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16. Abstract

As an alternative to traditional contracting, pavement warranty has been adopted in Mississippi since 2000, aimed to enhance pavement performance and protect the investment in pavement construction. Currently, a manual distress survey method and the associated deduct point-based pavement condition rating approach are employed to monitor the performance of warranty pavements (maintained projects). The main objective of this study is to evaluate the appropriateness of using the current deduct points and distress thresholds to monitor the performance of the maintained projects in Mississippi. In the study, a comprehensive literature review and online survey were conducted to review the recent state of practice of pavement warranty in North America. The analytical section of the study employed pavement distress and riding quality data collected from warranty pavements and the corresponding data of non-warranty pavements stored in MDOT's Pavement Management System (PMS) for the statistical analysis. Using raw data, converted deduct points, and composite index as performance indicators, basic statistics were developed to investigate the distribution of performance indicators at various service times and the corresponding percentiles associated with the existing threshold values. In addition, pairwise comparisons were conducted to examine the evolvement of distress over time for warranted and non-warranted pavements. Further, two sample t-tests were performed to compare the performance of warranted and non-warranted pavements at the same service time. The survey study has shown that most other pavement warranty programs in other states use direct measurements of pavement distresses or densities of pavement distresses for their distress indicators and thresholds while the pavement warranty program at MDOT employs deduct points based distress thresholds which are quantities converted from measurements of pavement distresses. The analytical results show that the performance of the warranty pavements is significantly better than that of the non-warranty pavements at the same service time level, and warranty pavements can maintain at high service levels for a longer time than non-warranty pavements. The pavement warranty program adopted by MDOT has improved pavement performance, and is effective in practice. However, the current distress thresholds adopted by MDOT are inconsistent with regard to the various corresponding percentile levels for different distress types at a same service time, and the different increase rates of the percentile level for different distress types over service time. It is suggested that direct measurements of pavement distresses or distress densities be used as distress thresholds, and consistent threshold levels be implemented for all distress types.

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The project was a joint effort that pools expertise from the Department of Civil and Environmental Engineering, and the Institute for Multimodal Transportation (IMTrans) at Jackson State University (JSU), Jackson, Mississippi. Dr. Yan Qi, Technical Manager of IMTrans contributed in conducting literature reviews, designing survey questionnaire, analyzing pavement distress data, and drafting the research report. Dr. Amin El Gendy, visiting scholar from the Port Said University, Port Said, Egypt conducted literature reviews, designed and implemented questionnaire survey, and drafted the survey study part of the research report. Mr. Yibo Li, visiting graduate student from the University of Shanghai for Science and Technology, Shanghai, China, JSU graduate student Ms. Yuxiao Zhou, and JSU undergraduate students Warren Hudson and Fatima Diop participated in analysis of data. Dr. Farshad Amini, professor and Chair of the Department of Civil and Environmental Engineering helped develop the proposal and plan for the project. Dr. Feng Wang, assistant professor of the Department of Civil and Environmental Engineering and Director of IMTrans served as the principal investigator of the project.

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CHAPTER 1. INTRODUCTION

1.1 Problem Statement

Pavement warranty is an innovative contracting procedure adopted by state transportation agencies in an attempt to reduce the amount of state highway agency resources required on a highway project, to reallocate performance risk, to increase contractor innovation, to increase the quality of constructed products, and to reduce the life-cycle cost of highway projects (Anderson and Russell 2001). It has been widely used in Canada and in Europe (D'Angelo et al. 2003). Although pavement warranties began in the United States as early as the first paved roads were being laid in the late 1800's, they fell out of use in the 1950's when the interstate construction started and the federal government began contributing to building highways. The main reason lies in the fact that the corrective actions required by warranties could fall under the category of maintenance activities, and federal dollars were not allowed to be spent on such activities. In the 1990's, the idea of pavement warranties resurfaced, and the federal regulations were revised in 1995 to allow state agencies to use pavement warranties to improve the long-term quality of roadways (FHWA 2010).

Currently, as most agencies and organizations, state highway agencies are experiencing pressure to improve cost, time and quality in project development and execution of facilities, while continuing to downsize, restructure their organizations, and reduce personnel. Consequently, state highway agencies are inclined to pursue innovative practices to shift more responsibilities and project risks to the contracting community, and in the meanwhile protect their investment in pavement construction (Hancher 1994). Therefore, more and more state highway agencies have adopted pavement warranty program in their project contracting, among which California, Wisconsin, Indiana, Michigan, and New Mexico are the pioneering states. The Mississippi Department of Transportation (MDOT) implemented its first pavement warranty project in 2000, and to date has awarded to 9 different contractors a total of 18 projects across the state, among which 13 are still active and within their warranty periods.

The most important technical challenge in implementing pavement warranty is to establish warranty specifications and to evaluate the performance of the warranty pavements. The purpose of the warranty specification is to establish responsibilities, expectations, and consistency in the department's implementation and administration of warranty requirements in maintained projects. Pavement warranty specifications usually include descriptions about the length of warranty period, the types and threshold levels of distresses or performance/distress indicators, the methods to measure the distresses or performance indicators, and the corresponding remedial actions. The proper selection of warranty items and establishment of their threshold levels constitute the most important component in the warranty/maintained projects.

Compared with the traditional procedures of project contracting, the use of warranties on roadway construction projects is a new practice with less than 20 years of implementation in the US. Since there was no national standard available for the implementation of pavement warranty projects, individual state DOTs developed their own warranty specifications, which varied in terms of warranty type, warranty period, risk allocation items, performance evaluation method, etc. Basically, four types of warranties are reported in the literature, namely, prepaid maintenance warranties, workmanship warranties, materials and workmanship warranties, and performance warranties (Hancher 1994). The duration of a warranty commonly ranges from 1 to 10 years, and long-term warranties of more than 10 years are also reported in the literature, such as a 5-20 year warranty period in New Mexico (Scott et al. 2006). The most common distresses in warranty specifications are rutting and various types of cracking. Some states include ride as a warranty item. Sometimes, friction, patching area, potholes, raveling, flushing, distortions, and disintegrated area can be in warranty specifications as well. To date, warranty programs have been implemented to all four pavement types including HMA, composite, JRCP, and CRCP in the United States.

MDOT pavement distress assessment and evaluation methods have evolved over the last decade. To date, 100% automated distress detection and density-based method have been used for network-level pavement distress data collection and evaluation of non-warranty pavements in Mississippi. However, currently MDOT still use accumulated deduct points based on human/visual rating, and a fail/pass result based on the distress threshold to monitor and evaluate warranty projects, since the automated technique is not sophisticated enough for project-level pavement distress survey. However, developed in the 1990's, the old deduct point curves and distress thresholds may not be suitable to evaluate the current warranty pavements due to the emergence of new pavement technology and new pavement materials. Therefore, there are research needs for MDOT to investigate the validity of the deduct point based distress threshold values. It is necessary to review the current practice of other states and learn the experiences in developing warranty specification with respect to warranty items, as well as warranty evaluation, warranty term, warranty project selection, etc.

1.2 Background

As the key component in the warranty specifications, the threshold system and threshold values vary by state, since distress thresholds are usually determined by local experience with pavement performance in every individual state. Currently MDOT sets the thresholds for each distress type as the maximum allowable deduct points converted from the corresponding pavement distress measurements, while many other states use thresholds directly based on pavement distresses measurements or distresses densities.

MDOT pavement distress assessment and evaluation methods have evolved over the last decades. Since 1990s, pavement distresses were measured manually and then converted to deduct points using the deduct point curve equations which were developed in 1995 for MDOT's pavement management system (George 1995). In recent years new technology has emerged in the data collection arena, and MDOT has changed from the human-rated survey method to 100% automated distress survey at the network-level since 2009. Subsequently, the conditions of these non-warranty pavements are evaluated by using deduct point equations for individual distress measurements and the revised distress density based pavement condition rating model. However, the distress assessment and evaluation methods for the warranty projects remain the same as before 2009, which is primarily because (1) the warranty projects were all contracted before 2009 and these contracts are still active; and (2) the manual distress survey method was regarded more appropriate for the project level (Qi et al 2010; Battey 2009).

A deduct point curve equation is actually a regression model that relates a pavement engineer's perception of loss of points in the rating of pavement performance corresponding to the measured distress of the pavement for the particular distress type. The major disadvantages of using the deduct points in the pavement warranty program are: (1) The conversions of distress measurements into deduct points using the regressed deduct point equations actually reduce the accuracy of the objective distress measurements by adding subjective components; (2) The deduct point equations were empirically developed in 1990s reflecting the data, experiences, and technologies of that time, and therefore, the validity and applicability of continual use of these deduct point equations has become problematic with time; and (3) The composite pavement condition rating (PCR) model that combines multiple pavement distresses along with the deduct point conversions on which the PCR model is based would be more needed for the project selection and prioritization of pavement management in the network level, than for the management of warranty projects which is indeed in the project level. The above disadvantages may explain the extreme unpopularity of the deduct point usage in pavement warranty programs in the US and Canada. This study was initiated to evaluate the appropriateness of the current thresholds for maintained pavements in Mississippi and make suggestions and recommendations to MDOT based on the research results.

The most widely claimed benefit of warranty contracts is that the shift of the performance risks and maintenance duties from the agency to the contractor results in better pavement performance and longer service life of the end product. Consequently, warranty clauses call for higher cost than similar traditional contracts. One major concern of warranty contracts is whether warranty pavements with extra cost perform better than non-warranty pavements. This is not a research subject solely interested by MDOT. During the last two decades, many states have conducted studies to evaluate their pavement program and a number of publications were reported in the literature.

Using individual distress index, composition index, or riding quality measurement as a performance indicator, most of the previous studies evaluated the warranty program through comparing the performance of warranty and non-warranty pavements. For example, Battaglia (2009) conducted a study to compare the performance for WisDOT pavements constructed under warranty and standard contracts using Pavement Distress Index (PDI) and IRI. It was found that HMA warranty pavements had lower distress levels and better ride quality than non-warranty HMA pavements, while no statistically significant difference was detected for the two contracting types of HMA overlay on PCC pavement. For JCP pavement, the difference in PDI was not statistically significant between non-warranty and warranty pavements. There was a statistical difference in IRI at several service ages, but no conclusive trend was evident.

Some states conducted research to study their long-term warranty pavements. For instance, Goldbaum (2007) compared the performance of long-term warranty pavements and control projects in Colorado using pavement condition and IRI data. The finding of the study showed that the performance of a warranty pavement was better than that of a control pavement for HMA surface type, while the opposite was found for PCC surface. Similar pavement warranty evaluation studies were reported in the literature (Aschenbrener et al. 2008, Singh et al. 2005, etc.). In addition, several comprehensive survey studies on pavement warranty were reviewed (Scott et al. 2006, Ohio DOT 2007, Wang et al. 2005, etc.).

The literature review shows that several states have reported and examined the performance of their pavement warranty programs. Inconsistent results were obtained with respect to the effectiveness of the warranty contracting for different pavement types and in terms of different performance measurements. Additionally, since individual state DOTs adopt self-developed warranty specifications, the study results from other states cannot be applied directly in Mississippi. Therefore, it is necessary for MDOT to conduct a comprehensive study to evaluate its pavement warranty program and learn from its experiences in developing warranty specifications. Moreover, the accumulation of performance data for over 10 years from the warranty pavements in Mississippi makes it possible to conduct statistical analyses to evaluate MDOT's warranty program. To address the research needs of MDOT, this study was initiated to evaluate the appropriateness of MDOT's distress threshold values for warranty projects and investigate the effectiveness of warranty contracting over non-warranty alternative in Mississippi.

1.3 Study Objectives

The research aims to evaluate the distress threshold values for warranty projects in Mississippi. In order to assist MDOT to implement more effective pavement warranties, the following objectives are to be achieved:

1) To search for the pavement warranty practice and specification in other states;
2) To investigate the effectiveness of MDOT's current warranty program;
3) To evaluate the appropriateness of current deduct points based distress threshold values adopted by MDOT; and
4) To explore a new density-based way for quantifying distress thresholds.

1.4 Scope

The scope of this study covers a comprehensive review and an online survey study on the previous pavement warranty studies and current state of pavement warranty practice in Mississippi and other states, as well as a systematic statistical analysis and comparison of distress data available for both warranty and non-warranty pavements.

1.5 Organization

The remainder of the report is organized as follows: Chapter 2 presents a summary of the literature reviewed in the area of pavement warranties, followed by Chapter 3 of a survey study on the current state of pavement warranty practice in North American. Chapter 4 describes the data used in the study. Chapter 5 is focused on the methodology employed in the research, while Chapter 6 presents and discusses the analysis results. The conclusions and future research are summarized in Chapter 7.

CHAPTER 2. LITERATURE REVIEW

Two types of pavement warranties are specified by FHWA, namely materials and workmanship warranties and performance warranties (FHWA 2010). Under a warranty, the contractor takes a specific set of duties and associated risks, and will take the resulting cost in case of a premature problem during the warranty period. The risk is transferred from highway agencies to the contractors to various degrees. For example, under a materials and workmanship warranty, the contractor is responsible for correcting defects in work elements within contractor control (materials and workmanship), during the warranty period. Since the owner is still responsible for project design, the contractor assumes no responsibility for defects due to design decisions. Under a performance warranty, the contractor assumes full responsibility for pavement performance during the warranty period.

Many states view implementing warranties as a way to protect their investments in pavement construction and mainly to enhance pavement performance (Wang et al. 2005). Since 1996, several state Department of Transportations (DOTs) started to investigate the feasibility and increasingly promoted the use of warranty contracts. According to the 2006 NCHRP project 20-07 (Scott et al. 2006), more than two-thirds of state DOTs had implemented at least one construction warranty project. The total number of pavement warranty projects completed by 2006 was more than 2150. The Michigan DOT accounts for nearly 50 percent of the total with more than 1000 pavement warranty constructed in the last 10 years. The Florida DOT accounts for the second highest percentage with about 700 pavement warranty projects, followed by the Ohio DOT and the Wisconsin DOT with more than 150 and 80 pavement warranty projects, respectively. The remaining percentage (about 5%) is spread over the rest of the 19 DOTs.

Around the same time period, another pavement warranty survey was conducted by Ohio DOT (2007). According to this survey, all projects done by Hawaii DOT have a warranty clause. Connecticut DOT had warranty projects in a very small percentage. Kansas DOT attempted to use warranty on pavement markings for a time but found the contractors could not provide the type warranty wanted at a reasonable price. Kentucky DOT had several material warranties. Maine DOT was investigating the requirements to extend warranty provisions on some of their paving projects, but has not advertised any to date of the survey, and all their projects have a one-year warranty. Warranty projects let by Minnesota DOT were still in the more or less pilot stage and were being studied further, and most of the warranties were for simpler projects such as rout and seal, asphalt overlay, or bridge painting. Mississippi DOT had warranty specifications for Hot Mix Asphalt (HMA) pavement, which were used on selected projects only. In Missouri, one "experimental project" was bid with a 15-year asphalt pavement warranty. This was an approximately $20 million project that was a partnership with a transportation corporation. Utah DOT and Virginia DOT warranty projects were mostly for electrical and traffic items (Traffic Signal warranties).

In practice, warranty projects are not limited to pavement warranties and may be extended to other items, such as bridge painting, pavement markings, and traffic signalization. The current study only focuses on pavement warranties, which most fall under the two categories of material and workmanship warranties and performance warranties. The following sections summarize the pavement warranty programs of other pioneer states reported in the literature, as well as previous studies on pavement warranty conducted by some of those states, and the document the current pavement warranty practice and related studies in Mississippi.

2.1 Colorado Department of Transportation

The Colorado DOT developed 3- and 5-year pavement warranty specifications and conducted three major studies to evaluate the short-term warranties (Aschenbrener and DeDios 2001, Aschenbrener and Goldbaum 2007; and Aschenbrener et al. 2007). Based on these studies, there was no appreciable difference in competition or performance of the warranty projects compared to the control projects. Moreover, the differential of initial cost of the warranty projects compared to the non-warranty projects (about $85,000) was determined to be negligible, which was approximately 3% of the overall project cost. The largest warranty cost is related to the cost of the weigh-in-motion (WIM) station installation and maintenance. WIM station was required to monitor the traffic load since under Colorado material and workmanship warranty, the warranty would be terminated if the cause of pavement defects (e.g. rutting) was due to the traffic load on a warranty project exceeding the design traffic load. Aschenbrener et al. (2007) recommended that the requirement of the WIM should be re-evaluated.

In addition, the Colorado DOT had studied two pilot projects containing long-term performance warranties (Goldbaum 2006). The report represents the baseline information needed to guide the Colorado DOT task force in the use of long-term warranties. It is concluded that the projects should be warranty with respect to riding quality, rutting, and cracking for a period of 10 years. The following are samples of the Colorado DOT's warranty documents presented at the Pavement Warranty Symposium (Michigan DOT 2003).

Criteria for Warranting Portland Cement Concrete Pavements

For a warranty Portland Cement Concrete pavement, the contractor is responsible for PCCP materials compliance, workmanship, and warranty work required by Colorado DOT for a period of five years against the types of distress listed in Tables 1 and 2.

Guideline for Selection of Portland Cement Concrete Pavement Warranty Projects

The following are some of the Guidelines for the selection of a Portland Cement Concrete Pavement （PCCP）5-Year warranty project used by Colorado DOT:

1) The primary scope of the project should be paving.
2) The structural design should be greater than 20 years.
3) The length of the project should be at least 3 miles.
4) The PCCP should be constructed on sub grade or an unbounded overlay. (The Contractor may choose to remove the existing pavement.)
5) The minimum PCCP thickness should be greater than 9 inches.
6) A Weigh-In-Motion or Automatic Traffic Recording Station should be installed on or near the project.

Table 1 Distress Types, Warranty Thresholds, and Remedial Actions for Portland Cement Concrete Pavements Used by Colorado DOT

Distress Type	Threshold Level	Remedial Action
Corner Breaks	Spalling ≤50 mm (2 in.); faulting of the crack or joint ≤7 mm (0.25 in.), width of crack ≤3 mm (0.125 in.); or the corner piece is not broken into two or more pieces.	No action required if less than 50% of the surveyed slabs are at or below the indicated threshold level.
	Spalling >50 mm (2 in.) to ≤150 mm (6 in.); faulting of the crack or joint >7 mm (0.25 in.) to ≤13 mm (0.5 in.); width of crack >3 mm (0.125 in.) to ≤13 mm (0.5 in.); or the corner piece is not broken into two or more pieces.	Rout and seal the crack and concrete patch the spalled area.
	Spalling >150 mm (6 in.); faulting of the crack or joint >13 mm (0.5 in.); width of crack >13 mm (0.5 in.); or the corner piece is broken into more than two pieces.	Remove and replace the affected area.
Longitudinal or Transverse Cracking	Spalling ≤50 mm (2 in.); faulting of the crack ≤7 mm (0.25 in.), width of crack ≤3 mm (0.125 in.); or the 4.5 meter (15 ft.) slab is not broken into more than two pieces.	No action required if less than 50% of the surveyed slabs are at or below the indicated threshold level.
	Spalling >50 mm (2 in.) to ≤150 mm (6 in.); faulting of the crack >7 mm (0.25 in.) to ≤13 mm (0.5 in.); width of crack >3 mm (0.125 in.) to ≤13 mm (0.5 in.); or the 4.5 meter (15 ft.) slab is not broken into more than two pieces.	Concrete patch the spalled location then route and seal the crack. If the crack has faulted >10 mm (0.4 in.), then cross stitch or retro fit tie bars in the crack.
	Spalling >150 mm (6 in.); faulting of the crack >13 mm (0.5 in.); width of crack ≥13 mm (0.5 in.); or the 4.5 meter (15 ft.) slab is broken into more than two pieces.	Remove and replace the slab or the affected area whichever is less.
Longitudinal or Transverse Joint Seal Damage	Total length longitudinally or transversely in a 4.5 meter (15 ft.) slab ≤ 0.6 m (2 ft.).	No action required if less than 50% of the surveyed slabs are at or below the indicated threshold level.
	Total length longitudinally or transversely in a 4.5 meter (15 ft.) slab >0.6 m (2 ft.) and ≤ 1.8 m (6 ft.).	Clean the joint and replace the backer rod and sealant material.
	Total length in longitudinally or transversely in a 4.5 meter (15 ft.) slab >1.8 m (6 ft.)	Remove and replace all the joint material in the slab.
Scaling	Scaling ≤ 0.18 m^2 (2.0 sq. ft.) per 4.5 meter (15 ft.) slab.	No action required if less than 50% of the surveyed slabs are at or below the indicated threshold level.
	Scaling > 0.18 m^2 (2.0 sq. ft.) per 4.5 meter (15 ft.) slab.	Remove partial depth and replace the affected area.

Table 2 Distress Types, Warranty Thresholds, and Remedial Actions for Portland Cement Concrete Pavements Used by Colorado DOT (cont'd)

Distress Type	Threshold Level	Remedial Action
Popouts Blowups (Due to transverse joint seal deterioration)	Popouts ≤ 2 per 0.91 m² (1.0 sq. yd.) or ≤ 50 mm (2 in.) deep.	No action required if less than 50% of the surveyed slabs are at or below the indicated threshold level.
	Popouts > 2 per 0.91 m² (1.0 sq. yd.) or > 50 mm (2 in.) deep.	Clean and patch all the locations in the slab.
	Any blowup	Remove a minimum of 0.6 m (2 ft.) in the longitudinal direction past the affected area on each side, reset the dowel bars and replace PCCP.
Faulting of Dowelled Pavement. (If dowels are missing or misplaced)	Faulting ≤ 7 mm (0.25 in.)	No action required if less than 50% of the surveyed slabs are at or below the indicated threshold level.
	Faulting >7 mm (0.25 in.) and ≤ 13 mm (0.5 in.)	Retro fit dowel bars. Grinding may be included.
	Faulting >13 mm (0.5 in.)	Remove and replace the slab with the required dowels and tie bars.
Lane-To-Shoulder or Lane-To-Lane Dropoff or Separation Patch/Patch in pavement Deterioration	Dropoff or Separation ≤ 13 mm (0.5 in.).	No action required if less than 50% of the surveyed slabs are at or below the indicated threshold level.
	Dropoff or Separation >13 mm (0.5 in.).	Clean the joint, cross stitch or retro fit tie bars, and then reset the backer rod and joint sealant.
	Same as PCCP pavement not patched	See previous preferred remedial actions

Criteria for Warranting Hot Mix Asphalt Pavements

The Hot Mix Asphalt Pavement project is warranty against the types of distresses (Performance Criteria) listed in Table 3. The annual condition data collected by the Colorado DOT as part of the pavement management program will be used as an initial indicator of performance. If the pavement management condition data indicates any threshold has been exceeded, a detailed manual distress survey may be performed for further evaluation before any remedial is required.

Table 3 Warranty Thresholds for Asphalt Pavements Used by Colorado DOT

Distress Type	Threshold Level (per tenth mile)
Permanent Deformation	0.50 in. in any wheel path
Longitudinal Cracking	30 ft.
Transverse Cracking	5 counts
Load Associated Longitudinal Cracking	50 sq. ft.
Bleeding	50 sq. ft.
Raveling	50 sq. ft.

Guideline for Selection of Hot Mix Asphalt Pavement Warranty Projects

Below are some of the Guidelines for the selection of a Hot Mix Asphalt Pavement 10-Year Warranty Project:

1) The primary scope of the project should be paving (at least 75%).
2) The length of the project should be a minimum of 3 miles. And a length greater than 5 miles would be preferred.
3) The design ESALs should be 20 years.
4) The project should be new construction or reconstruction.
5) The project should be a design/bid/build.
6) A weigh-in-motion station should be installed on or near the project unless a current station exists in the vicinity.

2.2 Illinois Department of Transportation

In 2000, Illinois DOT started its pavement warranty program with a 5-year performance-based warranty project (Wienrank 2004). Warranty specifications were developed for concrete pavements, asphalt (asphalt) pavements, and asphalt overlays. During Fiscal Years 2000-2004, the warranty specifications were included on 27 pavement projects. Illinois DOT adopted three different types of warranty: workmanship, material warranties and performance warranties.

Condition Data Acquisition

Collection of pavement distress data of a warranty project is done through manual survey or automated data collection. Lasers are used to collect roughness data. Cracking data is collected manually or through digital image. When International Roughness Index (IRI) is required, it is measured in each wheel path using ¼ car model and then averaged for each lane.

Warranty Enforcement

The Illinois DOT uses a Conflict Resolution Team (CRT) to provide a decision on disputes between the Illinois DOT and the Contractor regarding any claims of non-compliance of warranty requirements. The CRT is a three-member team that consists of a member representing the Illinois DOT, and a member representing the Contractor, and a third person mutually agreed upon by both the Illinois DOT and the Contractor. The compensation for the third person will be equally shared between the Illinois DOT and the Contractor. The decision of the CRT is final and binding on the Illinois DOT and the Contractor.

The following sections provide some samples of the Illinois DOT's warranty documents presented at the Pavement Warranty Symposium (Michigan DOT 2003).

Criteria for Warranting Concrete Bridge Decks and Bridge Approach Pavements

It is warranted that the concrete bridge decks and bridge approach pavements (the adjacent 200 ft. pavement on both sides) will be free from defects or failures for a period of 5 years after the construction. Tables 4 and 5 list the warranty distresses and their corresponding corrective action for the concrete bridge approach and the concrete bridge deck, respectively.

Table 4 Warranty Thresholds for Concrete Bridge Approach Pavements Used by Illinois DOT

Distress Type		Extent	Severity	Remedial Action
International Roughness Index (IRI)		Within bridge section	Avg. 180 in./mi.	Approach Grinding, Repair, or Replacement
Spalling	Longitudinal Joints, Transverse Joints & High Steel	10 lin. ft.	Moderate	Partial-Depth Patch 150% of Distressed Area using Polymer Concrete or Approved Equivalent
		Any within section	High	
Scaling		50 sq. ft.	All severity levels	Patch 150% Length and Full Width of Distressed Lane
Punchouts; in CRC pavement Only		Any within section	Moderate	Patch
			High	

Table 5 Warranty Thresholds for Concrete Bridge Decks Used by Illinois DOT

Distress Type		Extent	Severity	Remedial Action
International Roughness Index (IRI)		Within bridge section	Avg. 180 in./mi.	Deck Grinding, Deck Repair, or Replacement
Spalling	Bridge Joints	3 lin. ft.	Moderate	Partial-Depth Patch[1]
		Any within section	High	
Scaling or Delamination with Loss of Material		1 sq. ft.	All severity levels	Partial-Depth Patch[1]
Patch/Patch Deterioration		1 sq. ft.	Moderate	Partial-Depth Patch[1]
		Any within section	High	
Extrusion Above Pavement Surface or Loss of Joint Seal		2 lin. ft.	Any	Replace Joint Seal
Scaling with Loss of Material – Parapet Wall		3 sq. ft.	All severity levels	Patch

[1] 150% of distressed area using polymer concrete or approved equivalent.

Criteria for Warranting Concrete Pavements

For a warranty concrete pavement project, the Contactor warrants the project including materials and workmanship for 5 years. But the Contractor does not warrant the work against failures due to design defects such as unanticipated significant increases in traffic volume. Table 6 lists the distress thresholds and their remedial actions.

Table 6 Warranty Thresholds for Concrete Pavements Used by Illinois DOT

Distress Type		Extent	Severity	Remedial Action
Cracking	Transverse	10 lin. ft.	Moderate	Patch
		Any within section	High	
	Longitudinal	10 lin. ft.	Moderate	Patch Full Length of Distressed Lane
		Any within section	High	
	Corner Breaks	Any within section	Moderate	Patch
		Any within section	High	
International Roughness Index (IRI)		Within section	Avg. 150 in./mi.	Pavement Grinding
Spalling	Longitudinal Joints, Transverse Joints & High Steel	10 lin. ft.	Moderate	Partial-Depth Patch[1]
		Any within section	High	
Scaling		50 sq. ft.	All severity levels	Patch 150% Length and Full Width of Distressed Lane
Patch/Patch Deterioration		100 sq. ft.	Moderate	Patch
		Any within section	High	
Punchouts; in CRC pavement only		Any within section	Moderate	Patch
		Any within section	High	

[1] 150% of distressed area using polymer concrete or approved equivalent.

Table 7 Warranty Thresholds for Asphalt Pavements Used by Illinois DOT

Distress Type		Extent	Severity	Remedial Action
Fatigue Cracking		50 sq. ft.	Moderate	Patch 150% of Distressed Area
		Any within section	High	
Block Cracking		100 sq. ft.	Moderate	Mill & Replace
		Any within section	High	
Transverse Cracking		10 lin. ft.	Moderate	Seal
		Any within section	High	
Longitudinal Cracking	Within the Lane	10 lin. ft.	Moderate	Seal
		Any within section	High	
	Centerline Deterioration	10 lin. ft.	High	Seal
	Edgeline	10 lin. ft.	High	Seal
International Roughness Index (IRI)		Within section	Avg. 110 in./mi.	Mill & Replace
Potholes & Shoving		Any within section	All severity levels	Patch 150% of Distressed Area
Bleeding & Flushing & Raveling		500 sq. ft.	Moderate	Mill & Replace
		Any within section	High	
Rut Depth		Any within section	0.30 in.	Mill & Replace

Criteria for Warranting Asphalt Pavements

For a warranty asphalt concrete pavement, the Contactor warrants the project including materials and workmanship for 5 years. But the Contractor does not warrant the work against failures due to design defects such as unanticipated significant increases in traffic volume. Table 7 lists the distress thresholds and their remedial actions.

2.3 Indiana Department of Transportation

In Indiana, the first contract with warranty specifications was a section of Interstate 70, east of Indianapolis in 1996. As of the year 2003, INDOT had at least 13 warranty projects, most of which are located at high-volume Interstate sections and involve a structural hot-mix asphalt overlay on crack-and-seat or rubblized PCC pavements. The performance of these pavements is based primarily on the levels of surface roughness, cracking, rutting, friction within a warranty period of 5 years. The contractor is responsible for quality control and for conducting independent assurance verification of construction material samples. Apart from this, any coring, milling, and other destructive tests require prior approval from INDOT. The warranty bond amount is based on the estimated cost of complete placement of the warranty pavement.

According to Singh et al. (2007), the overall quality of warranty projects in Indiana is better than non-warranty projects, since the contractors are paying more attention to the quality of the work including non-warranty items. However, Indiana DOT only considers warranty as an approach to shift the risk to the contractor and prefers straight performance related warranty specifications.

Condition Data Acquisition

The Indiana DOT conducts pavement condition surveys annually between April 15 and May 15 to monitor pavement distresses for each 100 m. evaluation section according to the threshold values listed in Table 8. If any of the threshold levels are met or exceeded, remedial work will be performed according to Table 9. The Contractor is not responsible for distresses which are caused by factors beyond the control of the Contractor. For example, the Contractor is not responsible for distresses due to base or subgrade problems. Also the Contractor is not responsible for rut (distress) if the actual number of Class 5 trucks is 50% above the projected fifth year number of Class 5 trucks. For monitoring traffic, a Weigh-in-Motion (WIM) site will be installed within the project limits.

Table 8 Warranty Thresholds for Pavement Distresses by Indiana DOT

Distress Type	Threshold Level
International Roughness Index (IRI)	133in/mi.
Rut Depth	0.35 in.
Longitudinal Crack	Severity 2 or greater
Friction Number	25

Table 9 Remedial Actions for Warranty Pavements Adopted by Indiana DOT

Distress Type	Remedial Action
Alligator Cracks	Remove and replace distressed layers.[1]
Block Cracks	Remove and replace distressed layers.[2]
Flushing	Remove and replace distressed surface layer full lane width.[1]
Longitudinal Cracks	Rout and seal all cracks with rubber crack filling material, or agreed upon equal
Transverse Cracks	Rout and seal all cracks with rubber crack filling material, or agreed upon equal
Longitudinal Distortion	Remove and replace distressed layers.[2]
Other Disintegrated Areas[3]	Remove and replace the distressed area(s).[1]
Rutting	Mill surface with fine-toothed mill to remove rut, overlay. Remove and replace distressed layers full lane width.
Low Friction	Micro-surfacing distressed area full lane width.

[1] The removal area should be at least 150% of the distressed area to a depth not to exceed the warranty pavement.
[2] The removal area should be at least 110% of the distressed area to a depth not to exceed the warranty pavement.
[3] Including Potholes, Slippage Areas, Raveling, and Segregation.

Warranty Enforcement

The Indiana DOT uses a Conflict Resolution Team (CRT) to monitor the warranty asphalt pavement (Indiana DOT 1995). The CRT is a five-member team that consists of two members representing Indiana DOT, and two members representing the Contractor, and a fifth person mutually agreed upon by both Indiana DOT and the Contractor. The compensation for the fifth person will be equally shared between the Indiana DOT and the Contractor.

Cost Analysis

According to the NCHRP study conducted by Scott et al. (2006), the initial costs for HMA warranty projects were about 10% higher than for non-warranty projects in Indiana. In addition, Singh et al. (2005) reviewed the state of pavement warranty practice and evaluated the cost-effectiveness of warranty contracts in Indiana. The study confirmed that the warranty contracts generally had higher initial costs than traditional contracts, but produced pavements that had longer service life with better pavement condition (rutting, cracking and roughness). For long-term cost-effectiveness and when treatment service life was considered as the analysis period, the warranty contracts were generally more cost-effective than traditional contracts.

2.4 Louisiana Department of Transportation and Development

The Louisiana DOTD started its pavement warranty program in late 1990's. The following sections provide some samples of Louisiana DOTD's warranty documents presented at the Pavement Warranty Symposium (Michigan DOT 2003).

Warranty Specification for Asphalt Pavements

For the warranty asphalt concrete pavement, Louisiana DOTD divides a project into

500ft. segments. The Contractor warrants the workmanship, materials, quality, and performance for a period of 3 years. Louisiana DOTD conducts a distress and condition survey within 6 months prior to the end of the warranty period. Tables 10 and 11 list the distress thresholds and the corresponding remedial actions.

Table 10 Warranty Thresholds for Asphalt Pavements Used by Louisiana DOTD

Distress Type	Threshold Level	Remedial Action
Bleeding	10 square ft. (1 m^2)	Remove and replace[1]
Raveling	10 square ft. (1 m^2)	Remove and replace[1]
Rutting in 500 ft. (150 m) segment subdivided into 50 foot (15 m) lengths)	0.35 in. (10 mm) average in any 50 foot length (15 m) in any wheel path or any area with rutting greater than 0.50 in. (13 mm)	Fine tooth milling and overlay or remove and replace defective area
Shoving	Any occurrence	Remove and replace[1]
Fatigue Cracking	10 square ft. (1 m^2)	Remove and replace[1]
Longitudinal Cracking	50 linear ft. (15 m) total length with crack width greater than 0.25 in. (6 mm)	Route and seal cracks with rubberized crack filler
	More than 200 linear ft. (60 m) total length	Remove and replace entire segment
Transverse Cracking	50 linear ft. (15 mm) total length with crack width greater than 0.25 in. (6 mm)	Route and seal cracks with rubberized crack filler
	More than 200 linear ft. (60 m) total length	Remove and replace entire segment
Edge Cracking	50 linear ft. (15 m) total length with crack width greater than 0.25 in. (6 mm)	Route and seal cracks with rubberized crack filler
	More than 100 linear ft. (30 m) total length	Remove and replace entire segment
Potholes	Any occurrence	Remove and replace[1]

[1] The removal area should be equal to 200% of the distressed area.

Warranty Specification for Concrete Pavements

The Contractor warrants the workmanship, materials, quality, and performance, for a period of 3 years, for the warranty cement concrete pavement including Jointed Concrete Pavement (JCP) and Continuously Reinforced Concrete Pavement (CRCP). Transverse cracking that naturally occurs in CRCP is excluded from warranty requirements.

Table 11 Warranty Thresholds for Concrete Pavements Used by LA DOTD

Distress Type	Threshold Level	Remedial Action
Corner Breaks	Any occurrence	To be removed and replaced by full depth patching with a proper tie-in.
Longitudinal, Transverse, and Diagonal Cracking	Any occurrence	To be repaired in accordance with the Standard Specifications.
Transverse Joint Seal Damage	Any occurrence	Remove completely and replace seal materials across the travel lane or shoulder regardless of the length of failed material
Longitudinal Joint Seal Damage	Any occurrence	Remove and replace damaged or missing seal materials
Spalling of Longitudinal Joints	Spalls greater than 2 in. (50 mm) wide	Repair of affected area in accordance with a Department approved action plan
Spalling of Transverse Joints	Spalls greater than 2 in. (50 mm) wide	Full depth repair of affected area in accordance with a Department approved action plan
Faulting of Transverse Joints	Faulting greater than 0.125 in. (3 mm), but less than 0.25 in. (6 mm)	To be corrected (e.g. Jacking the slab by approved methods
	Faulting greater than 0.25 in. (6 mm)	Remove and replace
Lane-To-AC Shoulder Separation	Any visible separation	To be corrected by sealing
Popouts	Ranging in diameter from 1 in. (25 mm) to 4 in. (100 mm) and depth from 0.5 in. (15 mm) to 2 in. (50 mm)	Patching with low shrinkage high early strength mortar.
Spalled Areas	Spalled areas larger than 25 square in. (0.016 m^2) and/or with depth larger than 1 in. (25 mm)	Depending upon the type of spalling, action plan should be approved by The Louisiana DOTD

Warranty Enforcement

Louisiana DOTD uses a Conflict Resolution Team (CRT) to provide a decision on disputes between Louisiana DOTD and the Contractor. The CRT is a five-member team that consists of two members representing Louisiana DOTD, two members representing the Contractor, and a fifth person mutually agreed upon by both Louisiana DOTD and the Contractor. The compensation for the fifth person will be equally shared between Louisiana DOTD and the Contractor.

2.5 Maine Department of Transportation

In Maine, the Contractor warrants the pavement for a minimum period of 5 years (Michigan DOT 2003). The Contractor is not responsible for defects due to the excess of the cumulative ESALs. For monitoring warranty project, the project is divided into 100m. segments. Maine DOT selects two 100m. segments for the evaluation purpose. If any of the threshold levels are met or exceeded, remedial work will be performed according to Table 12. In addition to the 5-year warranty period, the Contractor may propose additional 1-year increments for a period of up to 5 years following the expiration of the initial 5-year term. In Table 12, period one is for the initial 5-year term and period two is for the second 5-year term.

Table 12 Warranty Thresholds for Pavements Used by Maine DOT

Performance Item *	Period One	Period Two	Remedial Action
Smoothness: IRI, max. (m/km)	< 1.25	< 2.0	Apply a microsurface, 30 mm overlay, or partial depth repair.
Rutting: Rut Depth, max. (mm)	< 7	< 15	Apply a microsurface 30 mm overlay, or remove and replace affected layers.
Cracking:			Remove and replace[1]
Transverse spacing, min. (m)	> 4.5	> 3.0	
Transverse width, max. (mm)	< 7	< 19	
Longitudinal wheelpath width, max. (mm)	< 7	< 19	
Raveling and Popout Areas: Max. depth (mm) over 5 m^2 or more.	< 10	< 10	Apply a microsurface or 30 mm overlay.
Pot Holes: Width, max. (mm) Depth, max. (mm)	<150 <25	<150 <50	Remove and replace[2]
Depressions and Shoving: Max. (mm) over a 3m length or max. (mm) for asphalt bridge approaches	<16	<18	Remove and replace[3]
Roadway Settlement: Max. (mm) within 30m of abutments[3] Max. (mm) beyond 100m of abutments[3]	< 50 < 75	< 50 < 75	Remove and replace affected area(s). Affected area may include the subgrade and subbase layers, or any layer of pavement.

* Note: Smoothness and rutting shall be the average of both wheel paths over a length of 3 km; Longitudinal cracking includes joint separations; Shoulders are not warranty for smoothness, depressions and shoving.

[1] Extended in the transverse direction from roadway edge to roadway edge.

[2] The removal area should be equal to 150% of the distressed area to a depth not to exceed the warranty pavement.

[3] The removal area should be equal to 110% of the distressed surface to a depth not to exceed the warranty pavement.

2.6 Michigan Department of Transportation

The Michigan DOT awarded its first pavement warranty contract in 1996 (Hamilton 2001). Over 300 warranty contracts were awarded from 1996 to 2000. Most of these warranty contracts were on Capital Preventive Maintenance (CPM) projects. Up to 2001, only 35 warranty contracts were on pavement rehabilitation projects, and only 12 on reconstruction projects. During this period, only one warranty contract was awarded on a new pavement construction project. The Department has used two different kinds of construction warranties on paving projects: materials and workmanship warranties, and performance warranties.

In order to ensure uniformity in application and evaluation of the warranty program, Michigan DOT provides Guidelines (Michigan DOT 2008) to administer warranties for highway and bridge construction contracts. The Guidelines include threshold limits for each warranty parameter (e.g. condition or distress parameter for materials and workmanship warranties each; or performance parameter for performance warranties). These threshold limits, if exceeded during the warranty period, trigger the need for corrective actions to be completed by the Contractor.

Guideline for Warranting HMA Pavements

Tables 13 and 14 present the distress threshold values and the corresponding corrective actions for warranty HMA pavements, along with the description of the rutting data acquisition.

Table 13 Warranty Thresholds for HMA Pavements Used by Michigan DOT

Distress Type	Threshold Limit per Segment (Length = 160 m)	Max. Defective Segments per Warranty Lane
Transverse Cracking	2 occurings	16
Longitudinal Cracking/ Open Joint	10% of segment length	16
De-bonding	5% of segment length	16
Raveling	8% of segment length	16
Flushing	4% of segment length	16
Rutting [2]	avg. rut depth = 10mm[1]	16
RQI [3]	50	0

[1] The rut depth threshold applies to each wheel path independently.

[2] The pavement surface will be evaluated for the presence of rutting on each driving land throughout the warranty period. The pavement surface will be measured beginning at the POB and every 40 m thereafter to determine average rut depth to quantify rutting for a particular 160 m segment. Rut measurements will be done using a straight rigid device that is a minimum of 2 m long and of sufficient stiffness that it will not deflect from its own weight, or a wire under sufficient tension to prevent sag when extended 2 m. Measurements will be taken by placing this "straightedge" across the pavement surface perpendicular to the direction of travel. The straightedge shall contact the surface on at least two bearing points with one located on either side of the rut. The straightedge is properly located when sliding the straightedge along its axis does not change the location of the contact points. Rut depth is then measured at the point of greatest perpendicular distance from the bottom of the straightedge to the pavement surface.

[3] The RQI condition parameter only applies to mainline lanes and ramps.

Table 14 Remedial Actions for HMA Warranty Pavements Used by Michigan DOT

Distress Type	Remedial Action
Transverse Cracking	Cut and Seal [1, 2]
Longitudinal Cracking	Cut and Seal [2]
De-bonding	Remove and replace affected courses
Raveling	Remove and replace affected courses
Flushing	Remove and replace affected courses
Rutting	Remove and replace affected courses [3]

[1] Any areas exhibiting Alligator or Block Cracking shall be removed and replaced as directed by the Engineer.
[2] Cut and seal is only a recommended action when cracking is in the top course only. Cracking that exists in the underlying leveling and/or base courses will require a different corrective action such as remove and replace to address the underlying cracking.
[3] Depth of removal is dependent on the depth of the rut susceptible material.

Guideline for Warranting Concrete Pavements

Similarly, Tables 15 and 16 provide the distress threshold values and the corresponding corrective actions for warranty concrete pavements.

Table 15 Warranty Thresholds for Concrete Pavements Used by Michigan DOT

Distress Type	Threshold Limits per Segment (Length = 160m)	Max. Defective Segments per Warranty Lane
Transverse Crack	1 occurring	16
Longitudinal	5 % of segment length	16
Map Cracking	10 % of segment area	16
Spalling	10 % each slab ≤ 2 slabs	16
Scaling	15 % of the slab area ≤ 1 slab	16
Corner Cracking [1]	1 occurring	16
Joint Sealant Failure	10 % joint length ≤ 2 slabs [2, 3]	16
RQI [4]	50	0

[1] Shattered slabs will not be an acceptable condition, and will be removed and replaced as approved by the Engineer.
[2] Can be non-contiguous. 10 % value applies to total perimeter (four sides) of the slab.
[3] Applies to all transverse and longitudinal joints on the perimeter of the slab. Noncontiguous lengths will be summed on a per slab basis.
[4] The RQI condition parameter only applies to mainline lanes and ramps.

Table 16 Remedial Actions for Joint Plain Concrete Warranty Pavements Used by Michigan DOT

Distress Type	Recommended Action
Longitudinal Cracking	Retrofit load transfer [1]
Transverse Cracking	Retrofit load transfer [1]
Corner Cracking	Full-depth, tied, concrete patch [2]
Map Cracking	Remove and replace [3]
Spalling	Repair with epoxy or cement motor [4]
Scaling	Diamond grind surface [5]
Joint Sealant Failure	Remove and replace seal material [6, 7]

[1] If multiple condition parameters are present, the recommended action may be revised. Removal and replacement is required if multiple crack types are present.
[2] The appropriate corrective treatment is dependent on the crack's location and depth. Full-depth/full-length L cracks require a slab removal and replacement, if outside influence of lane ties.
[3] Dependent on cause, if cracking is entirely from "drying shrinkage", no corrective action is required.
[4] Repair dependent on area and depth of spall. Use most current procedures and material mixtures recommended by department's Material's Research Group.
[5] Diamond grinding applies to entire slab surface area where cracking exists.
[6] Replace with existing material type. Neoprene seals are removed and replaced full-width.
[7] Shattered slabs shall be removed and replaced as directed by the Engineer.

Warranty Enforcement

If there is a roadway failure, MDOT and the contractor perform a joint field investigation to determine the cause. If MDOT and the contractor cannot agree, the issue is resolved by a conflict resolution team (CRT) comprised of two MDOT employees, two representatives of the contractor, and one expert acceptable to both MDOT and the contractor. The CRT determines if the failure is due to a design decision (MDOT's fault) or failure of materials or workmanship (contractor's fault) or some combination. If it is determined that the contractor is at fault, the contractor must propose a resolution acceptable to MDOT.

2.7 Minnesota Department of Transportation

The Minnesota DOT implemented warranties for the first time in 1995 (Bayraktar et al. 2004). In 1999, ten microsurfacing warranties were implemented with a 2-year warranty period that covers transverse and longitudinal cracking, debonding, raveling, flushing, rutting, and pop-outs. In 2001, two design-build warranty projects were issued followed by three pilot deck overlay warranty projects in 2002.

Minnesota DOT's 5-year and 2-year warranties are still only material and workmanship warranties, since it is believed that real performance based warranties should have longer warranty durations. According to Minnesota DOT's report (MnDOT 2011), the agency did not see any change in the number and the profile of bidders from non-warranty to 2-year warranty projects, except in one case where one contractor decided not to bid on warranty jobs for an unknown reason. In addition, it was reported that warranty provisions helped Minnesota DOT in getting more quality conscious contractors without a significant increase in cost.

Pavement Warranty Specification

For monitoring a warranty project, a pavement distress survey is conducted each year during the warranty period. The project is divided into nominal 1-mi. segments and a 500-ft. long segment is selected within each mile for the evaluation of pavement distress. If any of the threshold levels listed in Table 17 are met or exceeded, remedial work will be performed according to Table 18. The warranty on the saw and seal maintenance covers 100% of removing and replacing defective material (MnDOT 2011).

Table 17 Thresholds for Warranty Pavements Used by Minnesota DOT

Distress Type	500 ft. Segment Threshold Limit
Transverse Cracking - Low Severity	Three cracks per segment (minimum length = 6ft)
- Medium Severity	Three cracks per segment (minimum length = 6ft)
- High Severity	Two cracks per segment (minimum length = 6ft)
Longitudinal Joint - Low Severity	40% of the segment length.
- Medium Severity	None Allowed
- High Severity	None Allowed
Longitudinal Cracking	None allowed.
Multiple/Block Cracking	None allowed.
Alligator/Fatigue Cracking	None Allowed
Debonding & Potholes	None Allowed
Raveling	1% of the segment area.
Flushing (Single wheel path)	2% of the segment length.
Popouts	29/Square Yard (Minimum 20 SY/segment)
Rutting	Rut depth of 0.375 in. or greater (25 Ft. of the segment length)

Table 18 Remedial Actions for Warranty Pavement Used by Minnesota DOT

Distress Type	Remedial Action
Transverse Cracking - Low Severity	Rout and Seal
- Medium Severity	Rout and Seal/Mill and Resurface (2 ft. width) [1]
- High Severity	Mill and Resurface (2 ft. width)
Longitudinal Joints - Low Severity	Crack Fill
- Medium Severity	Rout and Seal.
- High Severity	Mill and Resurface (2 ft. width)
Longitudinal Cracking	Crack Fill
Multiple/Block Cracking	Mill and Resurface. (150% of distressed area)
Alligator/Fatigue Cracking	Mill and Resurface. (150% of distressed area)
Debonding	Mill and Resurface. (150% of distressed area)
Raveling	Mill and Resurface/Microsurface [1]
Flushing	Mill and Resurface.
Popouts	Mill and Resurface.
Rutting	Mill and Resurface/Microsurface [2]

[1] Corrective action is dependent on the extent of the distress.
[2] Corrective actions are dependent on the rut depth and in-place air voids.

Warranty Enforcement

The warranty requirements are waived when the accumulated number of ESALs on the warranty pavement is 50% above the projected fifth year number of the design 5 year accumulated ESALs. The Minnesota DOT uses a Conflict Resolution Team (CRT) to provide a decision on disputes between the Minnesota DOT and the Contractor regarding any claims of non-compliance of warranty requirements. The CRT is a three-member team that consists of a member representing the Minnesota DOT, member representing the Contractor, and a third person mutually agreed upon by both the Minnesota DOT and the Contractor. The compensation for the third person will be equally shared between the Minnesota DOT and the Contractor. The team will use the Minnesota DOT Distress Identification Manual to resolve a dispute as necessary.

2.8 New Mexico Department of Transportation

During the reconstruction of Highway US 550, New Mexico DOT incorporated innovative funding and contracting methods, and included warranties on the pavement and structure (Hall et al. 2010). In this project a Warranty Tracking Software was developed to facilitate the task of tracking economic transactions that include a warranty provision covering all or a certain amount of maintenance and repair expenditure.

The New Mexico DOT adopted long-term pavement warranty up to a period of 20 years (Michigan DOT 2003). The warranty requirements are waived when the accumulated number of ESALs exceeds 4,000,000. The New Mexico DOT conducts pavement condition surveys at least once each year between March 1 and May 30 to monitor pavement distresses according to the threshold values listed in Table 19. Since the warranty period is too long to be controlled by same level of performance, the threshold levels are adjusted every five-year period as shown in Table 19.

Table 19 Thresholds for Warranty Pavements Used by New Mexico DOT

Performance Item	Period One	Period Two	Period Three	Period Four
Smoothness: IRI, max. (m/km) [1]	< 1.25	< 1.7	< 2.1	< 2.5
Rutting: Rut depth, max. (mm) [1]	< 10	< 10	< 10	< 10
Cracking:				
Transverse spacing, min. (m)	> 4.5	> 3.0	> 1.5	> 1.5
Transverse width, max. (mm)	< 5	< 10	< 10	< 10
Longitudinal wheelpath width, max. (mm) [2]	< 5	< 10	< 10	< 10
Bleeding Areas: Minimum coefficient of friction over 50 sq. m or more	>0.05	>0.05	>0.05	>0.05
Raveling Areas: Max. depth (mm) over 5 sq. m or more	< 10	< 10	< 10	< 10
Delamination: Repairs to depth of layer	Any	Any	Any	Any
Pot Holes: Width, max. (mm) Depth, max. (mm)	 <150 <10	 <150 <10	 <150 <10	 <150 <10
Depressions and Shoving: [3] Max. (mm) over a 3 m length or max. (mm) for asphalt bridge approaches	<16	<18	<20	<22

[1] Smoothness and rutting shall be the average of both wheelpaths over a length of 3 km.
[2] Longitudinal cracking includes joint separations.
[3] Shoulders are not warranted for smoothness, depressions and shoving.

2.9 Ohio Department of Transportation

The Ohio DOT started implementing warranty programs in 1997 and awarded 390 warranty projects from 1997 to 2007. Ohio DOT has developed warranty specifications for various types of pavement management applications with warranty periods from 2 to 7 years as shown in Table 20 (ODOT 2010). New and major rehabilitation projects for asphalt and cement concrete pavements are usually under 7-year warranty period. Warranty program is tracked through the use of Quality Assurance Reviews.

Table 20 Warranty Specifications Developed by Ohio DOT

Warranty Item	Supplement Specification No.	Period (years)	Application
Asphalt	880	7	New and major rehabilitation
	1059	3	Preventative maintenance and minor rehabilitation
Bridge Deck	892, 893, 894	2	New Bridge deck concrete
Bridge Paint	885	5	Painting of Structural Steel
Concrete Pavement	884, 896	7	New and major rehabilitation
Chip Seal	882	2	Preventive maintenance
Hot In-place Recycling	886	3	Surface courses
Microsurfacing	881	2	Preventative maintenance

Criteria for Warranting Asphalt Pavements

Table 21 describes threshold levels and remedial actions for warranty asphalt concrete pavements.

Table 21 Thresholds and Remedial Actions for Warranty Asphalt Concrete Pavements Used by Ohio DOT

Distress	Threshold (per 0.1 mi. segment)	Remedial Action
Cracking	500 ft. (150 m) of cracks which average over 0.25 in. (6 mm) width	Rout out and seal all cracks
Disintegrated Area [1]	None	Remove and replace the distressed area to the depth needed to repair the distressed area
Flushing	125 square ft. (12 m^2)	Remove and replace the lane width of the distressed area to a depth of 1.5 in. (38 mm)
Previous Patching	300 square ft. (28 m^2)	Remove and replace the lane width to a minimum depth of 1.5 in. (38 mm)
Rutting	0.375 in. (9.5 mm)	Remove and replace the distressed area to the depth needed to repair the distressed area

[1] Including mix delamination, potholes, and raveling.

Criteria for Warranting Concrete Pavements

Table 22 provides threshold levels and remedial actions for warranty cement concrete pavements.

Table 22 Warranty Thresholds and Remedial Actions for Concrete Pavements Used by Ohio DOT

Distress	Threshold Level (per 0.1 mi. segment)	Remedial Action
Transverse or Diagonal Cracking	Width ≥ 1/16 inch (1.5 mm) for Non-Reinforced Concrete or ≥ 1/4 inch (6mm) for Reinforced Concrete	For one crack per panel, repair may include restore load transfer in the wheel tracks, a full depth repair, or replace concrete slab. For more than one crack per panel, replace concrete slab.
Longitudinal Cracking	Any longitudinal cracks: < 15 in. (380 mm) from a tied longitudinal joint	Rout and seal crack with hot applied joint sealer.
	all other longitudinal cracks	Replace concrete slab.
Disintegrated Area	Total surface distress greater than one (1) square foot (0.09 m^2)	Full depth repair or slab replacement as directed by the Engineer depending on the extent of deterioration.
Faulting	Any faulting greater than 3/16 in. (5 mm)	Repair joints or cracks according to specification

Cost Analysis

Since 1997 and up to 2007 ODOT has awarded 390 warranty projects with almost $653 million worth, which consisted of about 5 percent of the total pavement projects (Ohio DOT 2007). In 2006, the Ohio DOT warranty program has declined, and approximately $26,000,000 of warranty work was paid for, down from $185,000,000 in 2005.

The cost comparison of similar warranty and non-warranty items indicate modest cost differences. Warranty asphalt costs about 1% more, warranty concrete bridges cost 5.6% more, and warranty concrete pavement costs 7.8% less.

2.10 Texas Department of Transportation

The Texas Department of Transportation (TxDOT) had supported pavement warranty contracting as an alternative contracting practice that shows potential for reducing the life-cycle cost of while ensuring the quality of constructed facilities. The TxDOT used a Conflict Resolution Team (CRT) to provide a decision on disputes between The TxDOT and the Contractor. The CRT is a five-member team that consists of two members represented The TxDOT, two members represented the Contractor, and a fifth person mutually agreed upon by both the TxDOT and the Contractor. Table 23 presents the warranty indicators, threshold values, and possible remedial actions that the El Paso District selected for the warranty HMAC pavement project (Anderson et al. 2006).

Table 23 Warranty Indicators, Thresholds, and Remedial Actions for HMA Warranty Projects in El Paso, TX

Distress	Threshold Level	Remedial Action
Rutting	Rut depth equal to 0.5 in. or greater	Mill the distressed area and replace surface. Depth of milling would not exceed the depth of the warranty pavement.
Alligator Cracking	Area of an occurrence of alligator cracking is equal to or greater than 1 sq. yd.	Remove and replace the distressed layers.[1]
Raveling	Area of an occurrence of raveling is equal to or greater than 1sq. yd.	Remove and replace the distressed layers.[1]
Longitudinal Joint Cracking	Total length of longitudinal crack with a width of at least 1/16 in. is equal to or greater than 20 ft.	Rout and seal all longitudinal cracks with approved crack sealing material.
Shoving	An occurrence of a localized depression greater than 1 in.	Remove and replace the distressed layers.[1]
Potholes	An occurrence of a pothole with an area of 1 sq. ft. or greater and a depth greater than 1 inch	Remove and replace the distressed layers.[1]
Slippage Cracking	An occurrence	Remove and replace the distressed layers.[1]
Skid Resistance	20% reduction in FN from the initial post-construction skid measurement	Mill, apply surface treatment, or overlay to correct inadequacy. Remedial treatment should be a minimum of a lane width.
Ride Quality	20% increase in IRI from the initial post-construction ride quality measurement	Level-up, overlay, milling, or combinations thereof to correct inadequacies in the deficient section(s).

[1] The removal area should be at least 150% of the distressed area to a depth not to exceed the warranty pavement.

2.11 Wisconsin Department of Transportation

The Wisconsin DOT has been leading on the use of pavement warranties starting as early as 1995. From 1995 to 2009, 157 hot mix asphalt and 14 Portland cement concrete pavements were put under warranties. Physical distress is the main type of pavement condition warranty in Wisconsin (Battaglia 2009).

Condition Data Acquisition

Wisconsin DOT uses automated or semi-automated data collection to collect pavement distress data on warranty project. Lasers are used to collect roughness data, rut depth measurement, and joint faulting measurement. Cracking data is collected manually, with digital image or by film video. For monitoring warranty project, the project is divided into 1-mi. sections. The Wisconsin DOT selected two 0.1-mi. segments in each mile for the evaluation purpose. One of the segments is between 0.3 and 0.4 mi. from the start of the section. The second segment is selected randomly.

The Wisconsin DOT conducts pavement condition surveys annually between

April 15 and May 15 to monitor pavement distresses according to the threshold values listed in Table 24. If any of the threshold levels are met or exceeded, the associated remedial work will be performed. Rutting depth and length will be initially identified using standard Wisconsin DOT procedures.

If rutting depth meets the threshold criterion, the final rut depth and length will be established by a method mutually agreed upon by the Contractor and the Wisconsin DOT. The rutting threshold level is waived when the accumulated ESALs are 50% or more above the projected fifth year accumulated ESALs. The Contractor is not responsible for distresses related to the lack of proper thickness.

Table 24 Warranty Thresholds for Asphalt Pavements Used by Wisconsin DOT

Distress Type	Threshold Level	Remedial Action
Alligator Cracking	≥1% of the area in a segment.	Remove and replace distressed layers.[1]
Block Cracking	≥1% of the area in a segment.	Remove and replace distressed layers.[2]
Edge Raveling	≥10% of the segment length.	Remove and replace distressed layers.[2]
Flushing	≥20% of the segment length.	Remove and replace distressed surface mixture full depth.
Longitudinal Cracking [3]	>1000 linear ft. for cracks which average greater than 1/2 in. in width	Rout and seal all cracks with rubber crack filling material, or agreed upon equal.
	>1000 linear ft. with 25% of the linear ft. having band cracking or dislodgement.	If over 1000 feet, remove pavement and replace for the affected depth. If less than or equal to 1000 feet, place a patch 2 ft. in width and 2 ft. longer than the crack length, for the affected depth or agreed upon equal.
Longitudinal Distortion	≥1% of the segment length.	Remove and replace distressed layers.[3]
Rutting	≥0.25 in. in depth, <0.5 in. in depth.	Remove ruts by milling surface with fine-tooth mill, overlaying, or micro surfacing.
	≥0.5 in. in depth.	Remove and replace surface layer.
Surface Raveling	≥Slight (for segregation, a slight rating is three or more segregated areas per segment. A segregated area is 30 square ft. or more in size).	Apply a chip seal coat or partial depth repair.

[1] The removal area should be at least 150% of the distressed area to a depth not to exceed the warranty pavement.
[2] The removal area should be at least 110% of the distressed area to a depth not to exceed the warranty pavement.
[3] Shoulder line cracking is excluded from the segment measurements.

Table 25 Warranty Thresholds for Asphalt Pavements Used by Wisconsin DOT (Cont')

Transverse Cracking	When the warranty asphaltic pavement is constructed over a granular base course material, >25 cracks per segment which have an average open width greater than 1/2 in.	Rout and seal all cracks with a rubberized crack filler, or approved equal.
	When the warranty asphaltic pavement is constructed over concrete pavement, >50 cracks per segment which have an average open width greater than 1/2 in.	Rout and seal all cracks with a rubberized crack filler, or approved equal.
	>25 cracks per segment with 25% of the linear ft. of cracking having band cracking or dislodgement.	Remove and replace distressed layer(s) to a depth not to exceed the warranty pavement.
Transverse Distortion	≥1% of the segment length.	Remove and replace distressed layers.[4]
Patching	≥150 linear ft. of patching per segment (excluding longitudinal cracking remedial action).	Remove and replace the surface layer or place a minimum 1-1/4 in. overlay.
Potholes, Slippage Areas and Other Disintegrated Areas	Any presence of this type of distress.	Remove and replace the distressed areas.[5]

[4] The removal area should be at least 110% of the distressed area to a depth not to exceed the warranty pavement.
[5] The removal area should be at least 150% of the distressed area to a depth not to exceed the warranty pavement.

Performance Evaluation

Using Performance Distress Index (PDI) and International Roughness Index (IRI) as performance evaluation indices, Battaglia (2009) presented an evaluation of 12 years of the pavement warranty program to compare performance and cost data for Wisconsin DOT pavements constructed under warranty and traditional contracts. The study shows that after 12 years in service, warranty Hot Mix Asphalt (HMA) pavements constructed over flexible base performed better than non-warranty pavements. No statistical difference was found in performance between warranty and non-warranty HMA pavements constructed over rigid base. These pavements performed at approximately the same level during the first 10 years in service, with relatively equal increases in PDI and IRI over that time. The same conclusion is found for warranty and non-warranty Portland Cement Concrete (PCC) pavements. Both types of pavements performed at approximately equal levels during the analysis period.

Cost Analysis

According to Battaglia (2009), non-warranty and warranty hot mix asphalt cost $49.08 and $40.65 per ton in Wisconsin during the 2006, 2007 and 2008 construction seasons. The warranty pavement cost was lower by approximately 17 %. However, there were no significant differences in cost between non-warranty and warranty PCC pavements.

2.12 **Virginia Department of Transportation**

The development of a pavement warranty contract and a performance specification was considered by Virginia DOT in an effort to extend the value derived from limited funding resources by increasing the service life of pavement rehabilitation treatments. Virginia DOT first implemented a warranty program with the construction of a portion of Route 288, west of Richmond.

In a pilot project (Diefenderfer and Bryant 2005), Virginia DOT developed a performance-based warranty clause to be included as part of a typical resurfacing contract, where the contractor would be responsible for developing the resurfacing pavement design. But because of the extensive deterioration of the pavement, the warranty concept was not pursued for the pilot project. It is recommended however that the warranty concept be applied in another location as part of a future study.

2.13 **Mississippi Department of Transportation**

The Mississippi Department of Transportation (MDOT) implemented its pavement warranty program in 2000 with the purpose to foster innovation and improve pavement quality. To date, MDOT has awarded a total of 18 projects across the state to 9 different contractors, among which 13 are still within the warranty period. Of the total 18 projects, 15 are HMA pavements with two having a 5-year warranty and thirteen having a 7-year warranty period, while 3 are JRCP pavements with two in a 5-year warranty and one in a10-year warranty.

Warranty Items

The main type of pavement condition under warranty for pavement warranty projects in Mississippi is physical distress. In addition, ride quality data measured in International Roughness Index (IRI), m/km, is collected annually for construction acceptance of the pavement warranty projects in Mississippi.

The distresses are defined and measured according to the LTPP *Distress Identification Manual*. A deduct point value of the distress is then calculated by entering the appropriate empirical deduct point curve with the measured distress extent level and interpolating against the observed distress severity level. For each distress type, there is an associated threshold value. If the calculated deduct point exceeds the threshold level for the distress type, the contractor is required to perform the remedial action listed in Tables 26 and 27.

Condition Data Acquisition

The warranty pavement is surveyed annually, and a minimum of two 500 ft. sections are sampled per mile to collect pavement roughness and physical distress data. Roughness, rutting in asphalt pavement, and faulting in concrete pavements are collected on 100% of the sampled sections and stored electronically. Pavement distresses are evaluated by a videographic technique. Video logging for distress identification is conducted in both directions regardless of whether the road is divided or undivided. For multilane divided roads, the distress data is usually collected in the outside lanes, but MDOT also reserves the right to collect data in all lanes if needed. In addition to the severity level, the MDOT survey records distress extent information as well.

MDOT uses the High Speed Inertial Profiler to collect roughness data and transverse faulting on warranty pavements. The Institute National d'Optique (INO) technology has been applied to rutting data collection since spring 2009 to replace the 3-laser rut measurement. Surface friction on asphalt concrete pavement of warranty projects is measured using Pavement Friction Tester (PFT). Surface distress data of the sampled sections are collected by a videographic technique. A distress evaluation (measuring cracking, potholes, punchouts, etc.) is then performed on the video images. Trained personnel in the office review the video picture of the road surface and categorize and document the distress severity and extent.

Table 26 Warranty Thresholds and Remedial Actions for Asphalt Pavements Used by Mississippi DOT

Distress Type	Threshold Level (deduct points)	Remedial Action
Alligator Cracking	10.0	Remove and replace distressed layers, the area to be equal to 150% of the distressed area to a depth not to exceed the warranty pavement
Block Cracking	3.0	Remove and replace distressed layers, the area to be equal to 110% of the distressed area to a depth not to exceed the warranty pavement
Reflection Cracking	9.0	Seal cracks according to the current Department SOP.
Edge Cracking	3.0	Remove and replace the distressed layers, the area to be equal to 110% of the distressed area
Longitudinal Cracking	4.0	Remove and replace distressed layers to a depth not to exceed the warranty pavement
Transverse Cracking	3.0	Remove and replace distressed layers to a depth not to exceed the warranty pavement
Potholes	5.0	Remove and replace distressed layers, the area to be equal to 150% of the distressed area to a depth not to exceed the warranty pavement
Rutting	5.0	Remove and replace the surface layer
Raveling/Segregation	0.2	Apply a chip seal or a partial depth repair
Surface Bleeding	0.4	Remove and replace surface distressed area mixture full depth
Friction	35	Milling, surface treatment, or overlay to correct inadequacy

Table 27 Warranty Thresholds, and Remedial Actions for Concrete Pavements Used by Mississippi DOT

Distress Type	Threshold (deduct points)	Remedial Action
Corner Breaks	4.3	Saw and square affected area; place dowels on transverse joints
Faulting of Transverse Joints	2.7	Diamond Grind - ensure positive drainage
Joint Seal Damage	1.66	Seal according to current MDOT policy
Longitudinal Cracking single crack	1.4	Stitch and Seal according to current MDOT policy
Transverse Cracking, single crack	1.97	Retrofit 3 dowels per wheel path; seal entire crack
Multiple cracks involved	3.5	according to current MDOT policy
Spalling of Longitudinal Joints	1.15	Clean (hydro-blast, sandblast or other) and fill
Spalling of Transverse Joints	4.4	Clean (hydro-blast, sandblast or other) and fill
Map Cracking & Scaling	1.77	Thin overlay with material that has good adhesion to concrete

Warranty Enforcement

If a distress threshold is exceeded, the contractor will be notified of the results within 30 days of the annual survey and have 45 days to perform any required remedial action. If 30% of the project segments require a remedial action, then the entire project will receive that action. Should the contractor contest the results, the conflict resolution team will have to pass a judgment employing the simple majority rules.

Performance Evaluation

A preliminary study was performed to compare the performance of the HMA overlay warranty project in US-49 in Simpson County and its control road segment in terms of Pavement Condition Rating (PCR) and Distress Index after 4 years of service. The results show that over the four-year period, the pavement condition of the warranty project maintained a higher condition score with a slight trend of deterioration at the end of the period. On the other hand, the pavement condition of the non-warranty project deteriorated in an early stage at an accelerated rate.

Cost Analysis

To examine the amount of the increase in investment to achieve the warranty project objectives, the costs of two pairs of HMA warranty and non-warranty projects in MS were analyzed and compared. It shows that compared to the non-warranty projects, the warranty projects exhibited 15.40% and 33.35% increases respectively in unit cost per mile of the freeway as well as 11.86% and 53.65% increases in unit bid cost per mile of HMA material, respectively.

2.14 **Summary**

This section summarizes the available information in open literature on pavement warranty in other 12 states in the U.S., which mainly focused on the threshold values, and also included warranty type, warranty term, data acquisition, warranty enforcement, and several pavement warranty evaluation studies. The pavement warranty practice in Mississippi and the preliminary evaluation studies conducted by Mississippi DOT is also presented herein.

Most of the reviewed states have 2-year, 5-year, 7-year, and 10-year warranty terms, only New Mexico has long-term warranty clause up to 20 years. Warranty specifications were applied to both HMA and PCC pavements, mostly on preventive maintenance and rehabilitation projects and seldom on new construction projects, since most of the nation's roadway network is under rehabilitation. No specific guidelines on selection of warranty projects were reported in the literature, except for a general guide developed by Colorado DOT.

Most of the reviewed states use riding quality, physical distress, and skid resistance as pavement condition parameters under warranty. For physical distress, rutting and different types of cracking are the most popular condition parameters, and others include bleeding, raveling, shoving, and potholes for asphalt pavements, while cracking, spalling, faulting, scaling, and various joint failures are commonly used for concrete pavements. Maine DOT includes roadway settlement in the pavement performance warranty items. However, unlike Mississippi DOT that uses deduct point based threshold levels, all other states reported in the literature set the threshold limits directly from the maximum allowed value for each distress measurement within certain sample pavement segment. Compared to deduct points based thresholds, the distress measurements based thresholds are more straightforward and convenient to handle during warranty practice.

Most state DOTs survey the warranty pavement annually or biannually and sample one or two short segments within each mile for the distress evaluation. Limited information on pavement condition data acquisition methods was gathered from the open literature. Both manual and automated data collection methods were reported; however, no details on the individual distress data collection were available, except for the rutting and roughness measurements. As for the warranty enforcement, Colorado and Minnesota DOT monitor the traffic load of the warranty pavement, and the warranty requirements are waived when the accumulated number of ESALs exceeds the design traffic load. A Conflict Resolution Team (CRT) consisting of members form DOT, Contractor, and a mutual third party is commonly used to solve the disputes following the simple majority rule.

A few evaluation studies were reviewed in the literature. Inconsistent conclusions were drawn on warranty performance and costs. Similar to the preliminary study by Mississippi DOT, Indiana DOT reported higher costs and better long-term performance for warranty pavements, while Wisconsin DOT only found better performance in HMA pavement over flexible base and the warranty pavement cost was lower than non-warranty projects. Ohio DOT reported higher warranty asphalt costs but lower concrete warranty pavements. Since the warranty specification varies from state to state and no conclusive results were obtained from the previous state studies, it is necessary for Mississippi to conduct a comprehensive study to evaluate the distress threshold values and the effectiveness of warranty projects.

Since the information reviewed from previous studies in the literature is not up to date, and also the information regarding the current state of pavement warranty projects, distress protocol, data acquisition, pavement evaluation, etc. is incomplete. Therefore, a comprehensive survey on pavement warranty was conducted as part of the research effort to search for the current pavement warranty practice and specification in other states. The survey was designed in online format and circulated to the all DOTs in the U.S. and some provinces in Canada. The survey results are presented in Chapter 3.

CHAPTER 3. PAVEMENT WARRANTY PROGRAM SURVEY RESULTS

To identify and understand the good pavement warranty practices and specifications in other states, a comprehensive survey study on pavement warranty was conducted by the research team. Based on the literature review, a survey questionnaire was developed and converted into online format. The questionnaires included five major sections: 1) general information on pavement warranty projects, 2) pavement condition data acquisition, 3) pavement condition evaluation, 4) warranty enforcement, 5) state DOTs remarks.

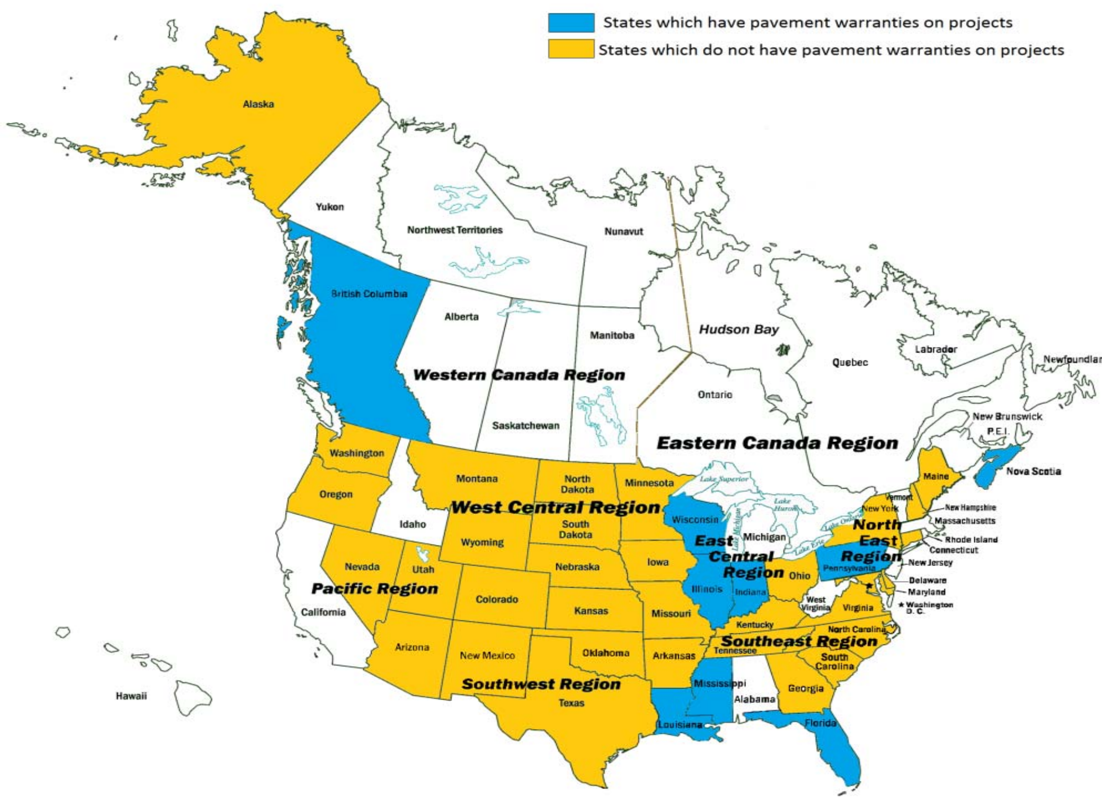


Figure 1 Pavement Warranty Programs in the United States and Canada

The questionnaire was distributed by emails to all state transportation agencies in the United States and Canada in February 2011, using the contact list of the Research Advisory Committee (RAC) of the American Association of State Highway and Transportation Officials (AASHTO). A total of 34 responses were received from 32 state DOTs in the United State and 2 provincial DOTs in Canada. Follow-up emails and phone calls were made to reach the remaining states for their responses. Except for 6 states that did not participate in the survey, all the other states provided their inputs.

Among all the respondents, 9 state DOTs reported that they had existing pavement warranty projects. It is noticeable that the number of states implementing pavement warranty is much lower than the number obtained from a previous NCHRP study. The reasons lie in that some states (for instance, Maine, Minnesota, and New

Mexico) used to have pavement warranty programs, but do not have pavement warranties on new projects and some states with pavement warranty programs did not participate in the survey. Those states indicating no pavement warranty projects also responded that they had no intention to adopt a pavement warranty program in the near future. Figure 1 shows the current status of pavement warranty programs in the United States and Canada based on the survey responses. In this report, the survey results are summarized along with the seven sections of the questionnaire, which are: 1) Warranty Project; 2) Warranty Specification; 3) Data Acquisition; 4) Evaluation of Pavement Condition; 5) Warranty Enforcement; 6) Distress Thresholds; and 7) State DOT's Remarks.

3.1 **Warranty Projects**

This section provides general information about the pavement warranty experience of each of the state DOTs that participated in the survey with respect to pavement type and warranty period.

Table 28 Pavement Warranty Projects by State

Agency	Pavement Type	No. of Projects	Warranty Period (years)
Indiana	HMA	4	5
	Pavement preservation (microsurfacing)	30	3
	JPCP	3	5
Illinois	HMA overlay	3	5
	Full Depth HMA (20- yr. design)	3	5
	Full Depth HMA (30- yr. design)	7	5
	JPCP (20- yr. design)	3	5
	JPCP (30- yr. design)	4	5
	CRCP (30- yr. design)	8	5
	CRCP (40- yr. design)	1	5
Louisiana	HMA	2	3
	JPCP	1	3
Mississippi	HMA	2	5
	HMA	13	7
	JRCP	2	5
	JRCP	1	10
Pennsylvania	HMA	8	5
Wisconsin	HMA	199	5
	HMA	8	3
	HMA	3	7
	Dowel Bar Retrofit	10	3
	JPCP	16	5

Table 28 summarizes the numbers of pavement warranty projects of each state DOT by warranty classification along with pavement type and warranty period. All the 6 respondents with existing warranty programs reported that they have warranty projects on HMA pavement, and the average warranty period required was 5 years for HMA pavements. Four out of six state DOTs stated that they applied warranties on JPCP (Jointed Plain Concrete Pavement) pavement projects, and the average warranty period required was 5 years. In addition, Indiana DOT has applied warranties to 30 microsurfacing projects; Mississippi DOT has used warranty contracting on 3 JRCP (Jointed Reinforced Concrete Pavement) projects; In Wisconsin, warranties were applied to 10 Dowel Bar Retrofit projects.

The results show that pavement warranty has been applied to different types of HMA and PCC pavements. In addition to the often applications in pavement preservation or rehabilitation projects, it was reported in the survey that warranties were also implemented for the full depth HMA and PCC pavement construction projects. The warranty period was usually between 3 to 7 years, and the most commonly used warranty term was 5 years, while no warranty period of more than 10 years was reported in the survey.

Warranty Specification

In order to ensure the uniformity in warranty application and facilitate the agencies to evaluate their warranty projects, warranty specifications are required. Since no national standards are available for the implementation of a pavement warranty, individual state DOTs developed their own warranty specifications. This section provides information on the warranty specifications with respect to warranty type and warranty item.

Warranty Type

There are several types of warranties that can be used for pavements with different focuses. Materials and workmanship warranties mainly focus on the responsibility for correcting defects in work elements within contractor control (materials and workmanship) during the warranty period, while the emphasis of performance warranties shifts onto the full responsibility of pavement performance during the warranty period.

As shown in Table 29, all nine states indicated that they used performance warranties, while five states implemented material and workmanship warranties at the same time. This indicates that state DOTs are inclined to shifting the risk and full responsibility of the pavement performance to the contractor through warranty clauses.

Table 29 Pavement Warranty Types Used by State DOTs

Agency	Material and Workmanship Warranty	Performance Warranty
British Columbia	√	√
Florida		√
Illinois	√	√
Indiana		√
Louisiana	√	√
Mississippi	√	√
Nova Scotia	√	√
Pennsylvania		√
Wisconsin		√

Warranty Item

Table 30 presents the warranty items specified by the nine states with active pavement warranty programs. As to the adopted performance warranties, all nine states set physical distresses under warranty for their pavement warranty programs. Ride quality is another typical warranty item used by most of the states. In addition, three states reported that safety was also considered under their warranty programs. Only British Columbia in Canada included structure capacity into the warranty items in their warranty program.

Table 30 Pavement Warranty Items Specified by State DOTs

Agency	Ride Quality/roughness	Physical Distresses	Structural Capacity	Safety
British Columbia	√	√	√	
Florida	√	√		
Illinois	√	√		
Indiana	√	√		√
Louisiana	√	√		
Mississippi		√		√
Nova Scotia		√		
Pennsylvania	√	√		√
Wisconsin	√	√		

Although no national warranty specifications are available, state DOTs commonly accept physical distresses as their warranty items. This is consistent with the results from previous studies and reviews of the literature, indicating that the preference for warranty items selection remains the same over time. The advantages of using physical distresses as warranty items lie in that the manifestation of surface deterioration is easy to detect and measure, and it is relatively easy to specify the corresponding remedial activities. Several reasons contribute to the unpopularity of including the structure capacity as a warranty item: the difficulty to take the structure capacity measurement, structural deficiency may occur beyond the warranty period, and the contractor is not responsible for the design of pavement structure in most cases.

3.2 Data Acquisition

Monitoring pavement condition and acquiring pavement condition data of consistently high quality are the key components in warranty management, based on which the performance of the warranty work is evaluated and needed remedial work is triggered. This section provides information on pavement data acquisition in terms of protocol, acquisition cycle, data collection technology, and sample location of the warranty programs included in this survey study.

Protocol for Distress Definition

As shown in Table 31, seven out of nine state DOTs have specified their own Protocols to define pavement distresses for warranty projects. Four respondents use Long-Term Pavement Performance (LTPP) Distress Identification Manual (DIM) individually or along with other protocols. In addition, Indiana DOT uses American Association of State Highway and Transportation Officials (AASHTO) distress manual in the warranty projects. LTPP Distress Identification Manual is the commonly accepted protocol for warranty projects and has served as the basis for the distress data acquisition protocols developed by individual states.

Table 31 Warranty Protocols Used for Pavement Distresses

Agency	LTPP	AASHTO	Agency Specified
British Columbia			√
Florida			√
Illinois	√		
Indiana	√	√	√
Louisiana	√		√
Mississippi	√		
Nova Scotia			√
Pennsylvania			√
Wisconsin			√

It should be noted that the individual state specified protocols and the national protocols are used interactively. For instance, Indiana DOT developed its own protocol, but also employs LTPP and AASHTO protocols; Mississippi DOT defined distresses for warranty projects according to the LTPP Distress Identification Manual, but made minor revisions to the definitions of distresses and severity levels.

Data Collection Cycle

The most commonly collected pavement distress data in warranty specifications are roughness, rutting, and cracking. These pavement distress data are measured manually and/or with automated data collection equipment at different collection cycles.

Table 32 Pavement Distress Data Collection Cycles

Agency	Annual	Biennial	Others
British Columbia		√	√
Florida	√		
Illinois			√
Indiana	√		
Louisiana			√
Mississippi	√		
Nova Scotia	√	√	
Pennsylvania	√		
Wisconsin		√	

As shown in Table 32, annual data collection is adopted by five state DOTs, while biennial survey is conducted in three states. Moreover, three states reported that their survey cycles were based on the contract warranty period or the pavement surface condition. The two provinces from Canada reported varied data collection cycles. Details of pavement survey cycle in each state are presented below.

Indiana DOT conducts pavement condition surveys annually between April 15 and May 15 to monitor pavement distresses for each 328-foot (100-meter) evaluation section. Mississippi DOT also conducts annual surveys on its warranty pavements, and a minimum of two 500-foot sections are sampled per mile to collect pavement physical distress and roughness data.

The pavement data collections in Nova Scotia are conducted in various cycles according to the highway functional classification. The major highways are surveyed annually, while collectors and trunks are surveyed biennially. Locals and other roads are surveyed upon request. Illinois DOT surveys at the end of the warranty period unless performance issues are discovered before then. Louisiana DOTD is required to conduct a distress and condition survey within six months prior to the end of the three year warranty period. British Columbia monitors asphalt pavement performance after construction to ensure the pavement meets the requirements set for the one year period based on their own pavement surface condition rating manual.

The results show that most states survey their warranty pavements annually or biannually within the warranty period. The annual/biannual surveys assist the state DOTs to manage their warranty programs and make needed corrective decisions/requests in a timely manner, and therefore help maintain the warranty pavements at an adequate service level. On the other hand, the experience in Nova Scotia to conduct surveys based on highway functional classification and upon request is also valuable to state DOTs in that it could reasonably distribute the highway agency's resources to road users and help reduce the management costs for the warranty projects.

Data Collection Technology

Roughness, rutting, cracking, and joint faulting are the most commonly surveyed pavement distresses for warranty projects. Both manual/semi-manual and automated data collection technologies were reported in the survey as shown in Table 33.

Table 33 Distress Data Items and Data Collection Technologies

Distress Type	Data Collection Technology	BC*	FL	IL	IN	LA	MS	NS*	PA	WI
Cracking	Manual	√	√	√	√	√		√	√	√
	Film Video					√	√			√
	Digital Image			√		√		√	√	√
Rut-Depth	Three Sensor		√		√			√		
	Scanning Laser	√		√		√	√			√
	Five Sensor					√				√
Joint-Faulting	Ultrasonic						√	√		
	Laser			√		√				√
	Handheld fault meter				√	√	√		√	

*Note: BC = British Columbia; NS = Nova Scotia

Nova Scotia uses ultrasonic equipment to collect roughness data while all other states use lasers equipment for roughness data collection. Manual surveying with eyeball observation and judgment of cracking category and severity is the commonly employed method for cracking data collection. Eight states employ the wholly manual method or a revised version, the so-called “semi-manual” method involving videotaping/digitalizing of road surface images in the field and manual data collection by watching the playback of the videotape or digital images in the office.

Automated technology is well developed and widely used for rutting data collection. All states reported gathering rutting data with sensors or laser technologies except for Pennsylvania. The Pennsylvania DOT uses a manual method with 12-ft straight edges and is intended to switch to scanning lasers in 2012.

As for joint faulting measurement, ultrasonic, laser, and handheld fault meter technologies were all reported in the survey. For instance, Indiana measures joint faulting with a handheld fault meter manually. Louisiana uses laser assessment for preliminary analysis of joint-faulting. And in the event of excessive distress, on-site assessment is conducted using handheld fault meter.

It is shown from the results that no technologies are predominantly accepted by the state DOTs for the distress surveys of their warranty pavements. Even though automated technologies are the emerging trend for pavement surface distress data acquisition, they are not sophisticated enough to be used at project level, especially when warranty clauses are involved.

Sample Location

One important consideration in distress data collection is the sample location, which includes choosing the sample lane(s) on roads with multiple lanes and sample wheel path(s). According to the survey, six states responded to this question and five of them use the right lane as their sample location, except for Louisiana, who uses the left lane as the sample location. For data collection involving wheel paths, seven state DOTs use both wheel paths. Only Indiana and Louisiana use the right wheel path in their data collections.

3.3 Evaluation of Pavement Condition

There are different ways of evaluating the overall performance of pavements from collected distress data. This section provides information on pavement condition evaluation with respect to the index used for pavement condition rating.

Table 34 shows the pavement condition indices used for pavement condition rating in each of the participating states. For instance, Louisiana DOTD uses a composite index for Pavement Condition Rating (PCR) derived from roughness (IRI) and Pavement Distress Index (PDI). Wisconsin measures pavement condition in terms of the Pavement Condition Index (PCI), on a 0-100 scale with 100 being the best possible condition.

It is noted that Florida, Indiana, Mississippi and Pennsylvania do not favor the use of a composite index for overall performance evaluation of their warranty pavements, since the pavement performance can also be assessed through the more straightforward individual distress data and any needed corrective decision can be determined by the corresponding threshold values.

Table 34 Indices for Pavement Condition Rating

Agency	Pavement Distress Index (PDI)	Pavement Condition Index PCI	Ride Quality/ Roughness	Composite Pavement Condition Rating PCR
British Columbia			√	
Florida				
Illinois			√	
Indiana				
Louisiana	√		√	√
Mississippi				
Nova Scotia	√		√	
Pennsylvania				
Wisconsin		√		

3.4 Warranty Enforcement

Warranty contracts contain specifications for the enforcement of warranty provisions. During the warranty period, if any of the pavement distress threshold levels is met or exceeded, then remedial work will be performed within a certain time window. In addition, the contractor is required to maintain a warranty bond for the warranty period in order to ensure that the warranty requirements are met. This section provides information on the warranty enforcement regarding the notification/remedial action time window and conflict resolution.

Notification/Remedial Action Time Window

According to the survey, most states notify the contractor and request for corrective actions within 30 to 60 days. No time window longer than 3 months was reported in the survey.

In Mississippi, for instance, if a distress threshold is exceeded, the contractor will be notified of the result within 30 days of the annual survey and have 45 days to perform any required remedial action. If 30% of the project segments require a remedial action, then the entire project will receive that action. In Indiana, the time window required for the contractor to take actions is 30 days, while in Florida and Pennsylvania the time windows are both 45 days. In Louisiana, the remedial action shall be performed within 3 months.

Conflict Resolution

When the contractor contests the results, most states reported that they solved the conflict through resolution team following a simple majority rule. For example, Illinois DOT uses a Conflict Resolution Team (CRT) to provide a decision on disputes between the Illinois DOT and the contractor regarding any claims of non-compliance of warranty requirements. The CRT is a three-member team that consists of a member representing the DOT, a member representing the contractor, and a third person mutually agreed upon by both DOT and the contractor. The compensation for the third person will be equally shared between the DOT and the contractor. The decision of the CRT is final. Similar CRT's are used by Indiana and Louisiana except that each team has five members: two representing the DOT, two representing the contractor, and a fifth person mutually agreed upon by both DOT and the contractor.

British Columbia has a variety of resolution methods from field upwards to senior, to arbitration, and to litigation depending on the contract. Florida specifies its own dispute review board.

3.5 Distress Thresholds

This questionnaire survey is part of the research effort of an MDOT funded study of pavement distress thresholds of the warranty program in Mississippi, and therefore, the primary purpose of the survey is to gather information about the distress threshold values used by other states. The results are summarized in Tables 35 through 40.

Table 35 Distress Thresholds for Asphalt Concrete Pavements (Part 1)

Distress Type	Distress Thresholds by State			
	Louisiana	British Columbia	Indiana	Illinois
Alligator Cracking	N/A	N/A	N/A	50 ft^2 moderate, any high severity
Block Cracking	N/A	N/A	N/A	100 ft^2 moderate, any high
Reflection Cracking	N/A	N/A	N/A	N/A
Edge Cracking	1)50 linear ft. total length with crack width great than 0.25 in. 2)More than 100 linear ft. total length	N/A	N/A	10 ft. high severity
Longitudinal Cracking	1)50 linear ft. total length with crack width great than 0.25 in. 2)More than 200 linear ft. total length	N/A	0 ft., severity 2	10 ft. moderate, any high
Transverse Cracking	N/A	N/A	0 ft., severity 1	10 ft. moderate, any high
IRI	N/A	IRI greater than 2 m/km	90 in./mi.	110 in./mi.
Rutting	0.35 in. averaged in any 50 foot length in any wheel path	Visible rutting after 1 year	0.25 in.	0.30 in.
Potholes	Any occurrence	Any occurrence	6 $in.^2$	Any occurrence
Surface Bleeding	$10ft^2$	Any occurrence	N/A	500 ft^2 moderate, any high
Friction	N/A	N/A	25	N/A
Raveling/ Segregation	$10ft^2$	Any occurrence	N/A	500 ft^2 moderate, any high
Others	shoving: any occurrence Fatigue cracking:10 ft^2	N/A	N/A	N/A

Table 36 Distress Thresholds for Asphalt Concrete Pavements (Part 2)

Distress Type	Distress Thresholds by State	
	Florida	Pennsylvania
Alligator Cracking	Cumulative length of cracking > 30 ft. per 0.1 mi. LOT for Cracks >1/8 in.	Medium: Average Crack Width > hairline and ≤ 0.25 in. High: Average Crack Width > 0.25 in.
Block Cracking	Cumulative length of cracking > 30 ft. per 0.1 mi. LOT for Cracks >1/8 in.	anything >0%
Reflection Cracking	Cumulative length of cracking > 30 ft. per 0.1 mi. LOT for Cracks >1/8 in.	N/A
Edge Cracking	Cumulative length of cracking > 30 ft. per 0.1 mi. LOT for Cracks >1/8 in.	anything >0%
Longitudinal Cracking	Cumulative length of cracking > 30 ft. per 0.1 mi. LOT for Cracks >1/8 in.	anything >0%
Transverse Cracking	Cumulative length of cracking > 30 ft. per 0.1 mi. LOT for Cracks >1/8 in.	Low: Average Crack Width > hairline and ≤ 0.25 in. Medium: Average Crack Width > 0.25 in. and ≤ 0.5 in. High: Average Crack Width > 0.5 in.
IRI	Ride Number, Remove and Replace any 0.1mile LOT with RN <3.5	N/A
Rutting	0.25 in.	> 9.5 mm (3/8 in.)
Potholes	Any potholes	anything > 0%
Surface Bleeding	Width ≥ 1 ft. and ≥ 10 ft. long	N/A
Friction	N/A	N/A
Raveling/ Segregation	Raveling length≥ 10ft , R&R full depth	Medium: Surface is rough and pitted, may have loose particles. High: Surface is very rough and highly pitted.
Other distress	N/A	*Miscellaneous cracking*: Low: Average Crack Width > hairline and ≤ 0.25 in.; Medium: Average Crack Width > 0.25 in. and ≤ 0.5 in.; High: Average Crack Width > 0.5 in. *Edge deterioration*: Low: Average Crack Width > hairline and ≤ 0.25 in. The width measurement may include crack spalling. No loss of pavement material is allowed in this category; Medium: Average Crack Width > 0.25 in. and ≤ 0.50 in. The edge of the pavement is becoming jagged; High: Average Crack Width > 0.50 in. The edge of the pavement is deteriorated and pieces of the pavement edge are broken loose or missing. *Left edge joint*: Low: Construction joint open < ¼" or sealed with sealant in good condition. If any cracks parallel to the joint are present, they are hairline width. No loss of material in this category and no patching; Medium: Construction joint open ¼" to ½". Random adjacent cracks are ≤ ¼" wide and interconnected forming jagged pieces. Some minor loss of material (spalling) visible but no patching present; High: Construction joint open > ½". Random adjacent cracks are > ¼" wide and interconnected forming jagged pieces. Visibly severe loss or breaking of material (spalling) or patching of construction joint present.

Table 37 Distress Thresholds for Asphalt Concrete Pavements (Part 3)

Distress Type	Distress Thresholds by State
	Wisconsin
Alligator Cracking	*Threshold:* $\geq$ 50 ft^2 in a segment of medium (M) or higher. *Remedial Action:* Remove and replace the distressed layer(s) of the warranty pavement the full lane width by the length of the distress. The extent of the repair limits will be determined by the contractor and the engineer.
Block Cracking	*Threshold:* $\geq$ 50 ft^2 in a segment of level low (L) or higher. *Remedial Action:* Remove and replace the distressed layer(s) of the warranty pavement the full lane width by the length of the distress. The extent of the repair limits will be determined by the contractor and the engineer.
Reflection Cracking	N/A
Edge Cracking	*Threshold:* $\geq$ 50 linear ft. of the segment length. *Remedial Action:* Non-Banded level low (L) or medium (M) Cracking - Rout and seal the crack following the requirements listed in section C.5.3. Banded or Dislodgement Level high (H) or higher - Patch the distressed layer(s) of the warranty pavement from the edge of the shoulder to the shoulder stripe by the length of the distress. The extent of the repair limits will be determined by the contractor and the engineer.
Longitudinal Cracking	*Threshold:* $\geq$ 50 linear ft. in a segment. *Remedial Action:* Level medium (M) or higher: Remove and replace the distressed layer(s) of the warranty pavement the full lane width in the distressed areas. The extent of the repair limits will be determined by the contractor and the engineer
Transverse Cracking	*Threshold:* $\geq$ 100 linear ft. in a segment of level low (L) or higher. *Remedial Action:* Remove and replace the distressed layer(s) of the warranty pavement the full lane width by the length of the distressed area. The extent of the repair limits will be determined by the contractor and the engineer.
IRI	N/A
Rutting	*Threshold:* $\geq$ 0.375 in. in depth *Remedial Action:* Remove ruts by milling the full lane width and overlaying the full distressed layer with a minimum 1.75 in. of HMA at or greater than the appropriate E-Mix type. The extent of the repair limits will be determined by the contractor and the engineer.
Potholes	Threshold: Any *Remedial Action:* Remove and replace the distressed layer(s) of warranty pavement the full lane width by the length of the distress. The extent of the repair limits will be determined by the contractor and the engineer.
Surface Bleeding	*Threshold:* $\geq$ 50 ft^2 in a segment of level medium (M) or higher. *Remedial Action:* Remove and replace the distressed layer(s) of warranty pavement the full lane width by the length of the distress. The extent of the repair limits will be determined by the contractor and the engineer.
Friction	N/A
Raveling/Segregation	*Threshold:* $\geq$ 50 ft^2 in a segment of level medium (M) or higher. *Remedial Action:* Remove and replace the distressed layer(s) of the warranty pavement the full lane width by the length of the distress. The extent of the repair limits will be determined by the contractor and the engineer.
Other distress	Longitudinal & Transverse Distortion (Includes Bumps & Sags, Corrugation, Depression, Swell and other distortions) *Threshold:* $\geq$ 50 ft^2 in a segment of level medium (M) with ½ in. of vertical distortion or higher. *Remedial Action:* Remove and replace the distressed layer(s) of the warranty pavement the full lane width by the length of the distress. The extent of the repair limits will be determined by the contractor and the engineer.

Table 38 Distress Thresholds for Portland Cement Concrete Pavements (Part 1)

Distress Type	Distress Thresholds by State			
	Louisiana	Indiana	Illinois	Florida
Corner Breaks	Any Occurrence	N/A	Any moderate or high	N/A
Faulting of Transverse Joints	0.25 in. maximum; 0.125 in. minimum	0.25 in.	N/A	N/A
Joint Seal Damage	Any Occurrence	12 ft. cumulative total	N/A	N/A
Longitudinal Cracking	Any Occurrence	0 ft., severity 2	10 ft. moderate, any high	Four cracks in any lane mile > 1/8 in. or any crack > 3/8 in.
Multiple Cracks Involved	N/A	N/A	N/A	Four cracks in any lane mile > 1/8 in. or any crack > 3/8 in.
Transverse Cracking	Any Occurrence	0 feet, severity 1	10 ft. moderate, any high	Four cracks in any lane mile > 1/8 in. or any crack > 3/8 in.
Spalling of Longitudinal Joints	Spalls greater than 2 in. wide	N/A	10 ft. moderate, any high	N/A
Spalling of Transverse Joints	Spalls greater than 2 in. wide	N/A	10 ft. moderate, any high	N/A
Map Cracking & Scaling	N/A	N/A	50 ft^2	Four cracks in any lane mile > 1/8 in. or any crack > 3/8 in.
IRI	N/A	90 in./mi.	150 in/mi	Ride Number, remove and replace any 0.1 mile LOT with RN <3.5
Other Distresses	Tine Texture (Tire Gauge): 0.125 in. mean texture depth Macrotexture (Sand Patch): 20% maximum loss over warranty period Lane-to-AC Shoulder Separation: Any Occurrence Popouts: Any occurrence Spalled Areas: Areas greater than 25 in^2 and/or with depth greater than 1 in.	N/A	Punchouts in CRCP – any moderate or high severity	Spalling is divided between "in wheel path" and "outside wheel path". In wheel path, four areas in any lane mile exceeding 1 inch in width and 6 inches in length OR any single area exceeding 3 inches in width. For areas outside wheel path, four areas in any lane mile exceeding 1.5 inches in width and 12 inches in length OR any single area exceeding 3 inches in width. Shattered slabs –cracking patterns that divide the slab into three or more segments require full slab replacement.

Table 39 Distress Thresholds for Portland Cement Concrete Pavements (Part 2)

Distress Type	Distress Thresholds by State	
	Wisconsin	Pennsylvania
Corner Breaks	N/A	N/A
Faulting of Trans. Joints	Three or more faulted joints or cracks per station with faulting greater than ¼ in. Retrofit dowel bars across cracks or repair full depth, repair joints full depth and spot diamond grind if necessary to restore ride	Medium: Absolute value of elevation difference is ≥ 0.25 in. and < 0.5 in. High: Absolute value of elevation difference is ≥ 0.5 in.
Joint Seal Damage	N/A	N/A
Long. Cracking	N/A	*Medium:* Average crack width ≤ 0.25 in. wide, spalling ≥ 2.0 in. wide for ≤ 50% length. Remedial Action: Crack seal as specified in Section 469. *High:* Average crack width > 0.25 in. wide, spalling 2.0 in. wide for > 50% length. Remedial Action: Remove and replace distressed layers full lane width to a depth not to exceed warranty pavement and length not less than 3 m (10 ft.) beyond the distressed area.
Multiple Cracks Involved	Broken panels	N/A
Trans. Cracking	8 or more broken panels	*Medium:* Average crack width > hairline & ≤ 0.25 in. wide, Spalling ≥ 2.0 in. wide for ≤ 50% length Or faulting ≥ 0.25 in. and < 0.50 in. Remedial Action: Crack seal as specified in Section 469. *High:* Average crack width > 0.25 in. wide, spalling ≥ 2.0 in. wide for > 50% length Or faulting ≥ 0.5 in. Remedial Action: Remove and replace distressed layers full lane width to a depth not to exceed warranty pavement and length not less than 3 m (10 ft.) beyond the distressed area.
Spalling of Long. Joints	*Threshold:* Any distress greater than 2 in. in width or any faulting less than ½ in. at the longitudinal joint within a 0.1-mi. segment. Remedial Action: If distress is less than four inches in width, clean and remove debris from joint and fill with epoxy concrete or other material as approved by the CRT. If distress is greater than 4 in. in width and one-half the pavement thickness or greater, remove and repair full depth. Repair limits are from transverse joint to transverse joint with the exception of distress less than 2 ft. from a joint. If distress is less than one half the pavement thicknesses in depth, repair should be in accordance with accepted partial depth repair methods. *Threshold:* Faulted longitudinal joint (greater than ½ in.). Remedial Action: Retrofitting tie bars and diamond grinding affected areas.	*Medium:* Average spalled width ≥ 3.0 in. and < 6.0 in. for an accumulated spalled length of at least 25 ft. Remedial Action: Crack seal as specified in Section 469. *High:* Average spalled width ≥ 6.0 in. for an accumulated spalled length of at least 25 ft. Remedial Action: Remove and replace distressed layer one foot either side of the joint transversely and a minimum of 610 mm (24 in.) beyond distressed pavement in all longitudinal directions.

Table 40 Distress Thresholds for Portland Cement Concrete Pavements (Part 3)

Distress Type	Distress Thresholds by State	
	Wisconsin	Pennsylvania
Spalling of Trans. Joints	*Threshold:* Distress 2 in. or more in width in the wheel paths on 5 joints or cracks in any one 0.1 mile segment. Remedial Action: If distress is between 2 and 4 in. in width, clean and remove all debris and patch distress with epoxy concrete or alternative method as approved by the CRT. If distress is greater than four inches, repair pavement with a 6-ft. full-lane width full depth repair or partial depth repair of affected area, or alternative method as approved by the CRT. If distress is less than 2 ft. in length and is adjacent to a joint or crack a full depth repair can be performed on the affected area only.	Medium: > 2.0 in wide for ≤ 50% of joint length High: > 2.0 in wide for > 50% of joint length
Map Cracking & Scaling	10% of surface	N/A
IRI	N/A	N/A
Other Distresses	Slab Breakup *Threshold:* cracks or slabs broken into two pieces. More than four cracked slabs per segment (0.1 mi.) at three years of age and more than eight slabs per segment at five years of age. A slab is defined as a section of pavement bounded on the ends by joints and on the sides by a centerline joint and/or the edge of pavement. *Remedial Action:* Evaluate per the Department's Construction and Materials Manual or alternative method as approved by the engineer or CRT. *Threshold:* One or more slabs broken into three or more pieces. *Remedial Action:* Remove entire slab and replace. Patching *Threshold:* No distressed patches. Any patch present must be in good condition and performing satisfactorily. *Remedial Action:* Full depth repair and replacement of all patches not in good condition. All remedial action under this item is contingent upon the repair originally being performed by the contractor as part of a remedial action to another distress. Surface Distress *Threshold:* Distress is present on greater than 0.5% but less than 10% of the surface area on any one 0.1-mi. segment. *Remedial Action: If* distress is less than 1 inch and greater than 10% of the surface area is affected, or distress is greater than 1 inch in depth, regardless of the percentage of surface area affected. *Threshold:* If surface distress is less than 1 inch in depth, distressed area should be milled partial depth repaired partial depth with concrete. *Remedial Action:* Repair full depth or partial depth repair method as approved by the engineer.	Broken slab: *Low:* At least 4 pieces in a 20-ft. length with average width ≤ hairline in the outside wheelpath, no faulting and IRI ≤ 100 in./mi.. *Medium:* At least 4 pieces in a 20-ft. length with an average crack width > hairline and ≤ 0.25 in., may have faulting > 0.25 in. and ≤ 0.50 in OR IRI > 100 and ≤ 200 in./mi.. *High:* At least 4 pieces in a 20-ft. length with an average crack width > 0.25 in., may have faulting > 0.5 in. OR IRI > 200 in./mi..

Unlike Mississippi DOT, who uses deduct point-based thresholds, all the states that responded with existing warranty programs set their distress thresholds on the direct measurements of pavement distresses. Although the kinds of pavement distresses selected by different states as warranty items tended to be quite similar, (for example, cracking, rutting, roughness were commonly selected by multiple states as warranty items); however, huge variety was found in the distress types/categories and threshold levels used by these states. Regarding the appropriateness of the existing threshold values, all the other states with existing warranty programs stick to their own view points.

3.6 **State DOT Remarks**

With varying levels of pavement warranty experience and different situations, state DOTs face different problems and challenges. The last section of the survey questionnaire requests the comments and concerns on pavement warranty from those states practicing in the survey. The remarks submitted by the participating states are summarized as below.

Warranty Period

Several states have concerns on warranty term and intend to extend the warranty period for longer warranties. For instance, British Columbia reported that a one-year warranty is a pretty short timeframe and issues can occur 3-4 years later. British Columbia DOT is considering the possibility of longer warranties. In Pennsylvania, a final specification is in the approval stages, one of the pending issues is how many years the warranty should be. Pennsylvania DOT is considering extending warranty terms from 5 to 7 years.

On the other hand, some concerns regarding long-term warranty were also reported in the survey. For instance, when Indiana DOT tried to extend warranty to 6 years, no contractor bid for the projects. Nova Scotia DOT is looking for a development of a full warranty specification for asphalt pavement projects. The DOT wants to have a 7-year warranty, but this seems to be a concern with the contractors' bonding companies.

Warranty Specification

Several states made remarks on the warranty specification. In Wisconsin, the distress threshold values were considered relatively low, and the specification for HMA warranties was rewritten in 2010 to relax the thresholds. British Columbia and Florida reported that they did not have concrete pavements under a warranty program.

Warranty Implementation

Two states indicated that they had difficulties in warranty implementation. In Louisiana, DOTD implemented a performance-based warranty program, but did not incorporate a design-build strategy. Contractors and bonding companies were faced with the full requirements and responsibilities associated with a performance-based warranty without having control over design and while also being subject to low-bid contracting. Federal regulations contributed to the number of projects dropped from warranties' consideration, because the introduction of a warranty clause would have made it impossible for smaller contractors to participate in the bidding process. Moreover, distress assessment requirements needed for warranty monitoring are excessively costly and time-consuming, since automated distress analysis technology is currently not sophisticated enough to assess distresses on a large-scale basis. In Pennsylvania, there are issues regarding repairs during the warranty period when pavement deficiencies were determined to be beyond the responsibility of the contractor (base failure for warranty overlay layers, etc.). No easy mechanism exists to pay the contractor for these repairs.

3.7 Concluding Remarks

A comprehensive online survey study was conducted to gather information on the most current status of pavement warranty practice and specification in North America and to complement the literature review results of previous reports and studies on pavement warranty. The survey results are summarized herein.

According to the survey, warranty has been implemented to both HMA and PCC pavements. In addition to preservation or rehabilitation projects, warranty clauses were also adopted on full depth HMA and PCC pavement construction projects. The warranty period is usually between 3 to 7 years and 5-year is the most commonly used warranty term. No warranty period longer than 10-year was reported in the survey.

All the states that responded with existing warranty programs adopt performance warranties. Meanwhile most of them also exercise materials and workmanship warranties. Regardless of the warranty type adopted, ride quality and physical distresses were the common pavement condition items under warranty. Rutting, cracking, and joint-faulting are the most commonly warranty physical distresses. Structural capacity and safety measurement were also reported in the survey, but only used by a few states as warranty items.

Although most of the states with existing warranty programs developed their own distress identification protocols, LTPP and AASHTO distress manuals serve as the reference for or are used jointly with agency specified protocols. Annual or biannual pavement condition surveys were commonly used data collection cycles. However, no prevailing technologies were reported for pavement condition data collection. Manual methods are still widely employed for warranty programs, since the automated technologies are not yet sophisticated enough to be employed at the project level, especially when warranty clauses were engaged.

Composite indices are still used for condition evaluation of warranty pavements, but the distress thresholds are the major criteria used by state DOTs to manage their warranty projects and specify the corresponding remedial actions. Unlike the practice in Mississippi, who uses deduct point based threshold levels, all the other states that responded with existing warranty programs set their threshold limits based on the maximum allowed value for each distress measurement within certain sample pavement segment. As for warranty enforcement, most states notify the contractor and request for the remedial actions to be conducted within 30 to 60 days. Conflict Resolution Teams (CRT) consisting of 3 or 5 members from DOT, contractor, and a mutually agreed third party are commonly used when the contractor contests the DOT’s decision based on the pavement survey results.

Several issues regarding pavement warranty were reported in the survey. Some states consider extending their warranty terms, but it seems to be a concern with the contractor and contractor's bonding companies. In addition, how to accurately determine the responsibilities of the contractor is also an issue, since the contractor has no control over design in most cases and some failures for warranty projects are beyond the contract scope. Moreover, some concerns regarding the tight threshold values and the benefits of pavement warranties were also voiced in the survey.

In summary, the survey study shows some common characteristics of pavement warranty practice shared by different states, including the warranty projects, warranty terms, warranty types, and warranty enforcement. On the other hand, the variety of warranty implementation in different states is also highlighted in the survey, with regard to the pavement condition data collection and setting of distress threshold values for the warranty program. Although pavement warranty has been applied in the U.S. for almost 20 years, there are still major issues concerning state agencies. In-depth studies need to be conducted to fully research on the appropriate specifications and the proper implementation of pavement warranties. Due to the variety of warranty practice and criteria in different states, it is necessary for Mississippi DOT to perform its own research study to investigate the appropriateness of the deduct point based pavement condition rating models, the associated distress threshold values, and the cost-effectiveness of the warranty program in Mississippi.

CHAPTER 4. DATA DESCRIPTION

To evaluate the warranty program and the distress threshold values for the warranty projects in Mississippi, distress survey data from both warranty and non-warranty pavements were employed in the study. This section describes the data sources, data items, data screening, and data reformatting. The pavement distress survey data used in the study were gathered over a long span of time, which assists in examining the performance of warranty and non warranty pavements over various service times.

4.1 Data Sources

The warranty pavement data used in the study were collected on an annual basis over a period spanning from 2003 to 2010. A total number of 2,738 pavement sections are involved, among which 2,133 sections are asphalt pavements and the remainder are concrete pavements. Each pavement section is approximately 0.1 mile in length according to MDOT's specification. Data items for warranty projects are shown in Table 41. The annual survey reports contain distress measurements and associated deduct points within each survey lane of the sample pavement segments.

The source of the non-warranty pavement data is the MDOT Pavement Management System (PMS), which contains the inventory, surface condition, and maintenance history data of the entire highway network managed by MDOT. The distress data from PMS are stored in raw measurement format. Each distress type has a corresponding distress code in the state maintained PMS database. For the purpose of evaluation of the warranty projects and the distress threshold values, only the distress types commonly contained in both PMS data and warranty projects survey data were analyzed in the study.

Table 41 Data Items and Distress Numbers for Warranty Projects in MDOT's PMS

HMA Pavement		PCC Pavement	
Distress	Distress# in PMS	Distress	Distress# in PMS
Rut	200	Faulting	NA
IRI	100	IRI	100
Alligator Cracking	19	Corner Break	7
Bleeding	29	Faulting of Transverse Joints	5
Block Cracking	20	Joint Seal Damage	9
Edge Cracking	21	Longitudinal Cracking	0
Longitudinal Cracking	22	Transverse Cracking	1
Potholes	27	# of slabs broken in 4 for more pieces	NA
Raveling & Weathering	28	Spalling of Longitudinal Joints	10
Reflection Cracking	30	Spalling of Transverse Joints	11
Transverse Cracking	23	Map Cracking & Scaling	12

4.2 Data Screening

Prior to the data analysis, the first step was to clean the dataset to remove all the null and unusable records in the PMS system. The main cause for unusable data is the incompleteness of pavement rehabilitation and maintenance history data. There is a considerable amount of the records that show improvement in pavement condition index without pavement improvement projects between two survey dates (as shown in Figure 2). In such cases, the service time of the pavement at the second survey date is unknown; therefore, the pavement condition data couldn't be used for the following statistical analysis and comparison.

Using Pavement Condition Rating (PCR), Roughness Rating Number (RRN), and Distress Rating Number (DRN) as pavement condition indicators, the criterion for determining unusable dataset is that the improvement in these indicators is larger than 15 and no pavement improvement project was recorded between two adjacent survey dates.

The discard of the unusable data is based on an underlying assumption that the improvement activities were missing in a random manner, and therefore, the absence of deleted data will not affect the analysis of the properties of pavement condition. Given the long term of data collection period, it is a fair assumption.

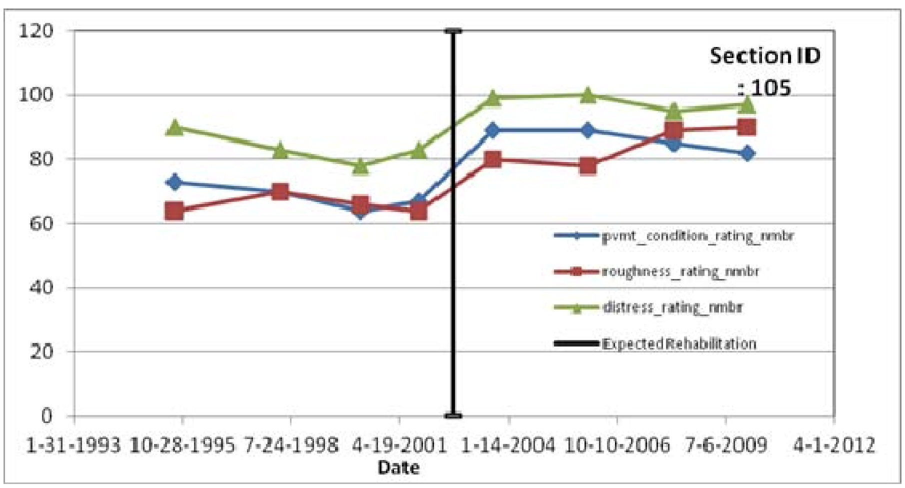


Figure 2 Composite Index Evolvement Curves of Section 105 with Suspected Rehabilitation Activity

4.3 Data Preparation

Corresponding to the warranty pavement types in Mississippi, only data collected from HMA (COMP, FLEX, and OFLEX) and JRCP pavements in the PMS were used in the analysis. The pavement service time at each survey date was calculated as the difference between the survey time and the actual ending date of the immediate pavement improvement project before the survey time.

To consider the potential effect of pavement structure on HMA pavement condition, the Structure Numbers (SNs) of HMA pavement sections at each survey time were calculated with the structure layer coefficient provided by MDOT. Another factor considered in the study is truck traffic volume. Since the complete traffic data over the service time is unavailable, only the truck volume data of 2010 was used to examine the effect of truck load on pavement performance. The writers recognize that the validity of the analysis results based upon truck volume in one single year can be questionable.

4.4 Data Items

Table 42 highlights the distress items with usable data from both warranty and non-warranty pavements after data screening. The data items for distress numbers 0, 1, 5, 7, 9, 22, 23, and 27either don't have valid data or the values are all zero.

Table 42 Valid Data Items for both Warranty and Non-Warranty Pavements

HMA Pavement		PCC Pavement	
Distress	Distress # in PMS	Distress	Distress # in PMS
Rutting*	200	Rutting*	200
IRI*	100	IRI*	100
Alligator Cracking*	19	Corner Break	7
Bleeding*	29	Faulting of Transverse Joints	5
Block Cracking*	20	Joint Seal Damage	9
Edge Cracking*	21	Longitudinal Cracking	0
Longitudinal Cracking	22	Faulting	NA
Potholes	27	Punchouts	6
Raveling & Weathering*	28	Spalling of Longitudinal Joints*	10
Reflection Cracking*	30	Spalling of Transverse Joints*	11
Transverse Cracking*	23	Map Cracking & Scaling*	12

* Distress type with enough data for statistical analysis in the study.

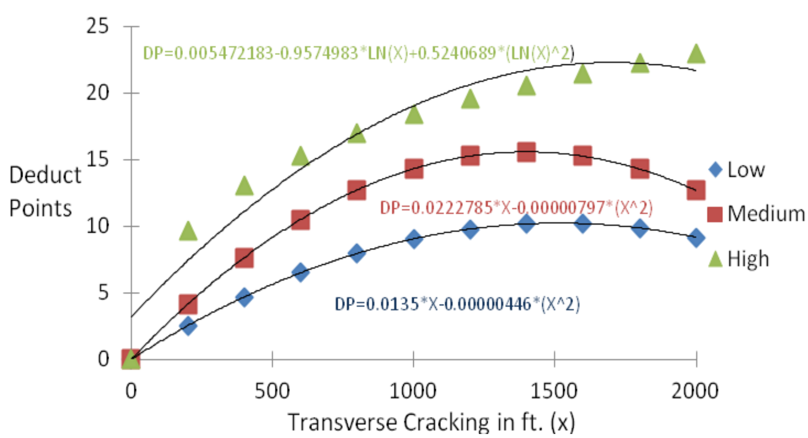


Figure 3 Deduct Point Curves for Flexible Transverse Cracking

For comparison purposes, each lane of the 500 ft. long pavement sample segments within every pavement analysis section was considered as a data point. The distress measurements stored in PMS database were converted to English units and then summed up by distress type, lane, sample segment, analysis section, and pavement survey time.

If the summed distress measurements fall into the valid ranges, deduct points will be calculated for each individual distress with the corresponding deduct point equations employed by MDOT. For illustration, Figure 3 presents the deduct point curves and calculation equations for low, medium, and high levels of transverse cracking for asphalt pavements.

Table 43 presents the number of records for each individual distress dataset of the non-warranty pavement before and after the possible outliers were removed. It shows that the valid distress data collected from asphalt pavements heavily outnumber the valid data from concrete pavements, due to the fact that most the state maintained highways are HMA surfaced. However, although the number of records for PCC pavements is much lower than that for HMA pavements, the PCC dataset sample size is large enough to perform the statistical analysis.

Table 43 Record Sizes for Individual Distress Types before and after Outlier Determination

Distress Number	Distress Type	Record Size before Outlier Check	Record Size after Outlier Check
1	Transverse Cracking	3548	3229
10	Spalling Longitudinal	268	232
11	Spalling Transverse	745	536
12	Map Cracking	146	120
19	Alligator Cracking	135156	135157
20	Block Cracking	32382	31641
21	Edge Cracking	14661	12211
28	Reveling	4736	2844
29	Bleeding	14711	13508
30	Reflective Cracking	28608	28557

4.5 Data Group

To investigate the performance characteristics over time, the data were categorized into groups of different service years. For the warranty projects, up to 7 years annual survey data are available, and therefore the data were categorized into 7 groups with the service time from 1-year to 7-year.

For non-warranty projects, after the cleaning and screening procedure, data from a total of 6166 pavement sections are included in the study, among which over 90% are data from asphalt pavements. Counting the service time from the most recent construction or rehabilitation, the screened PMS data span a wide range of service times of up to 25 years. Although the non-warranty projects have the data of up to 25-year service time, the number of records for projects of 10 years and longer is relatively small compared with those of shorter service times. Therefore, for non-warranty projects, all the data with service time of more than 10 years were categorized into one group, resulting in a total of 11 groups with 10 groups from 1-year to 10-year with interval of 1 year and one group of over 10 years.

CHAPTER 5. METHODOLOGY

This chapter presents the methodology employed in the study to evaluate the distress thresholds for maintained pavement projects. First, the approach to generally characterize and compare the distress data from both warranty and non-warranty pavements using data distributions and basic statistics is introduced, followed by the description of the assessment of the appropriateness of the distress thresholds. Then, the method to investigate the evolvement of distress over time for warranty and non-warranty pavement using pairwise comparison is presented. The remaining part of the section is focused on the method to statistically compare the performances of warranty and non-warranty pavements at the same service time with two sample t tests.

The distress data analyzed in the study are in the format of deduct points for the purpose of the evaluation of the deduct point based distress thresholds. In addition to the distresses commonly contained in warranty and non-warranty pavement datasets, riding quality data, IRI, are also included in the analysis.

5.1 Data Distribution and Basic Statistics

To distinctly present and interpret the distress data, the distributions of distress data by service time for warranty and non-warranty pavements were developed, and their corresponding basic statistics were calculated, including max, min, median, mode, mean (μ), and standard deviation (σ).

Figure 4 presents the distribution of rut data collected from non-warranty asphalt pavements. The curve superimposed in the figure is a fitted standard normal distribution curve. Since the rut, IRI, and deduct point distress data are all numerical data, their distributions tend to follow a normal distribution, if sufficient data are available.

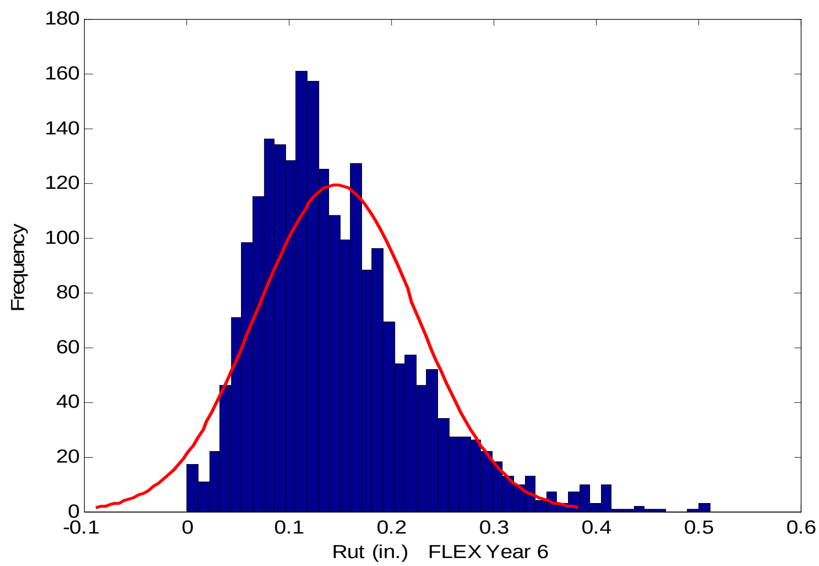


Figure 4 Histogram of Rut at 6-Year for Non-Warranty Asphalt Pavements

In order to evaluate the distress thresholds for warranty pavement, the Cumulative Distribution Functions (CDF) curves of the deduct point distress data at different service year were developed. The corresponding percentiles of the distress thresholds at the CDFs of both warranty and non-warranty pavement were then determined and employed to assess the appropriateness of the threshold levels for warranty pavements. Low percentile values indicate tight threshold levels, vice versa. For illustration, Figure 5 shows the CDF of the longitudinal cracking deduct point data from non-warranty PCC pavements at 3-year service. The corresponding percentile of the longitudinal crack threshold of 1.36 falls into the lower 5%, indicating extremely tight threshold level.

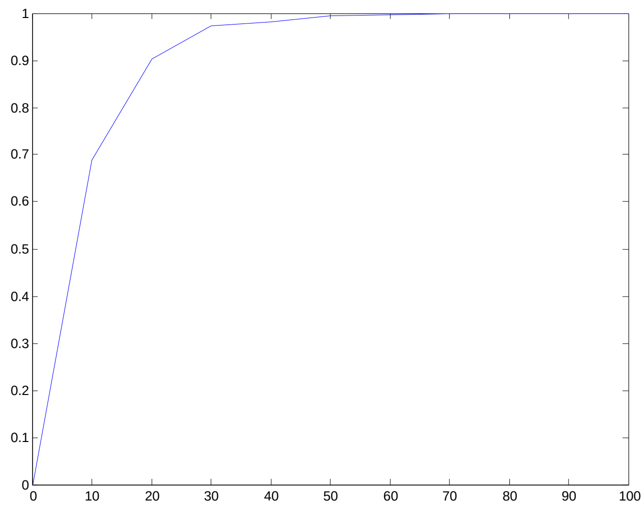


Figure 5 CDF Curve of the Longitudinal Cracking Deduct Point Data from Non-Warranty PCC Pavements at 3-Year Service Time

5.2 Pairwise Comparison

To investigate the deterioration patterns of warranty and non-warranty pavements, pairwise comparisons of the distress data distributions over service time were conducted. Tukey adjustment was employed to run the pairwise comparison, while 5% overall significance level was used to discriminate statistically different distributions.

Figure 6 presents the bar chart of the pairwise comparison for the rutting of non-warranty pavements over different service times. The vertical axis Group indicates the service time in years. The horizontal lines in the figure are the 95% confidence intervals of the rutting means for the 11 groups respectively. Two groups are significantly different if their corresponding confident interval lines are not overlapped.

It is shown in Figure 6 the rutting after 2-year service is significantly higher than that in the first year for non-warranty pavements, which means the pavement deteriorated rapidly once after the new pavement was placed into service.

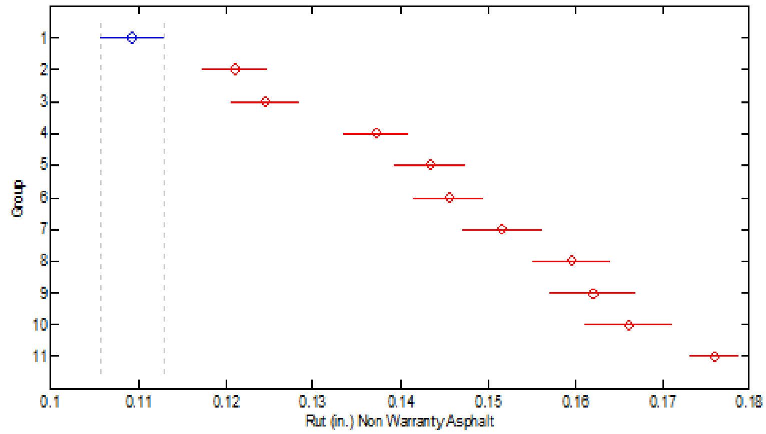


Figure 6 Pairwise Comparison of Rutting at Different Service Times for Non-Warranty Asphalt Pavements

5.3 Two-Sample T-Test

Using the distress data of warranty and non-warranty pavements at the same service time, two-sample t-tests were performed to compare the performance of these two contracting approaches.

Figure 7 presents the two-sample t-test results for the rutting data collected from asphalt pavements at service time of 7-year. The box plot on the left of Group1 is for non-warranty pavements, while the box plot on the right of Group2 is for warranty pavements. A p-value lower than 0.05 indicates significant difference between the two groups. As shown in Figure 7, the p-value is 0.003, indicating rutting values of warranty pavement are significantly lower than those of non-warranty pavements and better performance of warranty pavements.

year 7
p-value:
0.0033

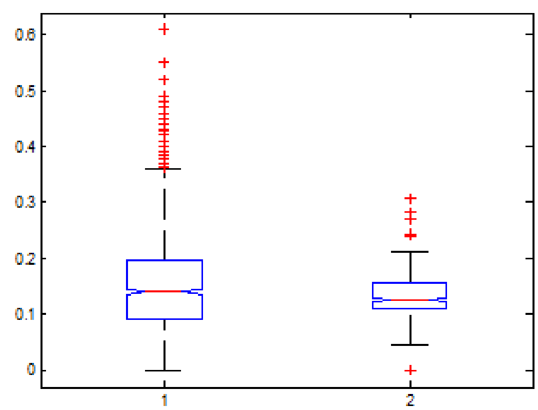


Figure 7 Two-Sample T-Test Results of Rutting Data for Asphalt Pavements

CHAPTER 6. RESULTS AND DISCUSSIOS

This chapter presents the results of the study following the methodology described in the previous chapter. First, the distributions of the pavement condition data from both warranty and non-warranty projects were developed, followed by the basic statistics and percentile analysis to evaluate the appropriateness of the corresponding distress thresholds. Then, the evolvements of pavement condition of warranty and non-warranty projects were investigated through a pairwise comparison procedure. Finally, the pavement conditions of warranty and non-warranty projects at the same service time were compared using two-sample t-tests. The effects of pavement structure and truck traffic on pavement condition were also examined in the study.

The pavement condition data were grouped into ride quality (IRI) and surface deformation (rutting), distress data from asphalt pavements, and distress data from PCC pavements for the data analysis.

6.1 Pavement Condition Data Distribution

The histogram and CDF distributions of pavement condition indicators at various service years for both warranty and non-warranty pavement sections were developed, along with the basic summary statistics. The corresponding percentile of each distress threshold was then determined to evaluate its appropriateness.

6.1.1 IRI and Rutting

Figure 8 and Figure 9 present the histograms of rut and IRI at 1-year and 5-year for warranty and non-warranty asphalt pavements, along with the standard normal distribution curve for each case. It shows that the distributions of rut and IRI data are approximately bell-shaped and the peak of the distribution shifts to the right as service time increases. Additionally, the figures show that the peak values of rut and IRI distribution for non-warranty pavements are slightly higher than those of warranty pavements. Similar trend was observed for rut and IRI data distributions at other service times and for PCC pavements.

Figure 10 and Figure 11 show the CDFs of rut and IRI data at various service years for asphalt pavement under warranty contracting and its traditional counterpart. Generally, the performance indicator percentile values of warranty pavements are lower than the corresponding values of non-warranty pavements for the same years, denoting a better performance of warranty pavements. In addition, it is shown in Figure 10 that the CDFs for different years follow a similar trend and the percentile values increase as service time increases. Figure 11 shows that the IRI CDFs of non-warranty pavements follow a same trend, while the CDFs of warranty pavements significantly vary with service time, especially at longer service times. Moreover, larger percentile values are observed on the right tails of both rutting and IRI distributions of non-warranty pavements than on the rutting and IRI distributions of warranty pavements. This indicates that the data from non-warranty sections are more scatteredly distributed than that of warranty sections.

Similar trends were observed for the rut and IRI data in different years of PCC pavements under warranty and non-warranty respectively. The following section examines in depth the performance indicators of MDOT's pavement warranty system using summary.

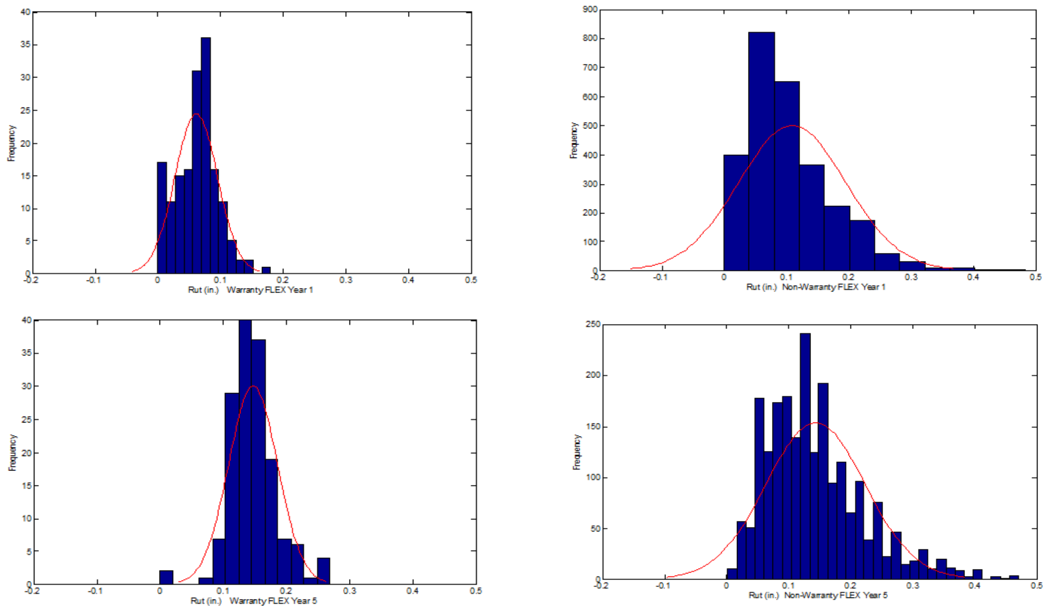


Figure 8 Histograms of Rut at 1-Year and 5-Year for Warranty and Non-Warranty Asphalt Pavements

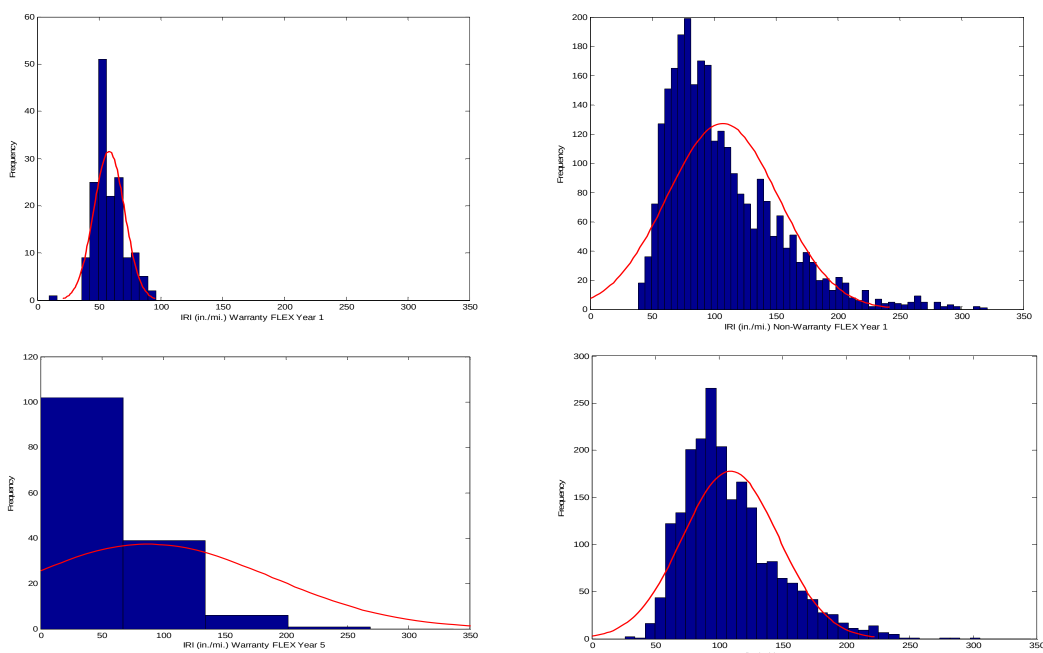


Figure 9 Histograms of IRI at 1-Year and 5-Year for Warranty and Non-Warranty Asphalt Pavements

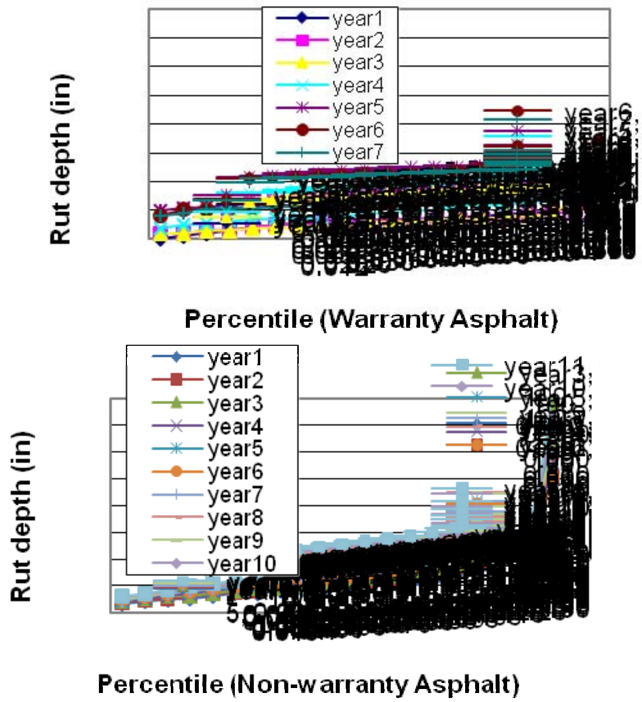


Figure 10 CDF of Rut at Different Service Times for Warranty and Non-warranty Asphalt Pavements

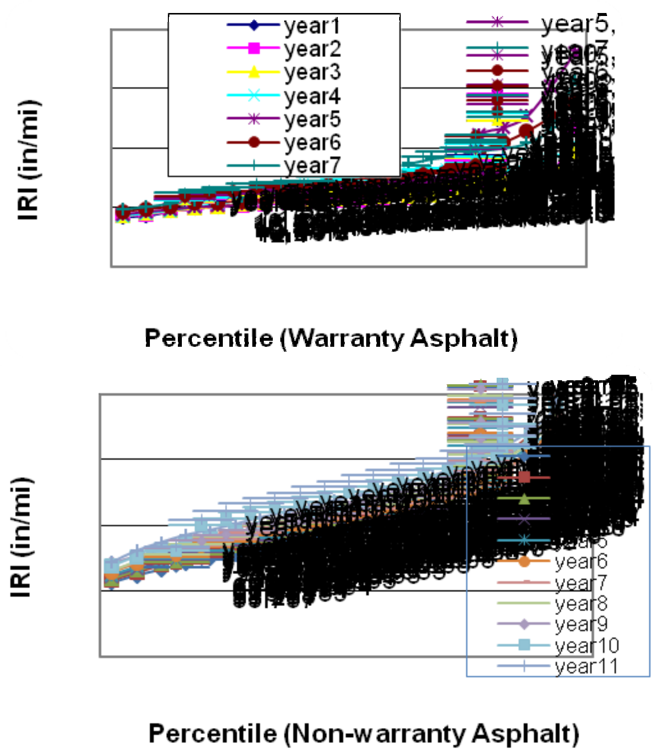


Figure 11 CDF of IRIs at Different ServiceTimes for Warranty and Non-warranty Asphalt Pavements

Tables 44 and 45 show the summary statistics of rut and IRI data for asphalt pavement under warranty and non-warranty. The two trends observed from above sections were confirmed by the summary statistics. The rut and IRI measurements increase as service time increases and the values of non-warranty pavements are generally higher than those of warranty pavements. Additionally, it is also shown in Tables 44 and 45 that the standard deviation (std) of rut and IRI from non-warranty pavements is steadily higher than that of warranty pavements at all service times. Similar patterns were obtained for rutting and IRI data of concrete pavements.

Table 44 Summary Statistics of Rut Data for Asphalt Pavements

Non-warranty (in.)							Warranty (in.)					
Year	max	mean	median	min	mode	std	max	mean	median	min	mode	std
1	0.59	0.11	0.09	0	0.05	0.09	0.18	0.06	0.06	0	0.06	0.03
2	0.51	0.12	0.11	0	0.06	0.07	0.14	0.059	0.07	0.01	0.02	0.03
3	0.78	0.12	0.11	0	0.06	0.07	0.15	0.058	0.06	0.01	0.03	0.03
4	0.56	0.14	0.12	0	0.05	0.08	0.25	0.1	0.09	0.03	0.12	0.04
5	0.69	0.14	0.13	0.002	0.13	0.08	0.269	0.15	0.14	0	0.14	0.04
6	0.51	0.15	0.13	0	0.08	0.08	0.337	0.14	0.13	0	0.12	0.04
7	0.61	0.15	0.14	0	0.08	0.08	0.307	0.13	0.13	0	0.12	0.04
8	0.58	0.16	0.14	0	0.08	0.09						
9	0.63	0.16	0.15	0	0.16	0.09						
10	0.73	0.17	0.15	0.002	0.13	0.09						
11	0.81	0.18	0.16	0	0.1	0.09						

Table 45 Summary Statistics of IRI Data for Asphalt Pavements

Non-warranty (in/mi)							Warranty (in/mi)					
Yr	max	mean	median	min	mode	std	max	mean	median	min	mode	std
1	334.54	109.98	97.57	0.00	77.30	46.17	77.53	56.69	55.00	39.0	58.0	9.30
2	212.89	92.95	76.03	38.65	60.19	42.67	86.00	56.54	53.83	9.45	51.0	12.27
3	287.65	95.83	87.44	38.65	70.33	37.71	96.10	60.84	58.50	40.0	56.0	13.17
4	320.60	107.21	95.04	39.28	74.77	44.87	87.00	59.77	58.00	37.0	43.0	12.44
5	213.52	106.35	112.78	48.15	62.09	34.31	119.0	58.61	55.20	40.0	54.0	12.71
6	276.88	96.99	89.34	43.72	67.16	34.09	75.00	54.66	56.00	39.0	44.0	8.70
7	598.12	110.53	100.11	30.41	77.30	45.57	97.00	59.22	58.88	30.17	50.0	11.57
8	262.94	128.22	115.32	48.79	90.61	51.49						
9	274.98	97.24	91.24	43.72	81.73	31.19						
10	380.79	111.27	100.74	17.74	72.23	44.91						
11	186.91	113.02	117.22	67.80	90.61	27.06						

6.1.2 Surface Distress of Asphalt Pavement

This subsection presents the histograms, CDFs, and summary statistics of surface distress data collected from asphalt pavements with and without warranty. The corresponding percentile of each threshold value was determined from the CDFs of the distress data to evaluate its appropriateness. Since the non-warranty pavement data significantly outnumber the warranty pavement data and the distribution developed from a large sample size tends to be closer to its true population distribution, percentile values calculated from the non-warranty asphalt pavement data would be more informative. This argument holds also because as the natural benchmark control for the warranty pavements, the non-warranty pavement data should be used to determine the distress threshold levels for the warranty pavements.

The warranty distress items for asphalt pavements cover 9 distress types. The annual survey of the warranty pavements reports the values of all the 9 distress types. As for the non-warranty pavements, the data contained in MDOT's PMS cover all the warranty distress items except for "Potholes" after the data screening process. All the distress data presented herein is in the form of deduct points.

Figure 12 shows the histograms of the alligator cracking data from non-warranty asphalt pavements at 1-year, 3-year, 5-year, and 10-year and above service times. Although most of the data fall into the range of small deduct point value close to 0, a clear increase trend was observed over service time as more larger deduct point values were found and the right tail of the histogram extended to the right when the service time increased.

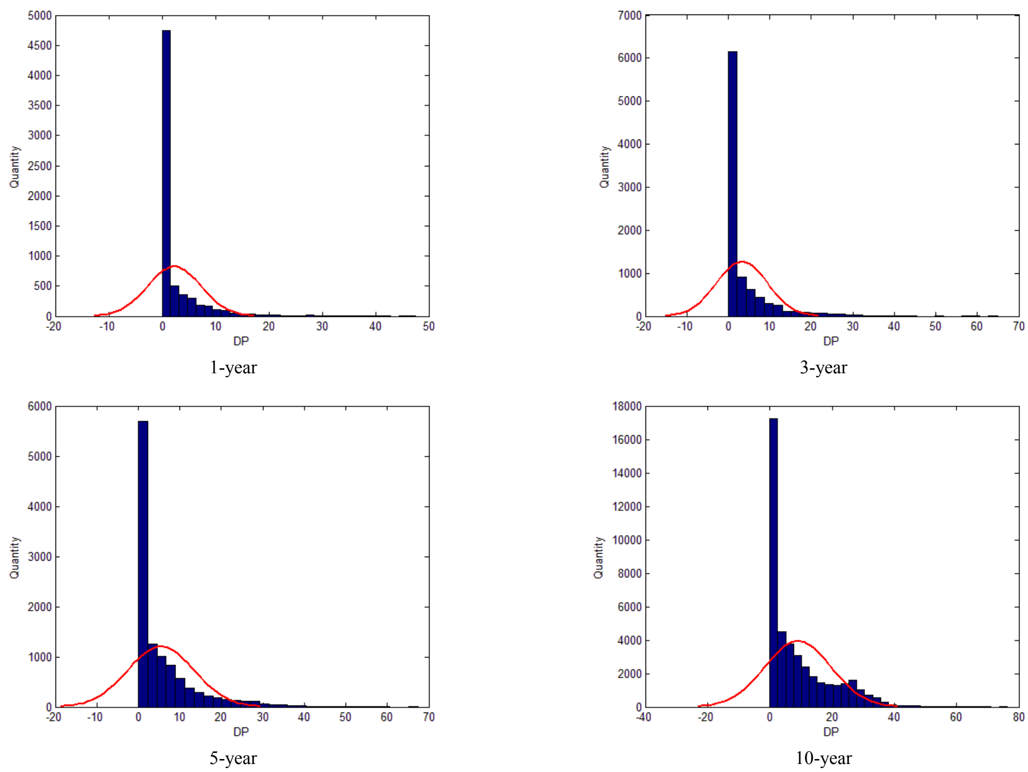


Figure 12 Histograms of Alligator Cracking Data from Non-Warranty Asphalt Pavements at Various Service Times

Similarly, Figure 13 shows the histograms of alligator cracking data for warranty asphalt pavements at service times from 1-year to 7-year. Clearly, the number of observations for the warranty pavements is much smaller than that of the non-warranty pavements. Most of the data are zero or close to zero, and larger deduct point numbers were only observed at service time of 7 years. Compared to the deduct point data for the non-warranty pavements, the deduct points for the warranty pavements are remarkably lower, indicating better performance of warranty asphalt pavements in terms of alligator cracking distress.

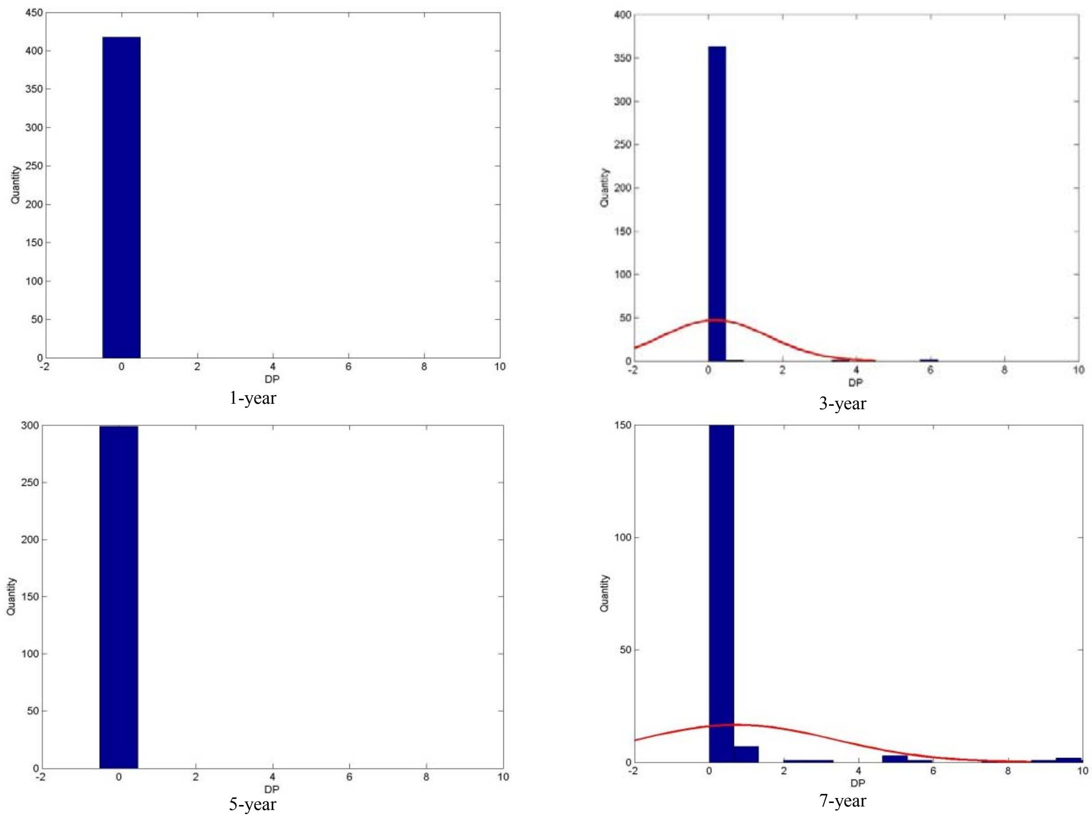


Figure 13 Histograms of Alligator Cracking Data from Warranty Asphalt Pavements at Various Service Times

Similar patterns were found for other warranty distress items of asphalt pavements. Generally, the deduct point values increase as the service time increases for both warranty and non-warranty asphalt pavements. However, at the same service time level, the deduct point values for warranty asphalt pavements are much lower than those of the non-warranty asphalt pavements.

Tables 46 and 47 present the summary statistics of the data for different warranty distress items for warranty and non-warranty asphalt pavements. It shows that for all warranty distress items, deduct point values of non-warranty asphalt pavements are generally higher than those of warranty pavements. Moreover, the distress data of non-warranty asphalt pavements have a more scattered distributed than that of warranty asphalt pavements, which can be reflected in the larger standard deviation (std) values from non-warranty pavements.

Table 46 Summary Statistics of Distress Deduct Points from Non-Warranty Asphalt Pavements

Num	Dis_Name	Item	Service Time (year)									
			1	2	3	4	5	6	7	8	9	10 and up
19	Alligator Cracking	max	47.6	64.9	64.9	86.8	67.4	66.6	57.9	65.9	65.9	76.2
		mean	2.3	2.9	3.3	4.4	5.5	6.0	5.8	6.8	7.8	9.0
		median	0.0	0.0	0.0	1.0	2.1	2.2	2.2	3.1	3.6	4.9
		min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		std	5.0	5.7	6.1	7.1	8.0	8.6	8.4	9.2	10.2	10.7
20	Block Cracking	max	36.8	40.4	36.8	47.8	42.7	40.8	41.7	43.3	59.7	49.4
		mean	7.8	8.3	7.5	8.6	9.6	9.6	10.6	10.0	10.7	12.0
		median	7.4	8.0	6.8	8.0	9.5	9.5	10.7	9.8	10.7	11.3
		min	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		std	6.0	6.6	5.7	7.0	7.3	7.3	7.8	7.7	8.0	8.6
21	Edge Cracking	max	17.9	19.3	16.1	24.8	21.1	28.9	20.4	15.4	16.6	25.4
		mean	1.3	1.2	1.3	1.4	1.7	1.4	1.3	1.5	1.3	2.0
		median	0.5	0.4	0.5	0.5	0.6	0.5	0.5	0.7	0.6	0.8
		min	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.1	0.0
		std	2.1	2.0	2.1	2.4	2.7	2.3	2.0	2.1	1.8	3.0
22	Longitudinal Cracking	max	178.8	415.6	463.2	1987.3	1827.6	1105.1	1063.5	1414.2	1781.7	1722.0
		mean	2.9	3.3	3.7	5.8	6.3	5.7	6.0	6.9	7.4	7.1
		median	1.7	2.1	2.2	2.6	2.8	3.0	3.0	3.3	3.3	3.7
		min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		std	5.4	6.8	9.8	35.2	43.1	24.0	22.6	37.7	43.4	31.2
23	Transverse Cracking	max	34.0	29.5	34.9	33.9	42.4	34.1	29.6	39.4	43.1	43.7
		mean	2.7	3.0	3.1	3.1	3.2	3.4	3.4	3.4	3.6	4.0
		median	1.6	1.7	1.7	1.8	1.7	1.8	1.9	1.8	1.9	1.9
		min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		std	3.0	3.3	3.5	3.6	3.7	4.0	3.9	4.0	4.2	4.8
28	Raveling & Weathering	max	27.8	27.8	27.9	27.8	27.9	28.7	11.2	27.9	27.9	27.9
		mean	4.3	5.4	4.6	4.1	4.6	5.2	3.3	4.7	4.6	4.4
		median	3.6	3.7	3.9	3.4	3.7	3.7	3.6	3.7	3.4	3.7
		min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		std	3.9	4.8	3.9	4.8	4.8	5.6	2.5	4.8	5.3	5.2
29	Bleeding	max	24.9	20.8	23.3	22.0	20.8	20.7	28.7	20.8	15.4	22.1
		mean	1.9	1.9	2.1	2.6	2.1	1.8	2.0	1.8	1.5	2.1
		median	0.8	0.9	1.0	1.6	1.0	0.8	1.4	1.0	0.7	1.5
		min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		std	2.5	2.2	2.7	3.1	2.4	2.2	2.1	2.4	2.0	2.5
30	Reflection Cracking	max	32.6	31.3	30.0	56.3	30.8	36.7	44.7	45.6	35.4	50.7
		mean	4.8	5.4	6.4	7.7	7.5	7.8	8.1	8.5	9.1	9.7
		median	4.6	5.9	6.4	7.8	7.7	7.9	8.2	8.8	9.8	10.0
		min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		std	4.2	4.1	5.0	5.2	5.4	5.6	5.9	6.0	5.8	6.1

Table 47 Summary Statistics of Distress Deduct Points from Warranty Asphalt Pavements

No	Distress	Item	Service Time (year)						
			1	2	3	4	5	6	7
19	Alligator Cracking	max	0	1.37	14.3	5.4	0	0	19.9
		mean	0	3.54E-3	1.85E-1	2.13E-2	0	0	7.29E-1
		median	0	0	0	0	0	0	0
		min	0	0	0	0	0	0	0
		std	0	6.96E-2	1.44	3.39E-1	0	0	2.63
20	Block Cracking	max	0	0	0	0	0	0	6.9
		mean	0	0	0	0	0	0	8.42E-2
		median	0	0	0	0	0	0	0
		min	0	0	0	0	0	0	0
		std	0	0	0	0	0	0	6.98E-1
21	Edge Cracking	max	0	0	0	0	0	0	0
		mean	0	0	0	0	0	0	0
		median	0	0	0	0	0	0	0
		min	0	0	0	0	0	0	0
		std	0	0	0	0	0	0	0
22	Long. Cracking	max	0	0	2	2.32	4.29	8.4	3.4
		mean	0	0	4.37E-2	1.80E-1	3.81E-1	4.37E-1	2.21E-1
		median	0	0	0	0	0	0	0
		min	0	0	0	0	0	0	0
		std	0	0	2.40E-1	4.50E-1	7.75E-1	1.11	5.75E-1
23	Trans. Cracking	max	0.9	0.4	2.5	7.4	11.04	5.8	4
		mean	1.10E-2	1.96E-3	1.22E-2	1.49E-1	3.91E-1	3.16E-1	1.69E-1
		median	0	0	0	0	0	0	0
		min	0	0	0	0	0	0	0
		std	7.69E-2	2.51E-2	1.34E-1	7.03E-1	1.05	8.12E-1	5.54E-1
27	Pothole	max	0.6	0	0.7	0	0	0	0
		mean	1.43E-3	0	4.58E-3	0	0	0	0
		median	0	0	0	0	0	0	0
		min	0	0	0	0	0	0	0
		std	2.93E-2	0	5.20E-2	0	0	0	0
28	Raveling & Weathering	max	0	0	1.4	0	0	0	0
		mean	0	0	3.77E-3	0	0	0	0
		median	0	0	0	0	0	0	0
		min	0	0	0	0	0	0	0
		std	0	0	7.27E-2	0	0	0	0
29	Bleeding	max	0	0	0.36	0	0	0	0
		mean	0	0	9.70E-4	0	0	0	0
		median	0	0	0	0	0	0	0
		min	0	0	0	0	0	0	0
		std	0	0	1.87E-2	0	0	0	0
30	Reflection Cracking	max	0	0	9.8	0	0	0	0
		mean	0	0	1.99E-1	0	0	0	0
		median	0	0	0	0	0	0	0
		min	0	0	0	0	0	0	0
		std	0	0	1.09	0	0	0	0

To examine the appropriateness of the distress thresholds, their corresponding percentiles were determined from the CDF of the distress data. Figure 14 presents the CDFs and the percentiles of the threshold value of 10 for alligator cracking from non-warranty asphalt pavements at different service times of 1-year, 3-year, 5-year, and 10-year and above. Usually the pavement surface condition deteriorates as the service time increases, and therefore, the distress deduct points value should increase over time. Accordingly, for a fixed threshold value, its corresponding percentile decreases with service time. This pattern is clearly shown in Figure 14, where the percentile of the threshold for alligator cracking drops from 93.55 to 66 as the service time increases from 1-year to 10-year and above. Based on the results from non-warranty asphalt pavement data, an 81st percentile for the threshold of alligator cracking at 5-year service is a fair criterion for deciding if a remedial action is needed to improve the pavement condition.

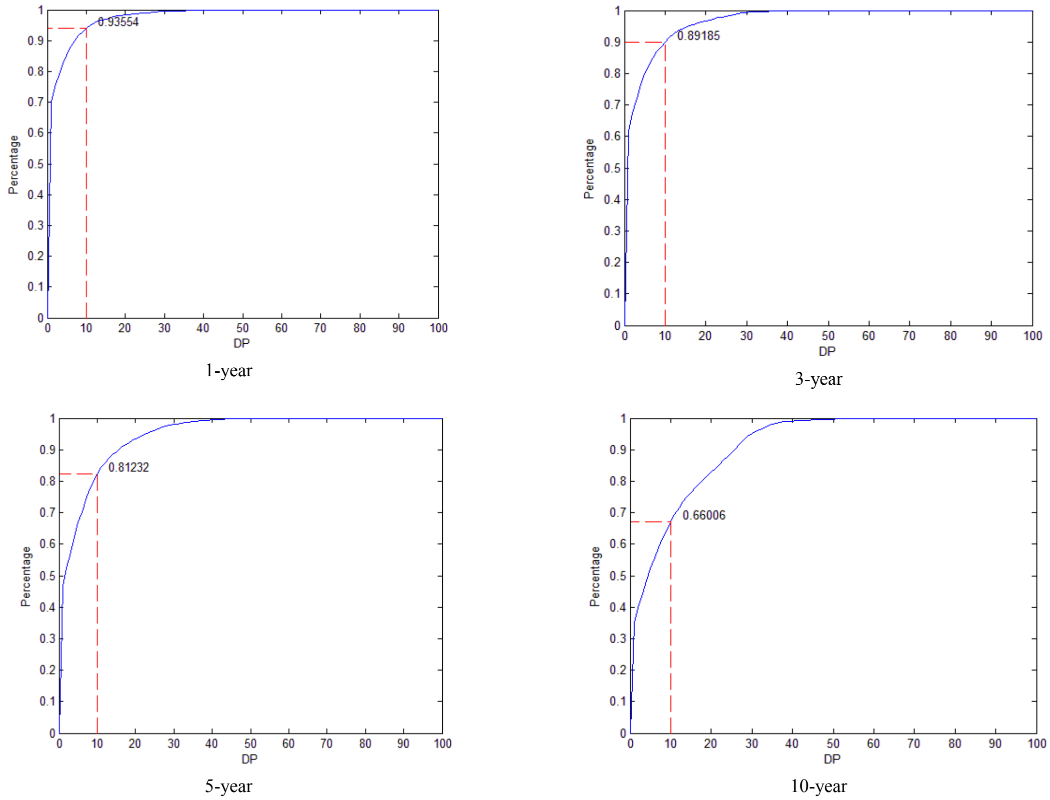


Figure 14 CDFs and Corresponding Percentiles of Threshold Value of 10 for Alligator Cracking from Non-Warranty Asphalt Pavements at Various Service Times

Similarly, Figure 15 shows the CDFs and the percentiles of the threshold value of 10 for alligator cracking from warranty asphalt pavements at various service times. Since most of the data are zeros, no convex CDF curve was obtained. Only the figure for the service time of 7-year barely shows a CDF curve. The corresponding percentile of the threshold value is 100 or approaching 100 during the service time from 1 to 5 years. The percentile number of 98.25 was obtained for the data collected at 7-year service, showing a slight deterioration trend of the pavements. The fact that a dominant majority of the asphalt warranty pavement sections meet the requirement for the distress of alligator cracking indicates either that the warranty asphalt pavements perform very well in terms of the distress item of alligator cracking or that the current threshold level for alligator cracking is a very loose control.

Tables 48 and 49 summarize the corresponding percentiles for the warranty asphalt pavement distresses calculated with data from warranty and non-warranty asphalt pavements respectively. It shows that under the current distress threshold criteria, the warranty pavements perform very well, given that over 95% of the pavement sections meet the threshold requirements for all distress types at all service times.

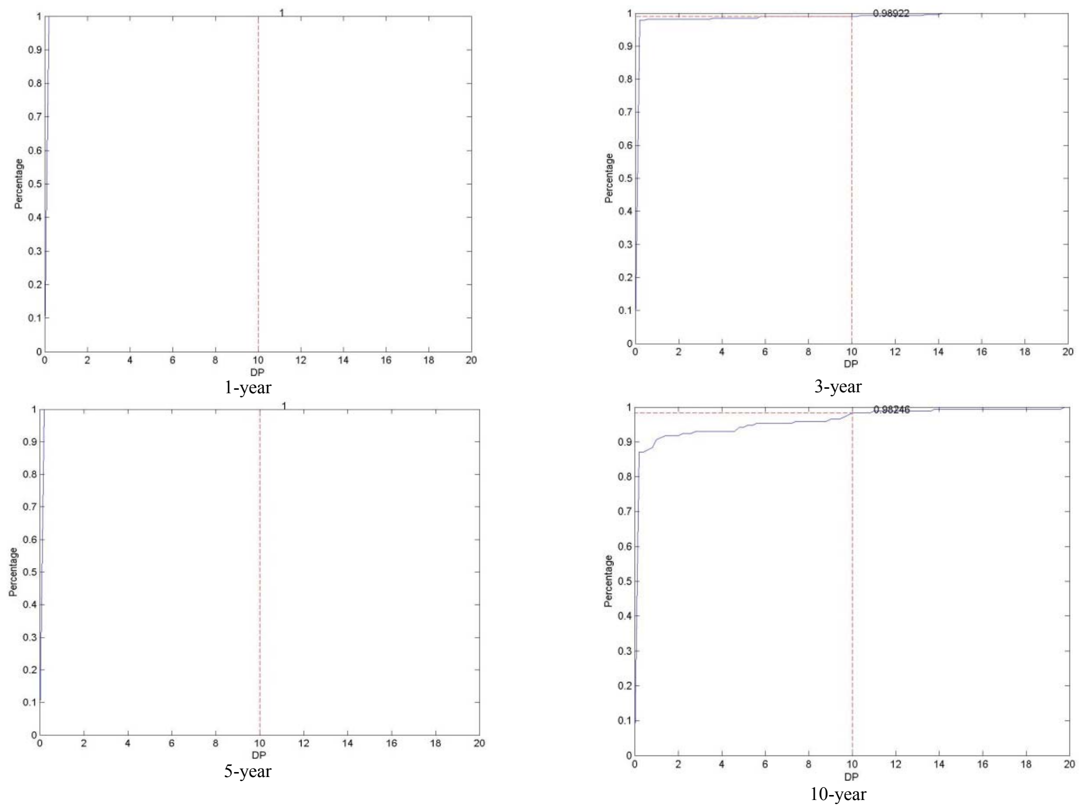


Figure 15 CDFs and Corresponding Percentiles of Threshold Value of 10 for Alligator Cracking Data from Warranty Asphalt Pavements at Various Service Times

Table 48 Percentiles of Warranty Distresses Calculated using Data from Asphalt Warranty Pavements

Num	Dis_name	Threshold	Service Year (percent)						
			1	2	3	4	5	6	7
19	Alligator Cracking	10	100.0	100.0	98.92	100.0	100.0	100.0	98.25
		15	100.0	100.0	98.92	100.0	100.0	100.0	99.42
20	Block Cracking	3	100.0	100.0	98.92	100.0	100.0	100.0	98.83
		5	100.0	100.0	98.92	100.0	100.0	100.0	98.83
21	Edge	3	100.0	100.0	98.92	100.0	100.0	100.0	100.0
22	Longitudinal Cracking	4	100.0	100.0	98.92	100.0	99.33	97.66	100.0
		6	100.0	100.0	98.92	100.0	100.00	99.22	100.0
23	Transverse Cracking	3	100.0	100.0	100.0	98.81	97.66	97.66	99.27
		5	100.0	100.0	100.0	99.21	99.33	99.61	100.0
27	Potholes	5	100.0	100.0	100.0	100.00	100.0	100.0	100.0
		12	100.0	100.0	100.0	100.0	100.0	100.0	100.0
28	Raveling & Weathering	0.2	100.0	100.0	99.73	100.0	100.0	100.0	100.0
		0.6	100.0	100.0	99.73	100.0	100.0	100.0	100.0
29	Bleeding	0.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0
30	Reflection	9	100.0	100.0	99.46	100.0	100.0	100.0	100.0

Table 49 Percentiles of Warranty Distresses Calculated using Data from Asphalt Non-Warranty Pavements

Num	Dis_Name	Threshold	Service Year (percent)									
			1	2	3	4	5	6	7	8	9	10
19	Alligator Cracking	10	93.55	90.72	89.19	85.40	81.23	78.29	78.92	75.31	72.20	66.01
		15	96.90	95.30	94.20	92.04	88.95	86.56	87.79	84.30	81.33	75.79
20	Block Cracking	3	26.79	28.01	27.62	25.11	21.40	22.06	19.09	21.63	18.34	16.00
		5	37.70	38.30	39.65	36.97	31.72	32.18	27.46	29.95	27.07	24.18
21	Edge Cracking	3	87.98	88.66	89.06	88.48	83.78	88.58	88.59	84.12	88.31	81.11
22	Longitudinal Cracking	4	75.09	70.42	69.18	64.16	62.63	60.00	59.36	57.27	56.37	53.03
		6	90.80	88.08	86.38	82.90	80.64	78.37	77.44	76.48	73.61	70.87
23	Transverse Cracking	3	70.58	67.44	66.22	65.95	65.85	64.38	64.29	65.37	63.61	61.13
		5	82.86	80.27	79.45	79.30	78.65	77.14	77.64	77.81	76.14	73.80
28	Raveling & Weathering	0.2	4.71	4.52	5.80	8.21	7.79	7.20	7.36	6.16	5.68	6.90
		0.6	8.27	7.94	9.31	14.01	12.99	15.68	12.12	9.95	11.74	15.18
29	Bleeding	0.4	89.12	90.18	89.38	84.31	90.65	89.54	95.38	94.46	93.23	90.12
30	Reflection Cracking	9	87.99	84.82	74.23	60.96	60.83	58.30	56.64	51.95	44.81	43.45

However, the percentile results from non-warranty asphalt pavement data shows heavy inconsistency regarding the distress threshold levels. Although the percentile number drops as the service time increases, the percentile levels for different types of distress vary significantly at the same service time level. For instance, the percentile for distress of raveling & weathering is under 10 at 1-year service, while the percentile for distress of alligator cracking is over 90 at the same service time. The heavy inconsistency is observed at all service time levels. For better management of the warranty pavements, consistent threshold levels should be implemented for all distress types. The threshold levels recommended by the research team are 60th and 80th percentile for tight and loose levels of control respectively.

For distresses numbers 19, 20, 22, 23, and 28, dual threshold levels were defined in the current criteria. However, the corresponding percentiles of those dual-level thresholds for the warranty pavements show marginal difference. This indicates the dual-level threshold control does not work as expected, and therefore, for future pavement warranty implementation, single threshold level would be suggested to replace the dual threshold level for simplicity.

6.1.3 **Surface Distress of Concrete Pavement**

The warranty distress items for concrete pavements contain 11 distress types. The annual survey of the warranty pavement reports the values of all the 11 distress types. As for the non-warranty pavements, MDOT's PMS only has valid data for 5 types of the warranty distress items after the data screening process. All the distress data presented herein are in the form of deduct points.

Figure 16 presents the histograms of the deduct points data of Longitudinal cracking from non-warranty concrete pavements at 4 different service times. Compared to the data from non-warranty asphalt pavements, the amount of data from non-warranty concrete pavements is much less abundant. As shown in Figure 16, the increase trend is not remarkable as service time extends from 1-year to 5-year. A very heavy right tail with larger deduct point values appears at service time of 10 years and above.

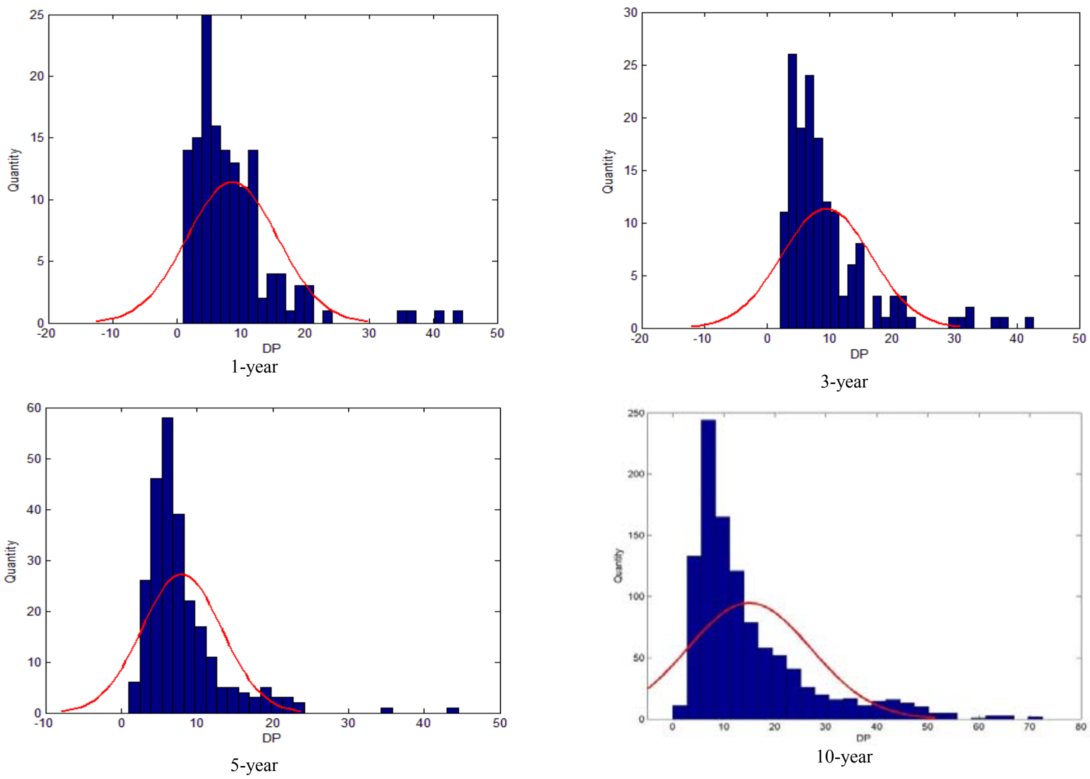


Figure 16 Histograms of Longitudinal Cracking Data from Non-Warranty Concrete Pavements at Various Service Times

Figure 17 shows the histograms of the deduct point data of longitudinal cracking from warranty concrete pavements at various service times. Due to the high frequency of zeros, no distribution curve was developed for the deduct points data at service times from 1 year to 3 years. Non-zero data were only observed after 5-year service, indicating good performance of the warranty concrete pavements in terms of the distress of longitudinal cracking within the first several years after being open to traffic. Comparing the histograms of the data from warranty and non-warranty concrete pavements, it clearly shows better performance of warranty concrete pavements, which is consistent to the observation from the histograms for asphalt pavements.

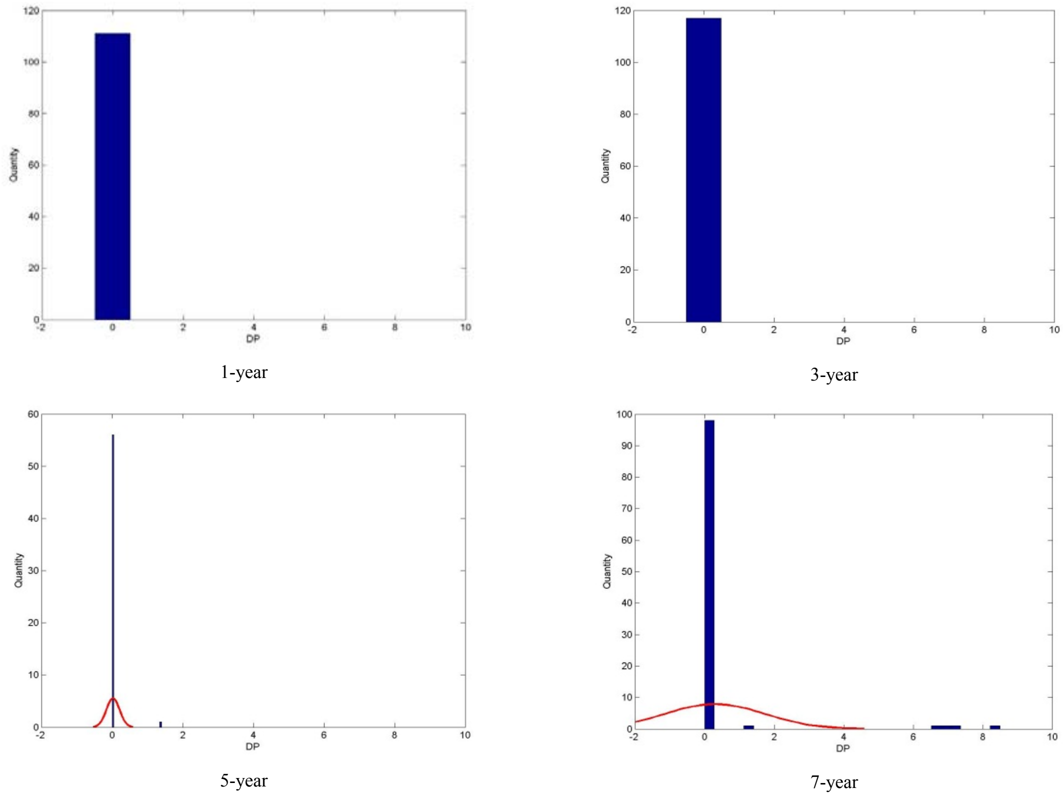


Figure 17 Histograms of Longitudinal Cracking Data from Warranty Concrete Pavements at Various Service Times

Similar patterns were observed for histograms of other warranty distress items for concrete pavements. Generally, the deduct point value increases as the service time increases for both warranty and non-warranty concrete pavements. However, at the same service time level, the deduct point values for warranty concrete pavements are much lower than those of the non-warranty concrete pavements.

Tables 50 and 51 present the summary statistics of the warranty distress item data for warranty and non-warranty concrete pavements. Cells with splash mean no valid data were obtained for certain type of distress at certain service time. Most of the statistic values for warranty pavements are zeros or close to zeros. It clearly shows that for the warranty distress items commonly contained by both warranty and non-warranty pavements, deduct point values of non-warranty concrete pavements are generally higher than those of warranty pavements. Moreover, the data from non-warranty concrete pavements have a more scattered distributed than that from warranty concrete pavements, which can be reflected in the larger standard deviation (std) values from non-warranty pavements. This may result from the larger dataset of the non-warranty pavements, the inconsistent QA/QC processes during the construction of the non-warranty pavements, or the various traffic volumes and structural capacities of the non-warranty pavement sections.

Table 50 Summary Statistics of Distress Deduct Points from Non-Warranty Concrete Pavements

Dis_Num	Dis_Name	Item	Service Time (year)									
			1	2	3	4	5	6	7	8	9	10 and up
0	Longitudinal Cracking	max	44.62	44.62	42.68	50.50	44.51	67.15	44.57	50.54	28.84	83.57
		mean	8.71	8.71	9.55	13.12	8.00	9.82	10.39	11.45	10.46	14.98
		median	6.90	6.90	7.14	9.85	6.54	7.02	8.43	9.93	8.14	10.78
		min	1.00	1.00	2.11	0.48	1.00	1.00	2.77	2.26	2.11	0
		std	7.07	7.07	7.18	10.41	5.27	9.11	7.06	7.57	6.09	12.11
1	Transverse Cracking	max	67.68	16.81	36.32	48.17	16.89	28.10	31.08	64.14	15.52	51.23
		mean	3.24	3.76	3.15	5.06	3.08	3.97	2.85	4.42	2.83	4.36
		median	1.18	1.70	1.70	1.70	1.65	2.88	1.18	1.70	1.70	2.54
		min	0	0	0	0	0	0	0	0	0	0
		std	6.27	3.88	4.62	7.58	3.75	4.34	4.36	6.97	3.35	5.95
10	Spalling of Longitudinal Joints	max	11.15	1.97	2.58	9.92	8.22	11.15	3.50	3.40	6.58	15.48
		mean	4.12	0.91	0.79	4.45	2.09	3.60	1.18	1.26	1.36	2.07
		median	1.32	0.71	0.42	2.20	1.39	1.39	0.88	0.91	0.71	0.96
		min	0.21	0.25	0.27	0.72	0.29	0.33	0.34	0.26	0.37	0.22
		std	4.70	0.74	0.80	3.89	1.98	4.05	1.00	0.92	1.73	2.93
11	Spalling of Transverse Joints	max	13.47	13.43	13.47	23.36	1.86	7.72	34.63	15.44	4.53	17.63
		mean	1.00	1.80	0.95	6.30	1.45	1.19	2.25	1.57	0.52	1.51
		median	0.12	0.36	0.07	2.49	0.07	0.59	0.07	0.04	0	0.35
		min	0	0	0	0	0	0	0	0	0	0
		std	2.30	3.09	2.07	7.95	2.48	1.64	6.12	2.89	0.96	2.70
12	Map Cracking & Scaling	max	6.86	12.69	6.85	10.75	11.92	0.87	5.62	28.59		13.31
		mean	2.22	2.69	4.21	5.82	2.55	0.72	5.60	6.31		2.88
		median	1.08	1.90	4.21	5.82	0.90	0.73	5.60	3.03		1.49
		min	0.57	0.09	1.57	0.90	0.58	0.57	5.57	0.59		0.57
		std	2.33	3.08	3.73	6.96	3.44	0.15	0.03	7.10		3.16

Table 51 Summary Statistics of Distress Deduct Points from Warranty Concrete Pavements

Dis_Num	Dis_Name	Item	Service Time (year)						
			1	2	3	4	5	6	7
0	Longitudinal Cracking	max	0	0	0	0	1.4	6.898	8.5
		mean	0	0	0	0	0.024561	0.32125	0.297087
		median	0	0	0	0	0	0	0
		min	0	0	0	0	0	0	0
		std	0	0	0	0	0.185435	1.354464	1.432087
1	Transverse Cracking	max	0	0	0	0	0.6		
		mean	0	0	0	0	0.014035		
		median	0	0	0	0	0		
		min	0	0	0	0	0		
		std	0	0	0	0	0.083321		
5	Faulting of Transverse Joints	max	0	0	1.9	0	0	0	0
		mean	0	0	0.040171	0	0	0	0
		median	0	0	0	0	0	0	0
		min	0	0	0	0	0	0	0
		std	0	0	0.217771	0	0	0	0
7	Corner Breaks	max	0	1.5	1.5	0	0	2.322	27.8
		mean	0	0.012821	0.012821	0	0	0.052773	1.365049
		median	0	0	0	0	0	0	0
		min	0	0	0	0	0	0	0
		std	0	0.138675	0.138675	0	0	0.350055	3.558825
9	Joint Seal Damage	max	0	0	0	0	0.4	0	0
		mean	0	0	0	0	0.007018	0	0
		median	0	0	0	0	0	0	0
		min	0	0	0	0	0	0	0
		std	0	0	0	0	0.052981	0	0
10	Spalling of Longitudinal Joints	max	0	0	0	0	0	0	1.3
		mean	0	0	0	0	0	0	0.029126
		median	0	0	0	0	0	0	0
		min	0	0	0	0	0	0	0
		std	0	0	0	0	0	0	0.164871
11	Spalling of Transverse Joints	max	0	0.7	0.3	1.7	1.8	0.229	4.3
		mean	0	0.005983	0.007692	0.087234	0.092982	0.015614	0.175728
		median	0	0	0	0	0	0	0
		min	0	0	0	0	0	0	0
		std	0	0.064715	0.047623	0.296807	0.278939	0.054174	0.566978
12	Map Cracking & Scaling	max	0	0	0	0	0	0	0
		mean	0	0	0	0	0	0	0
		median	0	0	0	0	0	0	0
		min	0	0	0	0	0	0	0
		std	0	0	0	0	0	0	0
0*	Longitudinal Cracking	max	0	0	0	4.6	5.1		
		mean	0	0	0	0.097872	0.175439		
		median	0	0	0	0	0		
		min	0	0	0	0	0		
		std	0	0	0	0.670979	0.928378		
1*	Transverse Cracking	max	0	0	0	0	0	0.651	4
		mean	0	0	0	0	0	0.014795	0.067961
		median	0	0	0	0	0	0	0
		min	0	0	0	0	0	0	0
		std	0	0	0	0	0	0.098142	0.430962
NA	#of slabs broken in 4 or more pieces	max	0	0	0	0	0	0	0
		mean	0	0	0	0	0	0	0
		median	0	0	0	0	0	0	0
		min	0	0	0	0	0	0	0
		std	0	0	0	0	0	0	0

*Note: Data items marked as "multiple cracks" with different threshold values from distresses 0 and 1, respectively (See Table 53).

Furthermore, the CDFs of the concrete pavement distress data were developed and the corresponding percentiles for the current distress threshold values were determined from the CDFs to examine their appropriateness. Figure 18 presents the CDFs and the percentiles of the threshold value of 0.96 for longitudinal cracking from non-warranty concrete pavements at various service times of 1-year, 3-year, 5-year, and 10-year and above. It shows that the percentile values at different service time levels are all close to zero. These extremely low percentile values indicate an extremely tight threshold control over the distress type of longitudinal cracking in concrete pavements.

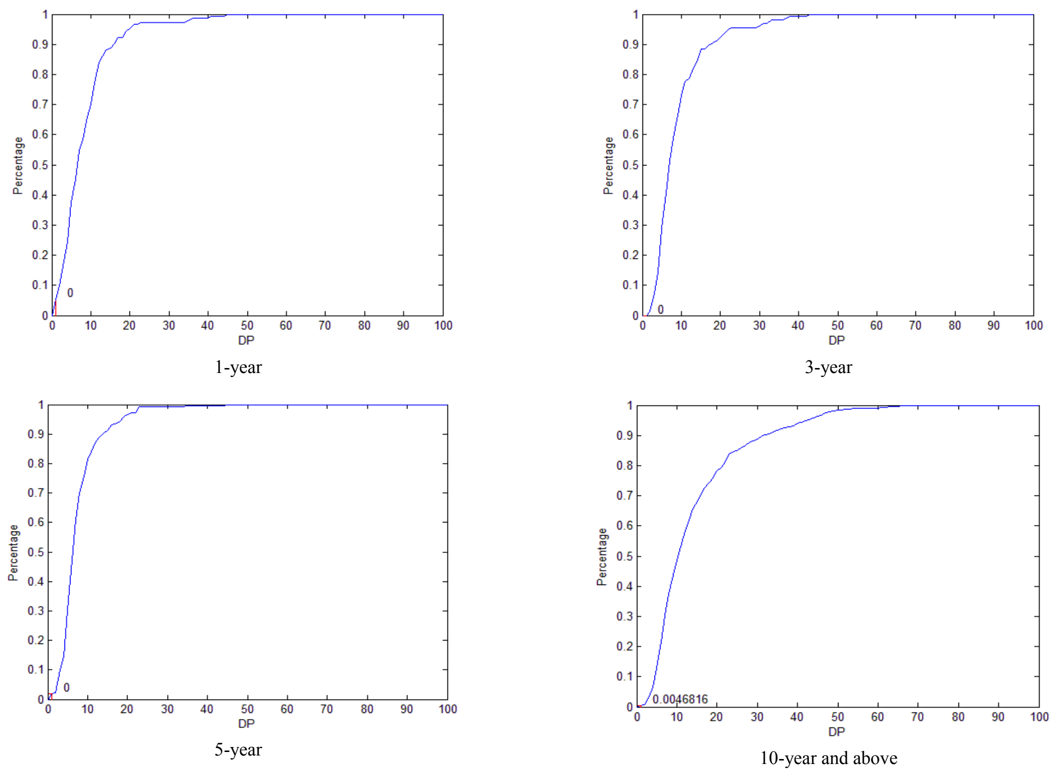


Figure 18 CDFs and Corresponding Percentiles of Threshold Value of 0.96 for Longitudinal Cracking for Non-Warranty Concrete Pavements at Various Service Times

Figure 19 presents the CDFs and threshold percentiles of longitudinal cracking data from warranty concrete pavements. It shows the opposite to the observation from the CDFs and percentiles of the non-warranty pavement data. The corresponding percentiles to the longitudinal cracking threshold are almost 100 at all service time levels. Although the non-warranty pavement data show a very tight threshold for longitudinal cracking, all the surveyed warranty pavement sections met the requirement at up to 5 years of service. Even at 7-year service, over 95% of the pavement sections met the longitudinal cracking threshold requirement.

The warranty and non-warranty pavement construction follow the same standards and procedure, the only difference lies in that one is under warranty and the other is not. However, the percentiles of the same threshold indicate two extreme ends at the percentile scale for the warranty and non-warranty pavements, which implies that the QA/QC procedure implemented during the pavement construction was not tight enough for the non-warranty concrete pavements to control and ensure the pavement quality. Under current construction technology level, there is much room to improve the concrete pavement performance. Simply taking cautions during the construction can result in end products of better performance and quality.

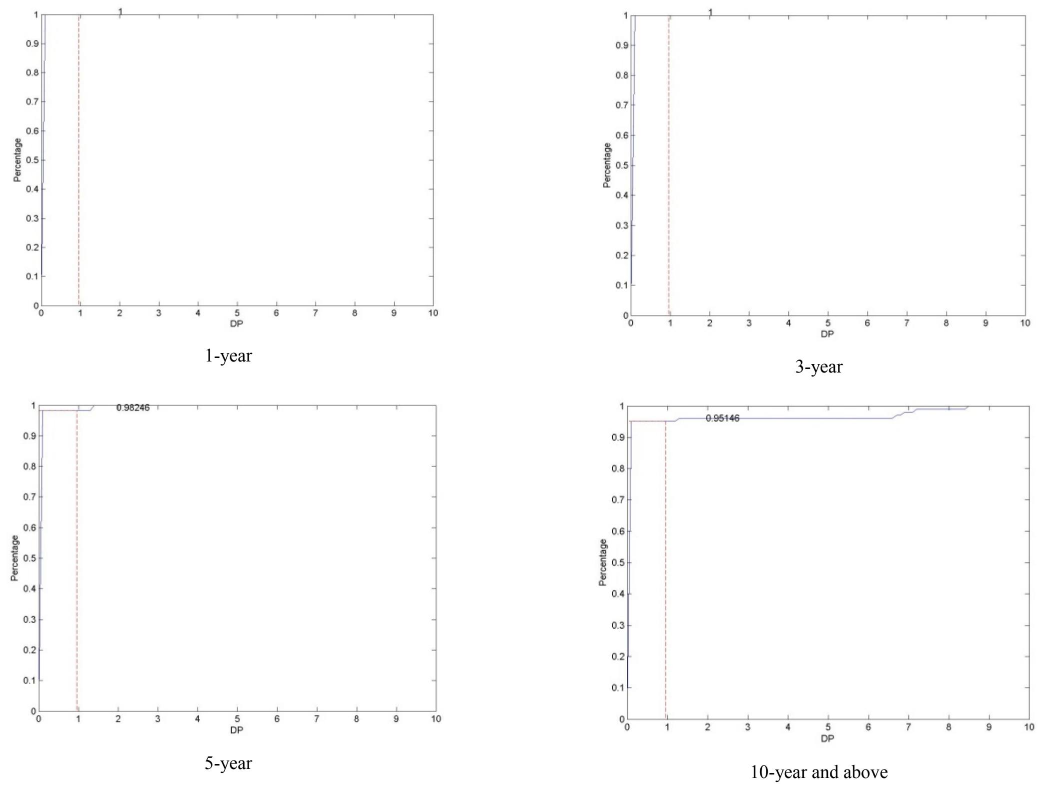


Figure 19 CDFs and Corresponding Percentiles of Threshold Value of 0.96 for Longitudinal Cracking Data from Warranty Concrete Pavements at Various Service Times

Tables 52 and 53 summarize the corresponding percentiles for the warranty distress thresholds calculated using data from warranty and non-warranty concrete pavements respectively. Similar patterns to the data from asphalt pavements were found for the concrete pavement data. Under the current distress threshold criteria, most of the warranty pavements meet the requirements, with all the threshold percentile values for warranty pavement are 100 or near 100.

Similarly, large inconsistencies in the distress threshold levels obtained from non-warranty concrete pavements were observed. Although the percentile value drops as the service time increases, the percentile levels for different types of distress vary significantly at the same service time level. Heavily inconsistent percentile values were observed at all service time levels. For better management of the warranty pavements, consistent threshold levels would be suggested by the research team to be implemented for all distress types. Again, the threshold levels recommended by the research team are 60th and 80th percentile for tight and loose levels of control respectively.

Table 52 Percentiles of Distress Thresholds Calculated using Data from Non-Warranty Concrete Pavements

Dis_Num	Dis_Name	Thres-hold	Service Year (percent)									
			1	2	3	4	5	6	7	8	9	10
0	Longitudinal Cracking	0.96	5.56	0.00	0.00	2.33	0.00	0.00	0.00	0.00	0.00	0.47
1	Transverse Cracking	0.75	34.23	19.05	29.71	19.55	35.51	15.65	31.16	23.53	31.64	19.91
10	Spalling of Longitudinal Joints	0.29	6.67	25.00	8.33	0.00	0.00	0.00	0.00	3.33	0.00	5.74
11	Spalling of Transverse Joints	0.29	85.71	72.41	85.39	42.86	74.05	70.69	77.78	71.43	93.48	75.13
12	Map Cracking & Scaling	1.77	63.64	42.86	50.00	50.00	61.90	100.00	0.00	33.33		61.54

Table 53 Percentiles of Distress Thresholds Calculated using Data from Warranty Concrete Pavements

Dis_Num	Dis_Name	Threshold	Service Year (percent)						
			1	2	3	4	5	6	7
0	Longitudinal Cracking	0.96	100.0	100.0	100.0	100.0	98.25	93.18	95.15
1	Transverse Cracking	0.75	100.0	100.0	100.0	100.0	100.0		
5	Faulting of Transverse Joints	1.75	100.0	100.0	99.15	100.0	100.0	100.0	100.0
7	Corner Breaks	2.32	100.0	100.0	100.0	100.0	100.0	97.73	83.50
9	Joint Seal Damage	1.66	100.0	100.0	100.0	100.0	100.0	100.0	100.0
10	Spalling of Longitudinal Joints	0.29	100.0	100.0	100.0	100.0	100.0	100.0	97.09
11	Spalling of Transverse Joints	0.29	100.0	99.15	97.44	87.23	92.98	100.0	88.35
12	Map Cracking & Scaling	1.77	100.0	100.0	100.0	100.0	100.0	100.0	100.0
0*	Longitudinal Cracking	1.63	100.0	100.0	100.0	97.87	96.49		
1*	Transverse Cracking	1.75	100.0	100.0	100.0	100.0	100.0	100.0	99.03
NA	#of slabs broken in 4 or more pieces	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0

*Note: Data items marked as "multiple cracks" with different threshold values from distresses 0 and 1, respectively.

6.2 Pairwise Comparison

To test whether the difference in pavement performance is statistically significant over time, pairwise comparisons were conducted in the section. The comparison of performance indicator data over time reveals the deterioration pattern of the pavement condition, which could be used to compare the performance of warranty and non-warranty pavements in short and long terms.

6.2.1 **Rut and IRI**

Figure 20 presents the pairwise comparison results for rut data collected from both warranty and non-warranty asphalt pavements. The horizontal lines in the figure are the confidence intervals of each group. Two groups are significantly different if their corresponding confidence interval lines are not overlapped. A significant level of 0.05 was used in the study.

It shows in Figure 20 that the rut after 2-year service is significantly higher than that in the first year of service for non-warranty pavements, which means the pavement deteriorated rapidly after the new construction and rehabilitation. On the other hand, rut has no significant change within the first three years for warranty pavement. Compared to the rut collected in the first few years, significant increase in rut depth is not observed until year 4 for warranty pavements.

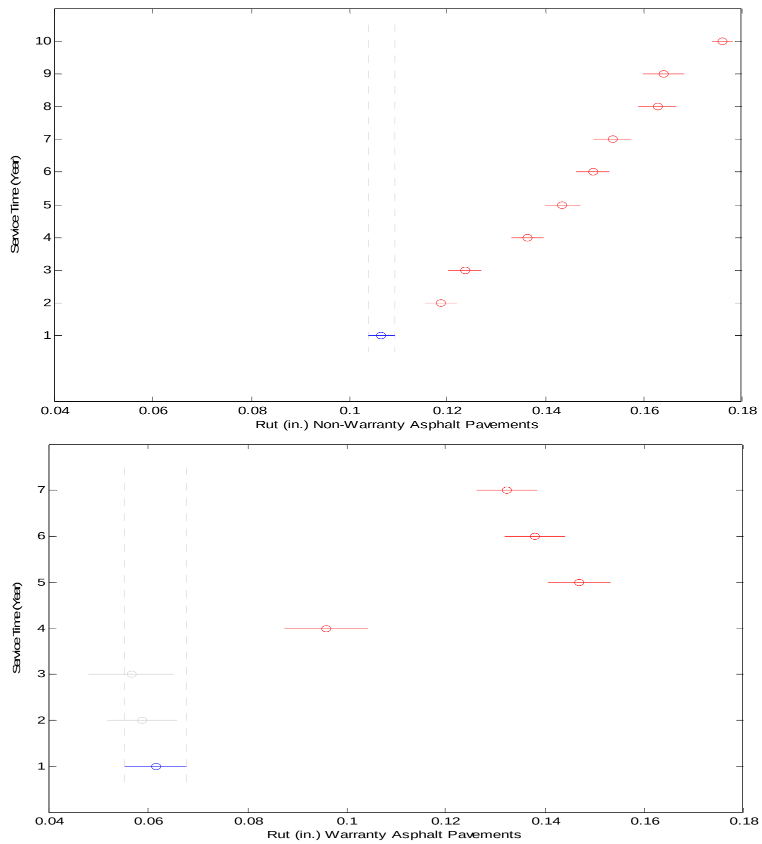


Figure 20 Pairwise Comparison of Rut at Different Service Times for Warranty and Non-Warranty Asphalt Pavements

The pairwise comparison results of IRI for asphalt pavements are presented in Figure 21. Similar to the rut data, the IRI measurements for warranty asphalt pavements are consistently lower than those of the non-warranty asphalt pavements. Remarkably, the IRI value of non-warranty asphalt pavements in the first year is even higher than that of warranty asphalt pavements in the seventh year. Moreover, the drop in ride quality for non-warranty asphalt pavements is faster than the warranty asphalt pavements, which is reflected in the fact that a significant increase in IRI from the measurement of non-warranty pavement in the first year was found at year 3, while for warranty pavements the significant increase was observed after 4 years of service. The large ranges of IRI data confidence interval for warranty asphalt pavements compared to that of the non-warranty asphalt pavements is due to the significant lower number of data from warranty asphalt pavements.

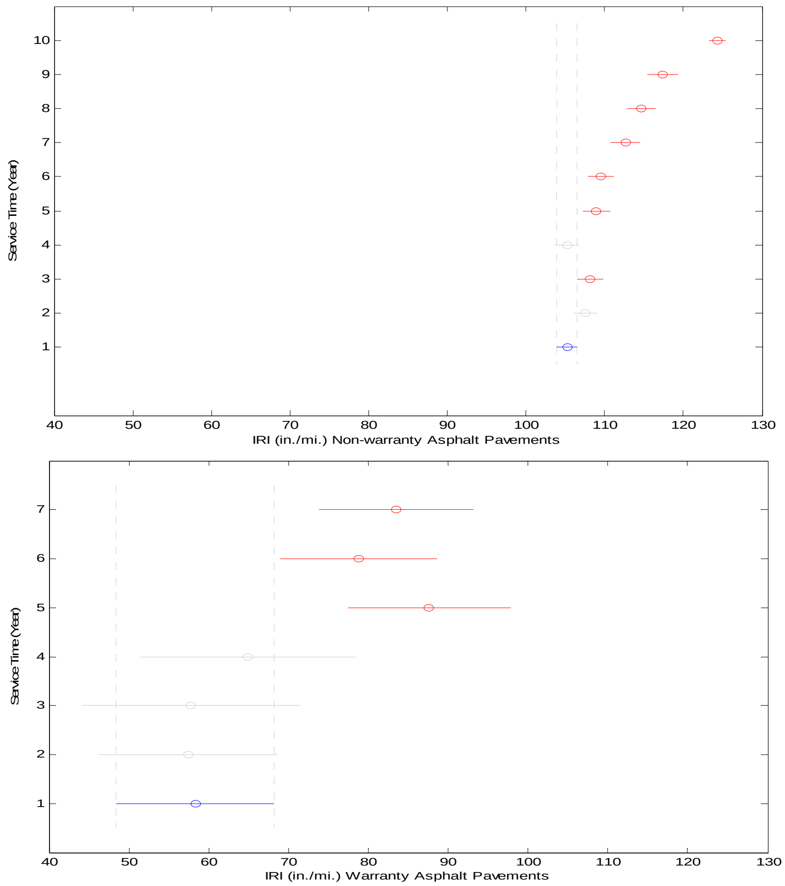


Figure 21 Pairwise Comparison of IRI at Different Service Times for Warranty and Non-Warranty Asphalt Pavements

Similarly, the pairwise comparison results for rut and IRI collected from warranty and no-warranty PCC pavements are presented in Figure 22 and Figure 23. The rut of warranty pavements is remarkably lower than that of non-warranty pavements, although no steady increase trend in rutting was found for either warranty or non-warranty concrete pavements. The rut data distributions at 1 to 7 years of service times are all statistically similar for warranty concrete pavement projects, while for non-warranty concrete pavements the rut data distributions at various service year times are all similar to that of year 1, except for the data collected at years 4 and 6. Additionally, it is noted that the rut measurements for both warranty and non-warranty concrete pavements are less than 0.1 in. These indicate that rut may not be an important distress type for concrete pavements and is of only marginal significance in evaluating the performance of concrete pavements.

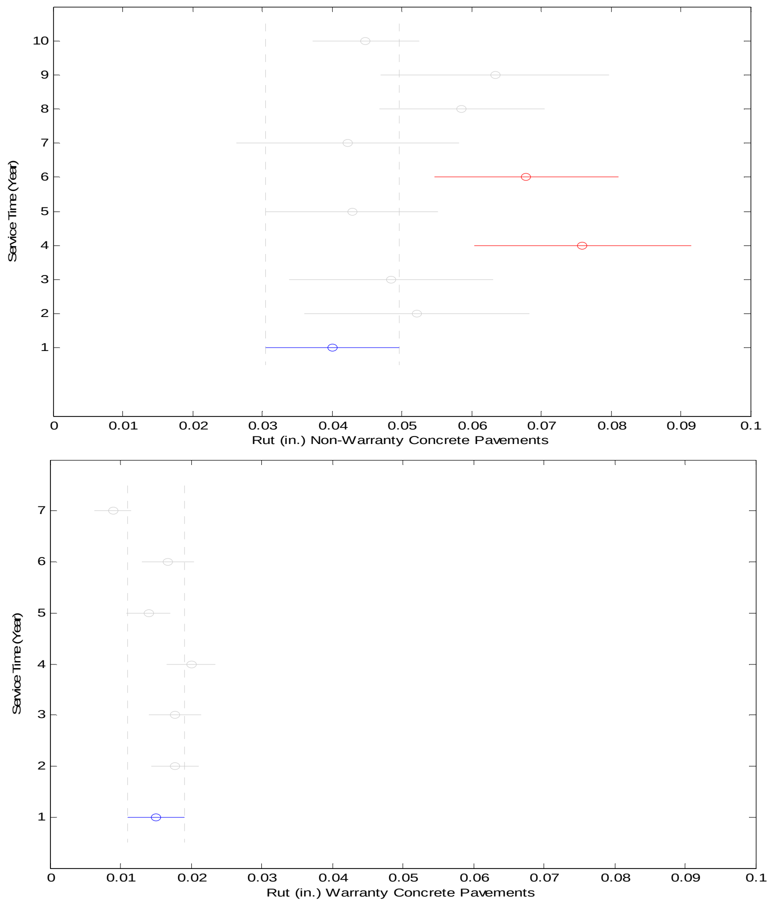


Figure 22 Pairwise Comparison of Rut at Different Service Times for Warranty and Non-Warranty Concrete Pavements

Unlike the rut data, the IRI measurements collected from both warranty and non-warranty concrete pavements show a clear increase pattern over service time. Similar to the IRI from asphalt pavements, the IRI measurements of warranty concrete pavements after 7-year service are even lower than those of the newly constructed non-warranty concrete pavements. In addition, the drop of riding quality for non-warranty concrete pavements is much faster than warranty concrete pavements. As shown in Figure 23, the significant increase in IRI was immediately found in service year 2 and afterwards except for years 3 and 6, while the IRI measurements for warranty concrete pavements remain at the low level as the new pavement until after 6-year service.

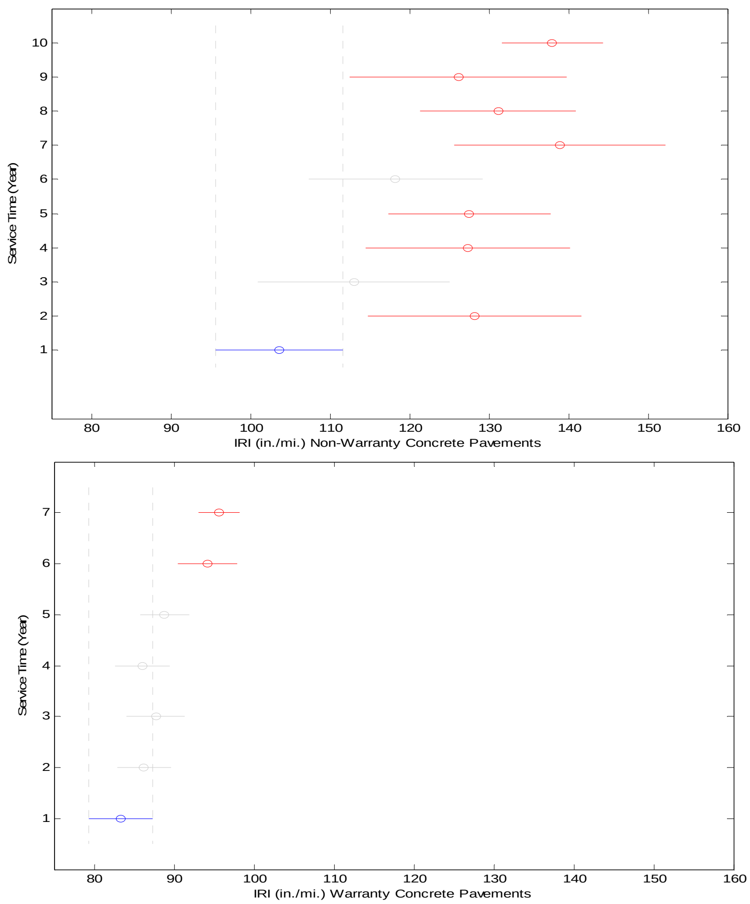


Figure 23 Pairwise Comparison of IRI at Different Service Times for Warranty and Non-Warranty Concrete Pavements

The pairwise comparison results show that the rut and IRI measurements of warranty pavements are consistently lower than those of non-warranty pavements, regardless of the pavement type. Particularly for the IRI data, the measurements of the warranty projects after several years of service are even lower than those of the new non-warranty projects. Moreover, it indicates that the increases in rutting of asphalt non-warranty pavements and in IRI of non-warranty projects for both pavement types are much faster than those in their warranty control pavements. Given the small values of rut measurements and the slow rate of change over service time, rutting should not be considered an important distress type for concrete pavements and should not be paid much attention in evaluating the performance of concrete pavements. Based on the pairwise comparison results above, it is concluded that the pavements under a warranty perform better at the beginning of the service and can maintain at a high performance level for longer time than pavements without a warranty.

6.2.2 **Surface Distress of Asphalt Pavement**

Figure 24 presents the pairwise comparison results of deduct point data of alligator cracking for warranty and non-warranty asphalt pavements. It shows that the deduct points of alligator cracking data for the warranty pavements are remarkably lower than those of the non-warranty pavements. The deduct points for warranty asphalt pavements after 7 years of service are even lower than the deduct points for non-warranty asphalt pavements after only 1 year of service. This indicates a much better performance of warranty asphalt pavements than non-warranty asphalt pavements in terms of alligator cracking.

As for the evolvement of alligator cracking, a distinct increase trend was observed for the deduct point data from non-warranty asphalt pavements, while no increase trend was found for deduct point data from warranty asphalt pavements. Moreover, the figure shows that the deduct point data for non-warranty asphalt pavements at 2 years and over 2 years of service are significantly larger than that at 1 year of service, implying the pavements deteriorate rapidly after being open to traffic for 1 year. On the contrary, the alligator cracking only has significant development after 6 years of service for warranty pavements, as shown in Figure 24. This implies that the warranty asphalt pavements maintain high levels of performance for longer time than non-warranty asphalt pavements. The pairwise comparison results are consistent with the results from rut and IRI data analysis.

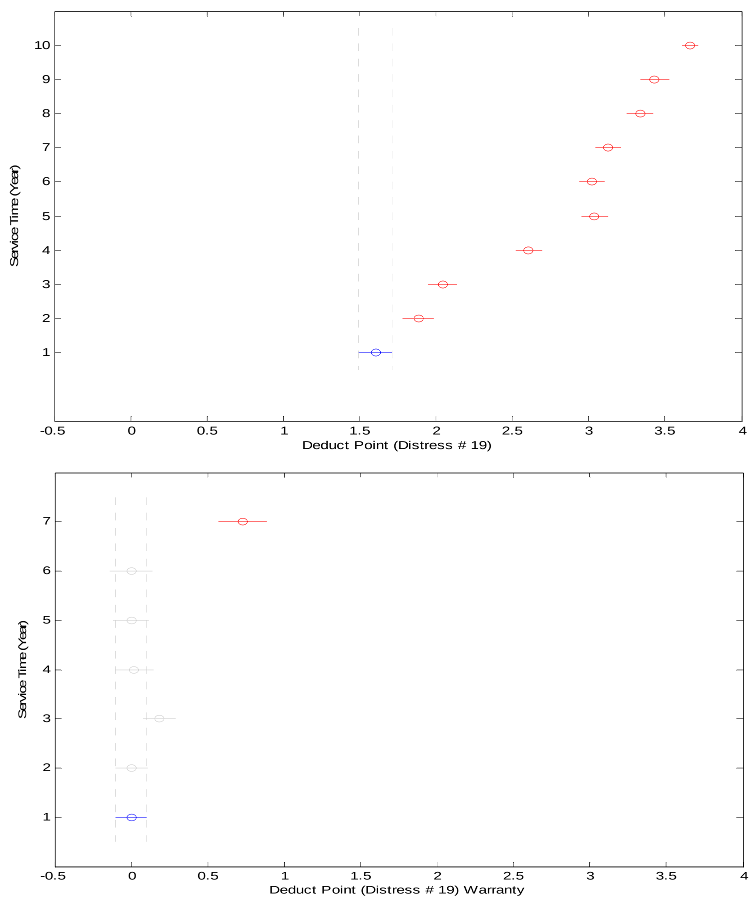


Figure 24 Pairwise Comparison of Alligator Cracking at Different Service Times for Warranty and Non-Warranty Asphalt Pavements

Similar patterns were found for the pairwise comparison results of other distress types for asphalt pavements. Consistently, the distress measurements for non-warranty asphalt pavements are larger than those from warranty asphalt pavements at the same service years. Moreover, the non-warranty asphalt pavements deteriorate much faster than warranty asphalt pavements. The above findings are consistent with the results from rut and IRI data analysis.

6.2.3 Surface Distresses of Concrete Pavement

Figure 25 presents the pairwise comparison results of longitudinal cracking data from both warranty and non-warranty concrete pavements. The same patterns obtained from rut, IRI, and asphalt pavement distress data were confirmed by the concrete pavement distress data. The deduct point values of longitudinal cracking data from warranty concrete pavements after 7-year service is even significantly lower than those from non-warranty concrete pavements only after 1 year of service. Also, the non-warranty concrete pavements deteriorate much faster than the warranty concrete pavements. As shown in Figure 25, the longitudinal cracking for non-warranty concrete pavements has significantly increased only after 3 years of service, while for warranty concrete pavements the significant increase was only found after 7 years.

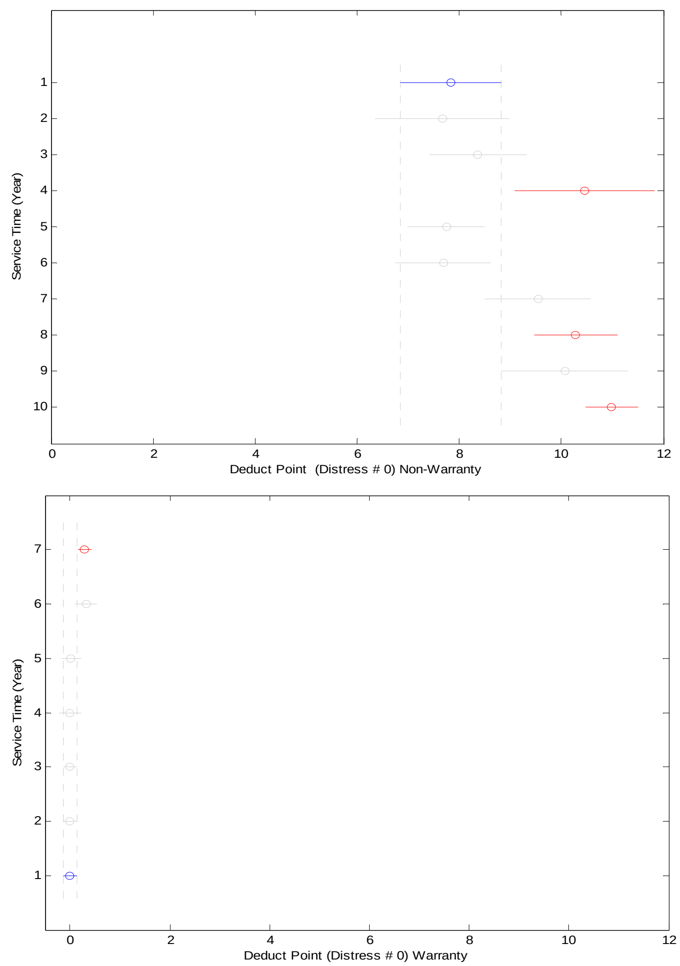


Figure 25 Pairwise Comparison of Longitudinal Cracking at Different Service Times for Warranty and Non-Warranty Concrete Pavements

Similar patterns were observed from the pairwise comparison results for other concrete pavement distresses. To sum up the pairwise comparison results from rut, IRI, asphalt pavements distresses, and concrete pavement distresses, the performance of warranty pavements is significantly better than that of non-warranty pavements at the same service time level and warranty pavements can maintain at high service levels for longer times than non-warranty pavements. The pairwise comparison results exhibit that the warranty program adopted by MDOT is effective in improving riding quality, pavement surface deformation, and surface distresses.

6.3 Two-Sample T-Test

To test whether the differences in performance are statistically significant between the two contracting methods, two-sample t-tests were conducted in this section. Comparing the pavement conditions under the two contracting methods at the same service times could be a straightforward approach to evaluate the warranty projects versus the non-warranty projects.

6.3.1 Rut and IRI

Figure 26 and Figure 27 present the box plots and p-values for two-sample t-tests of rut and IRI data from asphalt and concrete pavements respectively. In each individual box plot, the plot to the left is for non-warranty pavements, while the plot to the right is for warranty pavements.

It is shown in Figure 26 and Figure 27 that all p-values are smaller than 0.05 except for those from the tests of asphalt rut data at year 6 and year 7. This indicates that the rut and IRI values of warranty pavement are significantly lower than those of non-warranty pavements at almost all of the service times during the 7-year period. It can be concluded from the two-sample t-test results that the performance of warranty pavements is better than the performance of non-warranty pavements in terms of rut and IRI, regardless of the pavement type.

6.3.2 Surface Distresses of Asphalt Pavement

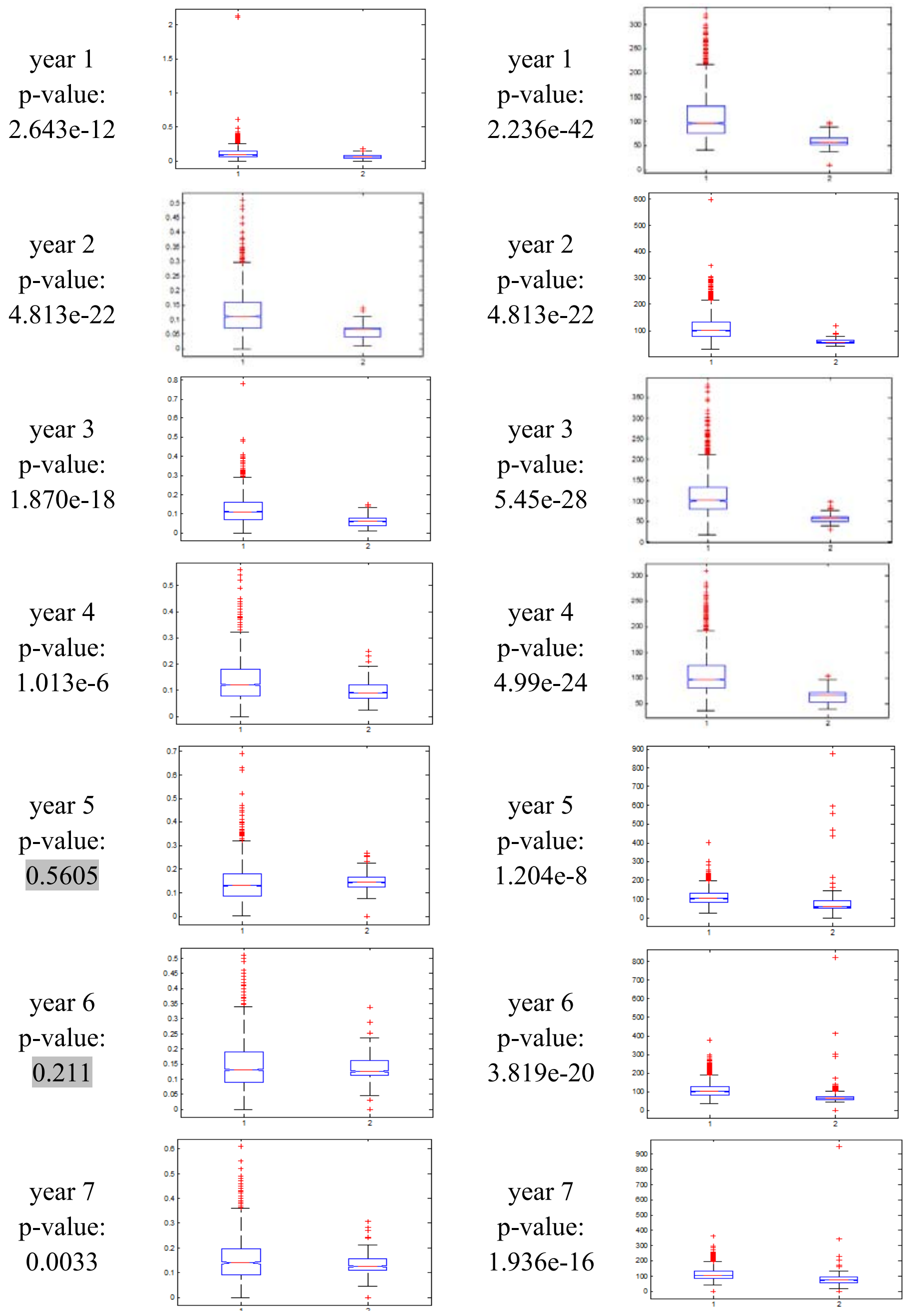
Figure 28 presents the two-sample t test results of block cracking data from asphalt pavements. The deduct points of block cracking data from warranty and non-warranty asphalt pavements were compared at the same service time level. Since only 7 years of data were available for warranty asphalt pavements, the two-sample t tests were conducted from year 1 to year 7. In the figure, type 0 on the left hand side is for non-warranty asphalt pavements, while type 1 on the right hand side is for the warranty asphalt pavements.

As shown in Figure 28, no clear box plots were developed for block cracking data from warranty asphalt pavement, since most of the deduct point values are zero or approaching zero. A few larger deduct point values were found at service time of 7 years. This is common for data of other distresses from asphalt warranty pavements. Further, the p-values of all the two-sample t tests are less than 0.0001, much lower than the 0.05 significant level. This indicates that the block cracking distress is significantly less severe for warranty asphalt pavements than for non-warranty asphalt pavements. Based on above two-sample t tests results, it is concluded that the warranty asphalt pavements perform better than non-warranty asphalt pavement in terms of the block cracking distress.

Similar patterns and results were obtained for other asphalt pavement distress data. The mean values of the distress deduct points from warranty asphalt pavements are much less than those from non-warranty asphalt pavements. Also, the p-values for all two-sample t tests are all much less than 0.05, regardless of the distress type and service time. Based on the above results, it is concluded that the warranty asphalt pavements perform better than non-warranty asphalt pavements in terms of the various pavement surface distresses. The asphalt pavement warranty program implemented in MS is effective.

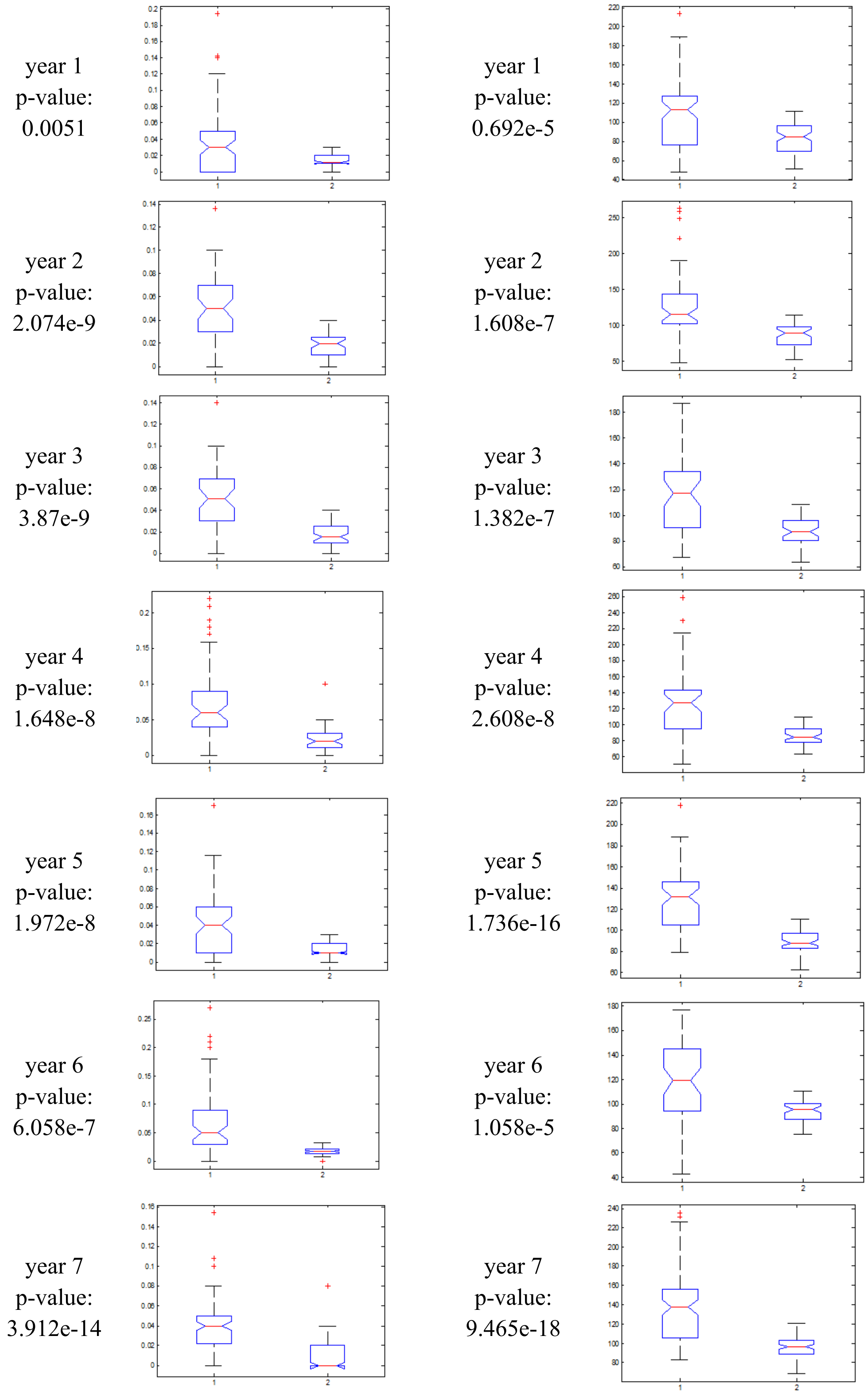
6.3.3 Surface Distresses of Concrete Pavement

Figure 29 presents the two-sample t tests results of the map cracking data from concrete pavements. Similar to the plots in Figure 28, no clear box plots were obtained for deduct point data from warranty concrete pavements, due to the high tendency to zero and limited number of the map cracking data. The same situation applied to the map cracking data collected from non-warranty pavements at year 3, year 4, and year 7. Again, the p-values of all the two-sample t tests from year 1 to year 7 are all less than 0.05 level and the mean levels of deduct point data from warranty pavements at all 7 year are much lower than those from non-warranty pavements. The results confirm the conclusion draw previously from the asphalt pavement distress data that the warranty pavements perform better than the non-warranty pavements.



(a) Rut **(b) IRI**

Figure 26 Two-Sample T-Test Results for Asphalt Pavements



(a) Rut **(b) IRI**

Figure 27 Two-Sample T-Test Results for Concrete Pavements

year 1
p-value:
<.0001

year 2
p-value:
<.0001

year 3
p-value:
1.870e-18

year 4
p-value:
<.0001

year 5
p-value:
<.0001

year 6
p-value:
<.0001

year 7
p-value:
<.0001

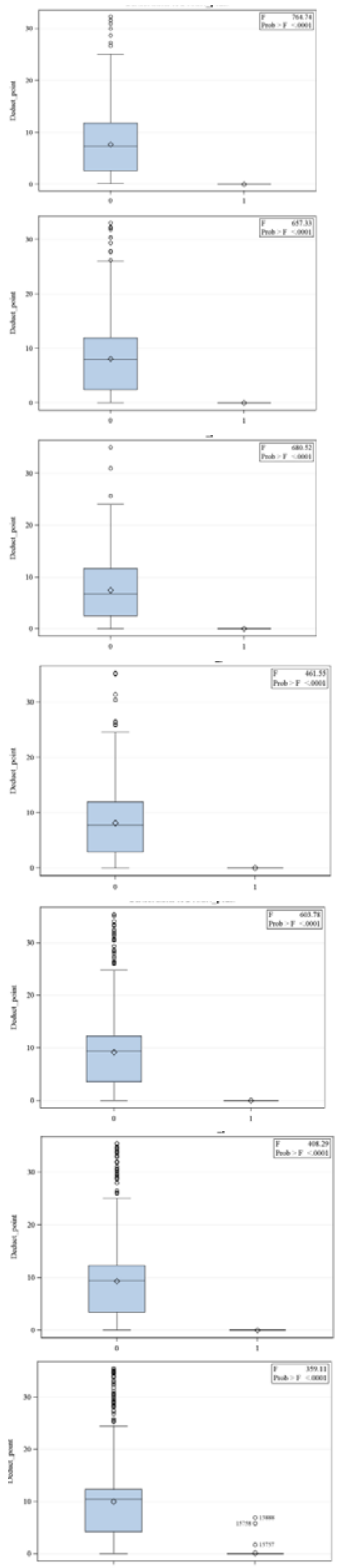


Figure 28 Two-Sample T-Test Results of Block Cracking Data from Asphalt Pavements

year 1
p-value:
<.0001

year 2
p-value:
<.0001

year 3
p-value:
1.870e-18

year 4
p-value:
<.0001

year 5
p-value:
<.0001

year 6
p-value:
<.0001

year 7
p-value:
<.0001

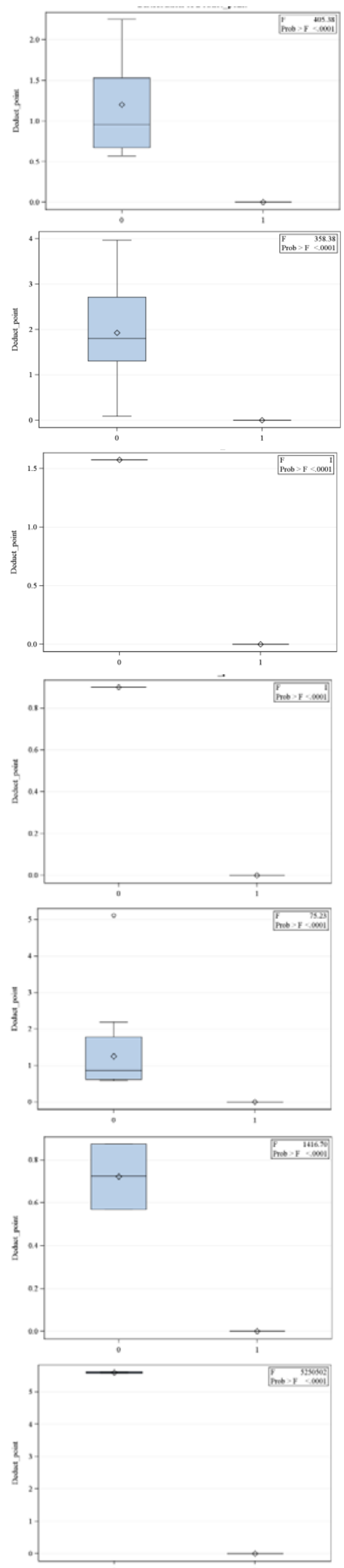


Figure 29 Two-Sample T-Test Results of Map Cracking Data from Concrete Pavements

CHAPTER 7. SUMMARY AND CONCLUSIONS

This study examined the effectiveness of the pavement warranty program in MS and evaluated the appropriateness of the distress threshold values adopted by MDOT for warranty (maintained) pavements. First, a comprehensive literature review was performed to review the pavement warranty practice and related studies in MS and other states. Then an online survey was conducted to gather the latest information on pavement warranty practice in North America, with a special attention paid to the warranty items, threshold values, and pavement surface condition data collection. Further, statistical analysis was performed using the data from both warranty and non-warranty pavements to compare the performance of in terms of the MDOT warranty items. The corresponding percentiles of each distress threshold value were determined from the Cumulative Distribution Function (CDF) curves of the pavement distress data, and then used to investigate the appropriateness of the threshold levels.

7.1 Literature Review

Pavement warranty programs in 12 other states in the U.S. were reported in the literature. Most of the reviewed states have 2-year, 5-year, 7-year, and 10-year warranty terms, only New Mexico has long-term warranty clause of up to 20 years. Warranty specifications were generally applied to both HMA and PCC pavements, mostly on preventive maintenance and rehabilitation projects and seldom on new construction projects, primarily because most the nation's roadways are under maintenance and rehabilitation.

Similar to Mississippi, most of the reviewed states use riding quality, physical distress, and skid resistance as pavement condition parameters under warranty, and for physical distress, rutting and different types of cracking are the most common condition parameters, others include bleeding, raveling, shoving, and potholes for asphalt pavements and faulting, scaling, and various joint failures for concrete pavements. Maine DOT includes roadway settlement in their pavement performance warranty items. However, unlike Mississippi DOT that uses deduct point based threshold levels, all the other states reported in the literature set the threshold limits based on the maximum allowable value for each distress measurement. Compared to deduct points based threshold, the distress measurement based thresholds are more straightforward and convenient to handle during the warranty practice.

Most state DOTs survey the warranty pavements annually or biannually and sample a few 500 ft. segments within each mile for distress evaluation. As for warranty enforcement, Colorado and Minnesota DOTs monitor the traffic load over the warranty pavements, and the warranty requirements are waived when the accumulated number of ESALs exceeds the design traffic load. Similar to the practice in Mississippi, a Conflict Resolution Team (CRT) consisting of members form DOT, Contractor, and a mutual third party is commonly used to solve any disputes following the simple majority rule.

7.2 Survey Study

Since the information reviewed from previous studies in the literature was not up to date, and also the information regarding the current status of pavement warranty projects, distress protocol, data acquisition, and pavement evaluation in other states are desired, a comprehensive survey on pavement warranty was conducted as part of the research effort to search for the current pavement warranty practice and specifications in North America.

According to the survey results, warranty has been implemented for both HMA and PCC pavements. In addition to preservation or rehabilitation projects, warranty clauses were also adopted on full depth HMA and PCC pavement construction projects. The warranty period is usually between 3 to 7 years and 5-year is the most commonly used warranty term. No warranty period longer than 10-year was reported in the survey.

All the states that responded with existing warranty programs adopt performance warranties. Meanwhile most of them also exercise materials and workmanship warranties. Regardless of the warranty type adopted, ride quality and physical distresses were the common pavement condition items under warranty. Rutting, cracking, and joint-faulting are the most commonly warranty physical distresses. Structural capacity and safety measurement were also reported in the survey, but only used by a few states as warranty items.

Although most of the states with existing warranty programs developed their own distress identification protocols, LTPP and AASHTO distress manuals serve as the reference for or are used jointly with agency specified protocols. Annual or biannual pavement condition surveys were commonly used data collection cycles. However, no prevailing technologies were reported for pavement condition data collection. Manual methods are still widely employed for warranty programs, since the automated technologies are not yet sophisticated enough to be employed at the project level, especially when warranty clauses were engaged.

Composite indexes are still used for condition evaluation of warranty pavements, but the distress thresholds are the major criteria used by state DOTs to manage their warranty projects and specify the corresponding remedial actions. Unlike the practice in Mississippi that uses deduct point based threshold levels, all the other states that responded with existing warranty programs set their threshold limits based on the maximum allowed value for each distress measurement within certain sample pavement segment. As for warranty enforcement, most states notify the contractor and request for the remedial actions to be conducted within 30 to 60 days. Conflict Resolution Teams (CRT) consisting of 3 or 5 members from DOT, contractor, and a mutually agreed third party are commonly used when the contractor contests the DOT's decision based on the pavement survey results.

Several issues regarding pavement warranty were reported in the survey. Some states consider extending their warranty terms, but it seems to be a concern with the contractor and contractor's bonding companies. In addition, how to accurately determine the responsibilities of the contractor is also an issue, since the contractor has no control over design in most cases and some failures for warranty projects are beyond the contract scope. Moreover, some concerns regarding the tight threshold values and the benefits of pavement warranties were also voiced in the survey.

In summary, the survey study shows some common characteristics of pavement warranty practice shared by different states, including the warranty projects, warranty terms, warranty types, and warranty enforcement. Meanwhile, implementation issues such as the pavement condition data collection and setting of distress threshold values for a warranty program are also inquired. Although pavement warranty has been applied in the U.S. for almost 20 years, there are still major issues concerning state agencies. In-depth studies need to be conducted to fully investigate the appropriate specifications and the proper implementation of pavement warranties.

7.3 **Statistical Analysis**

Pavement condition data collected from both warranty and non-warranty pavements were employed for the statistical analysis after a data cleaning and screening process to compare the performances of the two pavement contracting types. The data analyzed in the study include rut, IRI, and pavement surface distress data commonly contained in the PMS and warranty data items. First, the distributions of the pavement condition data from both warranty and non-warranty projects were developed, followed by the basic statistics and percentile analysis to evaluate the appropriateness of the corresponding distress thresholds. Then, the evolvements of pavement condition of warranty and non-warranty projects were investigated through a pairwise comparison procedure. Finally, the pavement conditions of warranty and non-warranty projects at the same service times were compared using two-sample t-test.

The data distributions and summary statistics show that pavement distress measurements increase as service time increases and the distress values of non-warranty pavements are generally higher than those of warranty pavements. Additionally, the standard deviation (std) of data from non-warranty pavements are steadily higher than that of warrant pavement at all service times. The percentile analysis of the non-warranty pavement data reveals a common increase trend of the corresponding percentile of threshold values over time. However, heavy inconsistencies regarding the distress threshold levels were found for the non-warranty pavement data. The inconsistency was reflected in the various percentile levels for different distress types at same service times as well as the different increase rates of the percentile level for different distress types over service time. It is suggested that for better management of the warranty pavements, consistent threshold levels should be implemented for all distress types. The threshold levels recommended by the research team are 60th and 80th percentile for tight and loose levels of control respectively. The percentile analysis for the warranty pavement data shows that under the current distress threshold criteria, the warranty pavements perform well, given that over 95% of the pavement sections meet the threshold requirements for all distress types at all service years.

The pairwise comparison reveals similar patterns for various pavement distress types. Consistently, the distress measurements for non-warranty pavements are larger than those from warranty pavements at the same service time. Moreover, the non-warranty pavements deteriorate much faster than warranty pavements. The two-sample t tests results confirm the findings from the basic statistics and pairwise comparison analyses, i.e. the mean values of the distress deduct points from warranty pavements are significantly less than those from the non-warranty pavements, regardless of the distress type and service time. Based on above analysis, it is concluded that the performance of warranty pavements is better than that of non-warranty pavements at the same service time level and warranty pavements can maintain at high service level longer than non-warranty pavements.

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