road sections evaluated for the Sterling Highway

Highway	No.	Age	Mile Post for Temp	Min Air (°F)	Min Pav (°F)	Max Air (°F)	Max Pav (°F)	ADT	IRI	Rut	PSR
Sterling	81	28	54.8	-29	-23	87	123	2981	137	0.38	2.9
	82	30	62.3	-21	-22	83	119	3910	115	0.69	1.9
	83	20	62.3	-21	-22	83	119	3561	94	0.48	3.7
	84	23	62.3	-21	-22	83	119	2970	94	0.58	2.3
	85	23	62.3	-21	-22	83	119	2970	80	0.5	3.6
	86	23	62.3	-21	-22	83	119	1890	104	0.6	2.1
	87	23	62.3	-21	-22	83	119	1890	119	0.45	3.1
	88	23	62.3	-21	-22	83	119	2680	113	0.51	2.2
	89	23	62.3	-21	-22	83	119	2467	114	0.45	3.1
	90	23	62.3	-21	-22	83	119	2467	138	0.69	1.8
	91	23	62.3	-21	-22	83	119	2960	117	0.47	3.1

Appendix E – Freezing Index Data

Table E1: Freezing index for Richardson Highway sections.

Highway	No.	WRCC Location	Freezing Index
Richardson	1	Thompson Pass	3797
	2	Thompson Pass	3797
	3	Thompson Pass	3797
	4	Ernestine	4002
	5	Ernestine	4002
	6	Ernestine	4002
	7	Tonsina	4392
	8	Tonsina	4392
	9	Tonsina	4392
	10	Tonsina	4392
	11	Copper Ctr	4527
	12	Copper Ctr	4527
	13	Paxon River	5265
	14	Paxon River	5265
	15	Paxon River	4557
	16	Paxon River	4557
	17	Paxon River	4557
	18	Paxon River	4557
	19	Big Delta AP	4248
	20	Big Delta AP	4248
	21	Big Delta AP	4248
	23	Big Delta AP	4248
	24	Big Delta AP	4248

Table E2: Freezing index for Alaska Highway sections.

Highway	No.	WRCC Location	Freezing Index
Alaska	25	Tok	5628
	26	Tok	5628
	27	Tanacross	5181
	28	Tanacross	5181
	29	Tanacross	5181
	31	Tanacross	5181
	32	Tanacross	5181
	33	Dot Lake	6050
	34	Dot Lake	6050
	35	Dot Lake	6050
	36	Dry Creek	5070

Table E3: Freezing index for Tok Cutoff Highway sections.

Highway	No.	WRCC Location	Freezing Index
Tok Cutoff	37	Slana	4429
	38	Slana	4429
	39	Tok	5628
	40	Tok	5628
	41	Tok	5628

Table E4: Freezing index for Glenn Highway sections.

Highway	No.	WRCC Location	Freezing Index
Glenn	42	Snowshoe Lake	5342
	43	Snowshoe Lake	5342
	44	Snowshoe Lake	5342
	45	Snowshoe Lake	5342
	46	Glennallen Kcam	4553
	47	Glennallen Kcam	4553
	48	Glennallen Kcam	4553

Table E5: Freezing index for Steese Highway sections.

Highway	No.	WRCC Location	Freezing Index
Steese	49	Fox2 SE	3889
	50	Fox2 SE	3889
	51	Gilmore Creek	4527
	52	Gilmore Creek	4527

Table E6: Freezing index for Elliott highway sections.

Highway	No	WRCC Location	Freezing Index
Elliott	53	Gilmore Creek	4527
	54	Gilmore Creek	4527

Table E7. Freezing index for Parks NR highway sections.

Highway	**No**	**WRCC Location**	**Freezing Index**
Parks NR	55	Chulitna River	2513
	56	Chulitna River	2513
	57	Chulitna River	2513
	58	Summit AP	5041
	59	Summit AP	5041
	60	Cantwell 2 E	4307
	61	Cantwell 2 E	4307
	62	Cantwell 2 E	4307
	63	Cantwell 2 E	4307
	64	McKinley Park	4086
	65	McKinley Park	4086
	66	McKinley Park	4086
	67	Healy 2 NW	3877
	68	Healy 2 NW	3877

Table E8. Freezing index for Parks CR highway sections.

Highway	No	WRCC Location	Freezing Index
Parks CR	69	Susitna Landing	3530
	70	Talkeetna	2165
	71	Talkeetna	2165
	72	Trappers Creek Camp	2161
	73	Trappers Creek Camp	2161
	74	Trappers Creek Camp	2161
	75	Trappers Creek Camp	2161
	76	Trappers Creek Camp	2161
	77	Chulitna River	2513
	78	Chulitna River	2513
	79	Chulitna River	2513
	80	Chulitna River	2513

Table E9. Freezing index for Sterling highway sections.

Highway	No	WRCC Location	Freezing Index
Sterling	81	Cooper Landing 5 W	1646
	82	Funny River	2310
	83	Funny River	2310
	84	Soldotna 5SSW	2397
	85	Soldotna 5SSW	2397
	86	Soldotna 5SSW	2397
	87	Soldotna 5SSW	2397
	88	Soldotna 5SSW	2397
	89	Homer 8 NW	1029
	90	Homer 8 NW	1029
	91	Homer 8 NW	1029