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Performance of Warranted Asphalt Pavements: Smoothness and Performance of Indiana Warranted Asphalt Pavements

Leila Sadeghi, Rebecca S. McDaniel, John E. Haddock

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AUTHORS

Leila Sadeghi
Graduate Research Assistant
Lyles School of Civil Engineering
Purdue University

Rebecca S. McDaniel, PhD, PE
Technical Director
North Central Superpave Center
Lyles School of Civil Engineering
Purdue University
(765) 463-2317 x226
rsmcdani@purdue.edu
Corresponding Author

John E. Haddock, PhD, PE
Professor of Civil Engineering
Lyles School of Civil Engineering
Purdue University
(765) 496-3996
jhaddock@purdue.edu
Corresponding Author

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16. Abstract

In the early 1990s the Indiana Department of Transportation (INDOT) developed a five-year warranty specification for asphalt pavements with the first project being built in 1996. In 2004, results indicated that the asphalt pavements built with the warranty specification had improved performance over the conventional asphalt pavements.

Nineteen years have passed since the original asphalt pavement warranty project was placed in Indiana. It has been eleven years since the performance of the warranted asphalt pavements has been analyzed to determine the effectiveness of warranties. Therefore, it is prudent to reexamine the potential benefits of asphalt pavement warranties. Hence, the ultimate goal of the project is to advise the INDOT on whether the use of asphalt pavement warranties has potential benefit for lowering the cost of ownership for asphalt paved roadways.

Overall, performance comparisons of Indiana's warranted and non-warranted asphalt pavements indicate that warranted asphalt pavements tend to perform more effectively than do non-warranted asphalt pavements. On average, warranted asphalt pavement sections had lower IRI values and rut depths than did non-warranted sections. The variability in IRI values and rut depths was also found to be less for warranted pavement sections than for the non-warranted sections. In terms of service life based on changes in IRI and rut depth, analyses indicate that warranted asphalt pavements could last 10 to 14 years longer than non-warranted asphalt pavements. When both initial capital costs and maintenance expenditures are considered, warranted asphalt pavements appear to be 15 to 40% more cost effective over a 5-year (short-term) period and 47 to 61% more cost effective over a 15-year (long-term) period. These savings do not include potential benefits of reduced user costs nor reduced INDOT inspection costs.

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EXECUTIVE SUMMARY

PERFORMANCE OF WARRANTED ASPHALT PAVEMENTS: SMOOTHNESS AND PERFORMANCE OF INDIANA WARRANTED ASPHALT PAVEMENTS

Introduction

Warranted asphalt pavements have been placed in Indiana, on a trial basis, since 1996 in an attempt to improve pavement performance, increase quality, and prevent premature failures. However, in terms of initial capital costs they are more expensive when compared to similar non-warranted asphalt pavements. Thus, to assess the benefits of warranted asphalt pavements, their performance life and the initial and maintenance costs should be evaluated simultaneously.

Findings

This study reviewed different types of warranties, the benefits and concerns related to warranted projects, and experiences with warranties in various states, including Indiana. Data from the warranted asphalt pavements constructed in Indiana were analyzed and compared to data from non-warranted pavements in a variety of ways.

In the first section of analysis, this study examined the performance impacts of asphalt pavement warranties by comparing International Roughness Index, rutting data, and friction numbers for both warranted and non-warranted asphalt pavements. The distributions of rutting, friction, and smoothness data were investigated and deterioration curves were developed. Initial costs, as well as short- and long-term maintenance expenditures for both types of projects, were estimated and compared. The results indicate that, overall, warranted asphalt pavements perform more economically than similar non-warranted asphalt pavements. Warranted asphalt pavements deteriorate more slowly and their service lives can be 10 to 14 years longer than traditional non-warranted asphalt pavements. When initial capital costs are considered, warranted asphalt pavements are 15–40% and 47–61% more cost-effective over short- and long-term comparisons with non-warranted asphalt pavements.

In the second section of analysis, five asphalt pavements built with a warranty specification in Indiana that had been evaluated in a previous study were selected. These pavements range in age from approximately 12 to 17 years. Each warranty pavement was identified by functional class, design traffic volume, and cross-section type. In addition, conventionally constructed pavements of the same ages, functional class, traffic level, and cross-section types were identified for comparison purposes. Results of five sets of pairwise comparisons indicate that in terms of service life, warranted pavements actually outlasted the comparable non-warranted pavements by 1 to 7 years and performed more effectively during their service life.

Implementation

Results of this study revealed that warranted asphalt pavements perform superior to and more cost-effectively than similar non-warranted pavements. Both projected and actual service lives were found to be greater for warranted pavements. Based upon the findings of this study, it would be prudent for the Indiana Department of Transportation to consider reinstituting an asphalt pavement warranty program. Recommendations are provided regarding how such a program might be established and administered.

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1. OVERVIEW OF RESEARCH

1.1 Background

A pavement warranty guarantees the performance of a pavement and shifts responsibilities for the repair of defects or replacement of the pavement to the contractor (Hancher, 1994). Warranties were offered on asphalt pavements as early as 1901 when the Warren Brothers Company began the practice with their patented "Warrenite Bitulithic Pavement" that was warranted for 15 years. During the boom of highway construction that began in the 1950s, the Federal Highway Administration (FHWA) disallowed pavement warranties on federally funded construction, but they were allowed for pavement maintenance activities, which were not federally funded. In the 1990s, interest in pavement warranties revived and the FHWA revised its rules to allow pavement warranties on federally funded pavement construction projects (Gallivan, 2011). A 2003 scanning tour documented the widespread and successful use of asphalt pavement warranties in Europe, which further increased interest in the USA (D'Angelo, 2003).

Since the reinstatement of pavement warranties, many states have implemented them on at least an experimental basis, sometimes with mixed results. For example, the California Department of Transportation (Caltrans) established warranties for asphalt overlays and for chip seal operations. Overall, Caltrans has been pleased with the results and continues to move forward with warranties (Scott et al., 2011). At the other extreme, the Colorado Department of Transportation (CDOT) issued a report in 2012 that concluded the implementation of asphalt pavement warranties in Colorado was not an effective tool for CDOT. This conclusion was based on ten years of performance data from Colorado's warranted asphalt pavement projects (Goldbaum, 2012).

In the early 1990s the Indiana Department of Transportation (INDOT) developed a five-year warranty specification for asphalt pavements with the first project being built in 1996. Over the next ten years several additional asphalt pavement warranty projects were built. Interest in the warranty specification waned by the mid-2000s and the specification was rarely if ever used. Reportedly, this was due, in part, to an attempt to increase the warranty period to ten years. In 2004, Gallivan et al. published an analysis comparing the performance of nine warranted asphalt pavement projects to similar projects built with standard (non-warranted) specifications. The results indicated that the asphalt pavements built with the warranty specification had improved performance over the conventional asphalt pavements. Considering fifteen years as the typical design life for an HMA pavement in Indiana, the authors estimated an expected typical pavement life increase of nine years for pavements built under the warranty specification (Gallivan et al., 2004). The most recent analysis of warranty project in Indiana was done by Singh et al. and was published in 2005. Their analyses projected that warranted pavements were 58–65% more cost-effective on the basis of both service life and pavement condition (Singh et al., 2005).

1.2 Problem Statement and Objectives

Nineteen years have passed since the original asphalt pavement warranty project was placed in Indiana. It has been ten years since the performance of the warranted asphalt pavements has been analyzed to determine the effectiveness of warranties. There is some support for the concept of using pavement warranties to improve performance, encourage innovation, limit agency risk and reduce construction oversight (Gallivan, 2011). Therefore, it is prudent to reexamine the potential benefits of asphalt pavement warranties. Hence, the ultimate goal of the project is to advise the INDOT on whether the use of asphalt pavement warranties has potential benefit for lowering the cost of ownership for asphalt paved roadways. The objectives of this study are therefore to: (1) re-evaluate and quantify the performance of asphalt pavements built under warranty specifications; (2) determine if there are compelling arguments to begin using asphalt pavement warranties again, and if so, what those reasons are; and (3) evaluate the current draft of the warranty specification and make recommendations to update it to reflect specification changes and potentials for improved performance of the specification.

2. LITERATURE REVIEW

This section includes a review of relevant literature related to the use of pavement warranties, focusing on asphalt pavements (though some information would apply to other types of pavement warranties). The literature review is presented in three main areas: general, worldwide information; regional experience; and past warranty use and research in Indiana.

2.1 General Warranty Literature

Interest in using warranties for pavements and other construction elements in the USA increased significantly in the 1990s and early 2000s. Federal regulations resulting from the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) lifted a long-standing ban on using warranties. Prior to ISTEA, the FHWA had ruled that warranties essentially constituted maintenance activities, which could not be funded with Federal Aid funds. ISTEA allowed states to use warranties off the National Highway System (NHS). A 1995 Interim Final Rule (IFR), fully adopted in 1996, further expanded the possibilities for using warranties on all Federal Aid projects, on or off the NHS (FHWA, 2015a).

Interest was spurred even more by the report from a 2003 scanning tour of Europe that focused on European use of pavement warranties. Several countries there had used various types of warranties for as long as 30–40 years. Most of these were materials and workmanship warranties, defined below, but the use of performance warranties with periods ranging up to 20 years was increasing as was use of design-build-finance-operate contracts lasting up to 30 years (D'Angelo et al., 2003).

2.1.1 Types of Warranties

A warranty, in this application, is defined as "performance specifications that guarantee the integrity of a product and assign responsibility for the repair or replacement of defects to the contractor" (Gallivan, 2011). Warranties can be considered a logical step on a continuum of specification development. Many states, including Indiana, have progressed from the use of method specifications, to quality control/quality assurance (QC/QA) specifications, to end result specifications (Figure 2.1). Method specifications prescribe in great detail what materials, equipment and processes a contractor must use; because the contractor has limited options, the agency mainly carries the risk for the final product and its ultimate performance. QC/QA specifications shift some of the responsibility and risk to the contractor by making him responsible for testing materials as they are produced. End result specifications shift the responsibility and risk further to the contractor by removing more restrictions on materials and methods, and testing the final product. Warranties can be viewed as an additional shift in responsibility and risk because under warranties, the contractor must guarantee the performance of the product for some period of time. However, despite the specification type, attention must be paid to all components, including materials, construction methods, testing, etc.

Most references cite two major types of warranties: materials and workmanship warranties and performance warranties, with a subdivision of performance warranties into short- and long-term (Anderson et al., 2006; FHWA, 1996, 2015c); others consider short- and long-term performance warranties as different types because of substantial differences in the time periods, evaluation criteria, and responsibilities of the parties involved (Scott et al., 2011).

Materials and workmanship (M&W) warranties are commonly used in Europe (D'Angelo et al., 2003; FHWA, 2015a) and some US agencies (Scott et al., 2011). This type of warranty holds the contractor accountable for correcting pavement deficiencies caused by poor quality of materials or construction practices but not for structural issues because the structure is designed by the agency (Anderson et al., 2006; FHWA, 2015a; Scott et al., 2011). M&W warranties are generally fairly short-term – two to four years (Anderson & Russell, 2001; FHWA, 2015a; Gallivan, 2011). In the US, M&W warranties can be used within a conventional low-bid system (Gallivan, 2011; Scott et al., 2011).

Performance warranties, on the other hand, place more responsibility for the ultimate pavement performance, over a prescribed time period, on the contractor. Under a short-term warranty, the agency typically still performs the structural pavement design, but the contractor is responsible for ensuring the performance of the elements of the construction within his control (Gallivan, 2011; FHWA, 2015a), such as material selection, mixture design and construction techniques. This type of warranty, which is typically five to ten years in duration, can be accommodated under either a low bid or alternate design-build contract. Under a long-term warranty, which may last for 20 years or more, the contractor is held to generally higher standards for performance and maintenance and completes the structural pavement design to provide that level of performance. Because of the greater responsibility and duration, long-term warranties often, but not always, involve design-build-warrant, public-private partnerships or concessionaire agreements (FHWA, 2015a; Scott et al., 2011).

2.1.2 Benefits and Concerns Attributed to Warranties

The major reason for the interest in using pavement warranties is the perceived potential for a number of benefits to the specifying agency, and therefore to the public, as well as to the contractor to some extent. These potential benefits include (Anderson et al., 2006; Anderson & Russell, 2001; D'Angelo et al., 2003; FHWA, 2015a):

- Reduced agency staffing and cost for inspection,
- Improved pavement performance,
- More opportunity for innovations,
- More appropriate allocation of risk and responsibility, and
- Lower life cycle costs.

A survey in Louisiana showed that contractors with warranty experience reported paying more attention to detail and making a greater effort to ensure quality. The Louisiana Department of Transportation and Development perceived that having a warranty in place gave them a means of redress if substandard materials or construction defects were discovered after placement (Martinez, 2012).

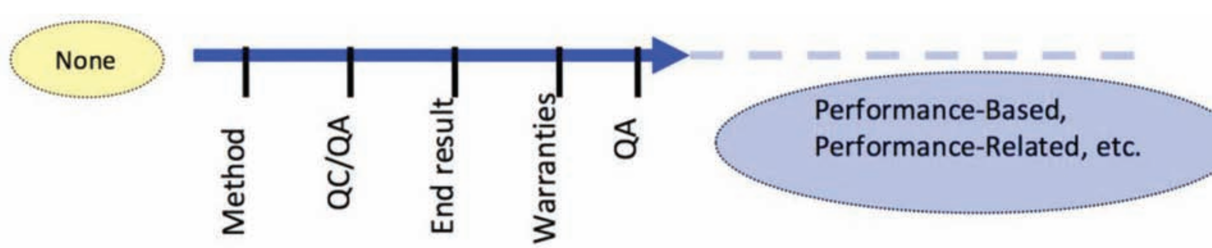

Figure 2.1 Specification development continuum (D'Angelo et al., 2003).

These benefits, however, are not attainable without some challenges and issues. For agencies, relinquishing control over a project can represent a major culture change (FHWA, 2015a). Legislative changes may be needed to allow the use of warranties, especially if changes are contemplated in contracting, such as to use best value or prequalification of bidders in addition to a warranty (FHWA, 2015a). Agencies also need to determine the most appropriate projects on which to employ warranties, what performance measures to warrant and threshold limits, bonding requirements and any contractual adjustments (Stephens et al., 1998).

Industry concerns are many. Under a warranty contract, the contractor must assume much more risk; this should be balanced by the agency giving the contractor more latitude to control quality and procedures (FHWA, 2015a). Contractors also face concerns about the impacts of elements outside their control, such as pre-existing conditions, changes in traffic or climate, and future maintenance activities (Stephens et al., 1998); the contractor should only be held accountable for those elements he can control (FHWA, 2015a). Industry also has concerns about attaining sufficient bonding, especially if warranties are long-term and commonly used (FHWA, 2015a, and others).

Agencies and industry share concerns about the potential impacts of warranty projects, and especially bonding requirements, on small contracting firms. Some surety companies have expressed concerns about providing bonds to small companies for longer-term warranties (greater than three years) (Anderson et al., 2006). Agencies do not want to see a decrease in the number of competent bidders on projects because of the effects of reduced competition. Contractors, especially the smaller ones, do not want to see reduced opportunities for work. A survey of 39 large (annual revenues over \$20 million) and medium/small contractors in Alabama showed that most would bid on warranty projects, but their willingness to bid depended on the type of project and warranty period (Sharma et al., 2009). As the warranty period increased from 1 to 3 years to greater than 5 years, the number of contractors who would bid decreased. Contractors also indicated more willingness to bid on new construction rather than overlays (Sharma et al., 2009). Statistical analysis showed that the size of the company did not have a significant impact on the survey results (Sharma et al., 2009).

2.1.3 Key Elements of Successful Warranties

While there are many options regarding various types of pavement warranties, there are some considerations and key elements that are necessary for successful implementation of a warranty program. These include buy-in from agency and industry management, appropriate project and warranty type selection, distress types and evaluation techniques, monitoring traffic and performance, contracts and administration, and bonding, among others.

The most successful warranty programs seem to be those that were developed jointly by the specifying agency and industry (Anderson et al., 2006; Anderson & Russell, 2001; FHWA, 2015c). Buy-in by both groups is important from the beginning because the use of warranties does represent a great shift in roles and responsibilities with major impact on financial matters. One prime example of the type of consideration both groups must agree upon is conflict resolution; if a dispute arises over, say, the cause of an observed pavement distress, a mutually agreed upon conflict resolution team is needed to resolve the issue. It is best if this team is established from the initiation of a project to be called upon only if needed (Gallivan, 2011).

Management on both sides needs to appreciate the potential impacts on their organizations. Agencies may benefit from reduced staffing for field inspection and testing, but depending on the structure of the agency and warranty program, may need increased staff for monitoring performance (FHWA 2015a; MnDOT, 2005). Additional agency staff time may also be needed for planning, developing warranty specifications and criteria, and training on the changed roles and responsibilities of both agency and contractor personnel (Anderson & Russell, 2001). Industry would be well-advised to devote more effort to up-front planning and evaluation of pre-existing conditions, material selection and testing, traffic phasing and other activities (Scott et al., 2011). Contractors have reported that they devote more time on warranty projects to recordkeeping to have documentation in case of a dispute (Anderson et al., 2006).

In general, warranties may not be suitable for all projects, so selecting appropriate projects and warranty types are critical considerations. Materials and workmanship warranties are appropriate for preventative maintenance (pavement preservation) activities (FHWA, 2015a; Gallivan, 2011). Performance warranties are applicable to overlays or new construction, though the duration and distresses included will vary depending on the scope of the project. Short warranty periods are generally considered appropriate for rehabilitation, resurfacing or new construction, while longer periods are more applicable to new construction. There is a difference of opinion regarding appropriate projects to select for warranty work. Some states, especially for pilot projects, select simple, straightforward projects where the traffic levels and existing conditions are well-known; others use warranties for more complicated, higher profile projects (Scott et al., 2007). The projects, however, should not have too many variables outside the contractor's control (Martinez, 2012). Colorado determined that projects suitable for warranties should be sufficiently large ($\geq$20,000 tons of mix) with a design service life of ten to 20 years and with a weigh-in-motion station nearby or installed under the contract to monitor traffic (Goldbaum, 2012). Oregon uses warranties only on structurally sound projects so that structural deficiencies will not contribute to distresses during the warranty period (Anderson et al., 2006). The somewhat unique warranty program in Florida, which will be described in the next section, is applied to essentially all asphalt paving projects (Page, 2015).

While it is generally recommended that the decision to apply a warranty to a given project be made early in the design process (Anderson & Russell, 2001), another approach is to allow design and construction to proceed as usual and elect to implement an optional warranty if any aspect of the construction is suspect (Hastak et al., 2003). Another approach is to let a contractor choose to provide a warranty in return for relief from some aspect of the specifications. For example, New York State allows a contractor to elect to provide a one-year warranty if he wants to place a surface course outside the standard seasonal limits; in this case, the agency alone determines if the surface course is defective and must be remediated (NYSDOT, 2010).

A wide variety of distress types have been the subject of warranties depending on the project scope and primary cause of the distress; the bottom line is that the warranted distress types should be those that are caused by elements within the contractor's control (FHWA, 2015a). Commonly warranted distresses include: rutting; various types of cracking, including longitudinal, transverse, block and alligator; raveling; bleeding; ride quality; debonding, potholes and others (Anderson et al, 2006).

Determining which distresses to warrant can have an impact on the level of effort required for monitoring performance. Less effort will be required for those distresses that can be monitored through the agency's existing pavement management system.

Another consideration is the length of the evaluation sections to be monitored. If sections are too long, localized severe distress can be masked. It is important that the length of the monitored sections specified in the contract be compatible with the system used for the measurement; Louisiana noted a discrepancy in their early warranty use between the specified measurement interval (50 and 500 ft sections) and the system used to collect the data (10^{th} mile sections) (Martinez, 2012).

The frequency of performance monitoring is another consideration. Annual performance surveys are common, especially if the data is readily available through the pavement management system. Some states have concluded, however, that less frequent inspections are sufficient. Michigan, for example, conducts a "windshield survey" at the mid-point(s) of the warranty period to ascertain if any significant distresses are occurring. If so, a more detailed inspection is performed. If not, the next inspection is a final inspection near the end of the warranty period (FHWA, 2015c; Martinez, 2012).

A critical element of warranty enforcement is the monitoring of traffic. Because traffic can cause or exacerbate pavement distress, most warranty specifications call for the warranty period to be terminated if the traffic exceeds the design traffic level by some specified amount (Martinez, 2012); a so-called escape clause. The amount may vary but is typically between 20 and 50% in excess of the design level (Gallivan, 2011). For performance warranties, especially where the contractor will be designing the pavement structure, the agency needs to provide reliable estimates of the design traffic (Gallivan, 2011). Traffic monitoring during the warranty period is also typically an agency responsibility and may require installation of a weigh-in-motion system, if it is not already in place (Goldbaum, 2012).

The warranty specifications should clearly define who is responsible for maintenance during the warranty period. While some agencies are concerned that contractors may not have the equipment and expertise needed to perform maintenance activities, is it inadvisable for the agency to continue to perform maintenance since the timing and type of maintenance could impact performance (Anderson et al., 2006). One common exception to this rule is the need for emergency maintenance to address a safety concern (Anderson et al., 2006); another is that the state may continue to perform operations like snow plowing or mowing that do not affect the pavement performance (Gallivan, 2011).

If remediation is required during the warranty period, the goal is to return the pavement to the appropriate position (age) on the performance curve, not to return it to its original, post-construction condition. Repairs that produce a "like-new" condition essentially extend the service life of the pavement beyond the original design life (Scott et al., 2011), which implies that the contractor is doing more than should be expected and is thereby assuming greater costs.

While communication between the agency and industry is considered essential, internal communication within the agency is also critical (FHWA, 2015b; MDOT, 2008). The maintenance branch, for example, needs to know the location of warranted sections so that they do not perform pavement maintenance activities in those areas that would void the warranty. Testing personnel also need to be aware of any changes in the QA testing on warranty projects.

Industry in particular is concerned about the impacts of carrying bonding for long periods of time. If they have multiple warranty projects at the same time, their bonding capacity may be reduced, which would hinder their ability to bid on more projects. There are several options that could help this situation. For example, the required amount of the bond can be decreased over time if the pavement is performing acceptably (Stephens et al., 1998). Another option is to withhold retainage in lieu of or in addition to requiring a bond, especially for shorter-term warranties (Anderson et al., 2006). Industry in Texas expressed concern about the impacts of this approach on cash flow (Anderson et al., 2006). However, releasing portions of this retainage over time could be a financial incentive for the contractor to maintain the pavement performance (Hastak et al., 2003). In California, for example, 10% of the contract price for three- and five-year warranted pavements is retained and released at 10%, 25%, 45% and 70% over time if the warranty provisions are met (FHWA, 2015a).

Surety companies reportedly prefer two- to three-year warranty periods since they find it difficult to determine the financial stability of a company farther into the future (Hastak et al., 2003). Annually renewable bonds after the initial time period would be more acceptable to the bonding companies (Hastak et al., 2003).

2.1.4 Experiences with Warranties

This section provides summaries of the experiences of three states outside the Midwest. Regional experience with warranty projects is described in the next section.

2.1.4.1 Colorado. Colorado initiated warranty contracting in 1998 to give contractors more responsibility for material selection and workmanship. Contractors performed the asphalt mix designs, which were not reviewed and approved by CDOT. The factors evaluated included rutting, ride and cracking (low, moderate or high severity). Based on good performance of three-year warranted pavements, in 2007 CDOT was developing longer, more performance-oriented warranties that would give contractors more pavement design responsibilities (Shuler et al., 2007).

Costs for six warranted pavements reported on by Shuler et al. (Shuler et al., 2007) were about 3% higher than similar control projects. Almost all of that additional cost was related to the installation of WIM at each site. There were no differences in the number of bids submitted on the warranty vs. conventional jobs (average of 3.7). CDOT had used both approaches of adding the warranty cost to the HMA and having a separate line item for the warranty; using a separate line item was recommended to facilitate cost analysis. The cost of the warranty was considered negligible.

A 2012 report reviewed the cost effectiveness of short-term (three to five year) warranties on hot mix asphalt in Colorado compared to conventional control projects ten years after construction (Goldbaum, 2012). This evaluation included nearly 215 lane-miles of warranted pavement constructed under ten pilot projects, as mandated by the state legislature. Results of the analysis suggested that the warranted pavements cost more to construct but cost less to maintain.

The cost-benefit analysis considered initial construction, maintenance and user cost estimates; reduced CDOT personnel costs for the warranted projects; and estimated benefit through longer service life. The warranty projects were found to cost about $12,635 more per lane mile to construct than the control, but the maintenance costs were $5,616 less per lane-mile over the warranty period. Construction cost considerations included economy of scale (for projects of different sizes in different regions), warranty cost (as a line item or increase in HMA unit price), cost of a WIM station; reduction in CDOT quality testing, and cost of Pavement Evaluation Team (PET). The PET cost included $2500 for an independent consultant for each inspection; CDOT staff time and traffic control costs were also included (Goldbaum, 2012).

Performance was evaluated using PMS data on International Roughness Index (IRI); rut depth; and fatigue, longitudinal and transverse cracking on 0.1 mi segments. (Fatigue cracking was not a warranted distress type.) The extension of service life was calculated as the difference in time between when the warranted and comparison control sections reached the same value. The smallest increase in service life for one of the distress types was considered to be the life extension. The cost savings associated with extended service life was estimated at $20,200 per lane-mile based on comparing the cost to rehabilitate the network divided by the number of miles rehabilitated in a given fiscal year (2011) (Goldbaum, 2012).

Of the ten pairs of pavements compared, some showed the warranted projects to be cost effective and others did not. Service lives were either equal or slightly longer for the warranted pavements. Cost/benefit ratios ranged from 0.49 to 1.50 with an average of 1.16. Goldbaum (2012) noted that this could be reduced to 1.05 if WIM stations and the PET were not considered or needed.

2.1.4.2 Mississippi. Qi et al. (2013) performed a study comparing the performance of pavements constructed under Mississippi's warranty program to those constructed under conventional specifications. Mississippi initiated its warranty program in 2000 for both HMA and PCC pavements. Ten distresses were compared for the asphalt pavements.

Statistical analysis showed that the warranted pavements had consistently lower levels of distress and slower deterioration rates than the non-warranted pavements. The analysis included up to seven years of performance on the warranted pavements and ten years on the non-warranted pavements.

2.1.4.3 Florida. The Florida DOT (FDOT) has routinely used a standard specification since 2002 that requires a three-year warranty period after contract acceptance (Page, 2015). Their program is unique in that bonding is not required. Under this program, if a contractor fails to perform remedial work or otherwise fails to comply with the requirements, their prequalification to bid on additional projects can be suspended or revoked (Page, 2015). The suspension lasts for six months or until the remedial work has either been completed by the contractor or the contractor has paid for work performed by the agency (FDOT, 2015). A "Statewide Disputes Review Board" handles dispute resolution regarding administration and enforcement (FDOT, 2015). This process has been found to be highly successful (Page, 2015).

Remedial work is required when distresses exceed the thresholds, as measured by the routine Pavement Condition Survey Program or engineer's observations. Thresholds and remedial actions are spelled out in the specifications for three categories of pavements including mainline and other roads (access and frontage) designed for speeds 55 mph and greater; pavements and incidental areas (parking lots, turn lanes, rest areas, etc.) with design speeds less than 55 mph; and bicycle and walking paths, crossovers, etc. (FDOT, 2015). The values of the thresholds were established based on typical well performing pavements at three years post-construction (Page, 2015). Remedial work is not required if the design thickness is inadequate, the traffic is 25% greater than the design traffic (ESALs), the distress is caused by underlying layers, or the distress is caused by a third party (unless that third party was performing work under the contract) (FDOT, 2015).

2.2 Regional Experience with Warranties

The Midwest has several states with extensive experience with warranties. In some cases, this experience was the result of legislation requiring the DOT to experiment with or implement warranties. For example, in 1999 the Ohio legislature required the Ohio DOT to use warranties on 20% of its capital projects; in 2005 this was revised to require warranties on no more than 20% of projects and, for new projects, the warranty period could be no longer than seven years (FHWA, 2015a). The Illinois legislature required IDOT to construct at least 20 projects with pavement warranties between 2000 and 2004. Consequently, IDOT let a total of 27 asphalt, concrete and asphalt overlay projects (Wienrank, 2004). The legislature in Michigan required the use of warranties "where possible" beginning in 1997 (Egan, 2014).

2.2.1 Ohio

A 2003 report on Ohio's existing warranty program looked at its advantages and disadvantages; it should be noted, however, that this report included a wide variety of projects, not just asphalt. ODOT reported an 8% increase in the unit prices for asphalt with a three-year warranty and 9% for five- to seven-year warranties. Higher quality levels were observed with warranties in general but were often slight. ODOT district personnel did not expect significant decreases in maintenance or life cycle costs for warranties overall, though they did see warranties as insurance against early failures. A reduction in construction time had not been observed. Contractors were also reportedly conservative and risk-averse, so innovative techniques had not been employed. While increased litigation was a concern identified in a survey of 40 states, it had not occurred in Ohio (Hastak et al., 2003).

One Ohio contractor provided some insights into changes made in their normal practices when constructing a warranted pavement. These changes are outlined in Table 2.1.

2.2.2 Michigan

Michigan has the most experience with warranties of any state in the region and the nation. They had used warranties on over 3,000 projects between 2000 and

TABLE 2.1
Contractor-implemented changes (after Gallivan et al., 2004).

Improvement Area	Improvement Details
Asphalt Plants	• Quality control improvements, including communication with the aggregate supplier producing aggregates for the project and constant review of gradations, absorption and specific gravity • Constant RAP analysis assuring gradation and RAP asphalt content are consistent with initial mix design • Improved communication and sharing of test results with plant personnel
Asphalt Production	• More frequent calibrations of all facets of the plant • Calibrations of cold feed bins, virgin and RAP scales, and liquid asphalt meters • Proper loading of 302 big rock mixes and 880 warranty intermediate mixes
Paving	• Produced manual for laydown crews outlining expectations and practice of paving fundamentals on warranty projects • Use electronic averaging systems more effectively and ensure proper training of personnel behind the screed on these averaging systems • Use material transfer machines to provide continuous paving on intermediate and surface courses, minimizing thermal and mat segregation • Full-width paving eliminated longitudinal joints along with polymerized AC band on all full-depth lifts of asphalt • Survey cuts and fills on each lift of asphalt through intermediate on mainline, as well as into and out of bridge approaches • String line 200 ft (60.9 m) into and out of bridge approaches • Improve transverse joint construction – straight edging 10 to 15 ft (3 to 4.5 m) of previous day's mat and sawing/sealing of transverse joint before production • Measure compaction on all lifts of asphalt • Measure smoothness for profile corrections before placement of surface mix • Mill phase joint on intermediate before placement of surface, i.e., the intermediate joint that is constructed during inside and outside phases • Profile milling generates smoothness numbers in the center lane • Increase use of flowboys

NOTE: Comments courtesy of Kokosing Construction Company, Inc., 2007.

2013 (Egan et al., 2014), including asphalt overlays, microsurfacing, chip seals, surface seals, ultra-thin overlays and concrete pavements (MDOT, 2008).

MDOTs warranty program is somewhat unique in a couple of aspects. For one, MDOT does not perform annual inspections to monitor performance. Instead, they perform a cursory "windshield" survey at an interim point (or points) during the warranty period to determine if there are any significant distresses, which would trigger a more detailed survey. For asphalt preventative maintenance overlays, the interim inspection is conducted 32 months after initial acceptance; for new and reconstructed asphalt pavements and overlays, cursory inspections are required at 30 and 54 months after initial inspection. Distresses evaluated include longitudinal cracking, debonding, potholes, raveling, flushing, and rutting. A final survey is also performed near the end of the warranty period to determine if any corrective action is needed before the warranty lapses. Between 3 and 13% of projects have required remediation, depending on the type of project (Egan, 2014; Kennedy, 2005). The report authors attributed this lack of corrective action to greater awareness by the contractors of the impacts of materials and workmanship on pavement performance (Kennedy, 2005).

Another noteworthy aspect of Michigan's program is its administration. In an attempt to ensure uniform reporting and administration, a Statewide Warranty Administration Team (SWAT) and a Statewide Warranty Administration Database (SWAD) are used. The SWAD is a central database to track inspections and consolidate information about all of the warranty projects in the state. MDOT also has written guidelines and forms for inspections (Egan, 2014).

MDOT has not observed an increase in bid prices and has seen reductions in construction inspection. They caution, however, that quality assurance testing is still needed (Kennedy, 2005) and recommend at least a daily spot check (MDOT, 2002). Contractors are required to submit quality control plans and daily reports (MDOT, 2002).

Kennedy (Kennedy, 2005) notes that a given project may have multiple initial acceptance dates, defined as when the roadway segment is continuously open to traffic and the department has accepted the warranty work. For example, if lanes in one direction are paved and opened to traffic before the other direction has been completed, the different directions would have different initial acceptance dates and therefore the warranty would expire at different times (Kennedy, 2005). The SWAD helps to track these details. The warranty bond must remain in force until the warranty period ends on the last section accepted (MDOT, 2002).

Recently, however, Michigan's warranty program has come under fire. A state audit in 2015 found some lapses, and lawmakers have called for action (Hinkley, 2015; Hinkley & Reed, 2015). MDOT reviewed the records for nearly 2,000 warranted projects where the warranty period had expired. Of those, 95% had been inspected on time, 2.2% were inspected late and 2.8% had not had a final inspection. Over 300 warranted projects (16%) had required some sort of remedial action, and of these only nine (3%) had not had the remedial work performed or scheduled (Hinkley, 2015).

It should be noted again that MDOT's warranty program covers many types of maintenance and construction, not just asphalt pavements. Of 430 projects requiring remediation, more than half (52%) were for bridge coating; preventative maintenance and paving account for the rest (Hinkley & Reed, 2015).

In response to the criticism of the program, MDOT is implementing changes. Now regional managers are responsible for overseeing the program. One responsibility of the regional managers is to communicate with the local offices to ensure they do not do maintenance on any projects where the warranty is still in force: there have been three instances where the Department performed maintenance that should have been done by the contractor (Hinkley, 2015). In addition, a Warranty Improvement Team has been working to improve the system (Hinkley, 2015).

2.2.3 Wisconsin

Wisconsin began constructing warranted asphaltic pavements in 1995. The agency and industry worked together to develop the specifications for the five-year warranties. WisDOT, the industry and FHWA agreed on the following (Krebs et al., 2001):

- WisDOT would define the condition and performance of the final pavement product.
- Warranties may improve performance and reduce the agency's cost of project delivery.
- Both the agency and industry share risks – of reduced performance or costs to repair.
- Contractors should have the freedom to construct the pavement as they choose, which may open up more cost efficient construction options.

Levels for specific distresses were set at typical five-year performance, as indicated by the PMS.

Wisconsin adopted a five-year warranty period because it was felt that was long enough to establish acceptable performance without tying up the contractors' bonding capacity for prolonged periods of time. Criteria were developed by examining the in-service performance of similar pavement structures and setting the limits so that about 90% of projects would meet them [Similar to INDOT's two standard deviations from the mean.] (Stephens et al., 1998). However performance criteria are set, they must be set so the agency has some assurance the resulting pavement will continue to perform past the initial warranty period.

A report by Krebs et al. (2001) summarized the background and status of the program after five years. By 2000, 24 asphalt pavements had been constructed under warranty specs. Initially the warranty only applied to the mainline and mainline shoulders, but by 2000, ancillary pavements (side roads, entrances, tapers, ramps, turn lanes, etc.) had been added. The mainline and ancillary pavements were separate bid items. WisDOT specified the project location, pavement structural design (including base and pavement thickness) and schedule. WisDOT did not conduct independent assurance inspections on any warranty projects. The distresses considered included:

- Alligator cracking
- Block cracking
- Edge raveling
- Flushing
- Longitudinal cracking
- Distortion
- Rutting
- Raveling
- Patching and potholes.

Distresses, thresholds and remedial actions were specified in the contract (Krebs et al., 2001).

After five years, none of the distresses on any project had reached the thresholds, so no remedial actions had been required. The only distresses noted were some transverse and longitudinal cracks. The warranty pavements were performing significantly better than the non-warranty pavements in terms of ride (IRI) and Pavement Distress Index (PDI). There had been no need for a conflict resolution team either (Krebs et al., 2001).

A limited cost comparison (limited because pavement life could not yet be determined) showed that warranted pavements cost less than conventional pavements. This comparison included the average bid prices for mix, asphalt and tack plus the cost for quality management and state maintenance (crack routing and sealing). An alternate comparison also included the savings in state project delivery cost (inspection and testing) (MDOT, 2002).

WisDOT developed guidelines for selecting projects suitable for warranties. These included considerations of adequate subgrade support and use of correct subgrade values in the pavement design. Contractors were allowed to offer innovations in the cross section, but these had to be approved by WisDOT (Krebs et al., 2001).

Industry reported that warranties encouraged team building among their employees who paid greater attention to quality. Warranties allowed the contractor to react quickly to changes in the production and placement of asphalt mixes, which could save them time and money. To improve quality on warranted pavements, contractors (Krebs et al., 2001):

- Implemented performance tests during the mix design phase to verify durability (loaded wheel tests, Superpave tests).
- Chose better quality materials.
- Monitored the QC process and performing QA.
- Held subcontractors and suppliers responsible for their materials, thereby sharing the risk.
- Rubblized concrete pavement rather than just patching before paving.
- Used different pavement materials on an experimental basis and monitored their performance. (WisDOT was informed of the innovations used so that they could monitor and consider wider implementation.)
- Modified the work schedule to allow traffic on lower pavement layers to test performance before surface layers are constructed, presumably allowing corrections to be made.
- Added equipment (e.g., rollers, profilographs on lower layers, etc.).

WisDOT acknowledged a need to improve the accuracy of cost estimates for warranted pavements. There were cases where all bids were rejected because they were much higher than the engineers estimate (Krebs et al., 2001).

After five years with no remedial work needed, WisDOT and industry were considering either lowering the thresholds to encourage even better performance or increasing the warranty period by two to five years. They also considered adding incentives for exceptional performance, which could either be a reduction in the warranty period after the exceptional performance was verified or a monetary incentive. Another potential change recommended was to bid all contracts conventionally then decide whether to buy a warranty (Krebs et al., 2001).

For bonds, the warranty project specifications required that the standard first year contract bond also include the warranty work. The remaining four years of the warranty period could be covered by either one four-year warranty bond or two two-year renewable bonds. If the paving was done by a subcontractor, that sub provided the warranty (Krebs et al., 2001).

A QC plan was required. At the completion of the project, the contractor was required to provide the engineer with results of all QC test and any changes to pavement widths and thicknesses (Krebs et al., 2001).

Monitoring on the mainline was conducted annually by the department and included pavement distress surveys on at least two 0.1 mi segments from each mile of warranted pavement. Any segment that appeared to meet or exceed a threshold could be inspected. Ancillary pavements were inspected at the five-year mark or when requested by the contractor or district. The contractor could perform non-destructive testing for monitoring purposes, but any destructive work (coring or milling) had to be approved by the DOT. The contractor was also allowed to perform preventative maintenance. Crack routing and sealing were required in year four. Documentation of all warranty work had to be provided to the department annually (Krebs et al., 2001).

By the end of 2008, WisDOT had used warranty specs on 157 HMA pavements (over flexible and rigid bases) and 14 jointed plain PCC pavements with dowels. (WisDOT did not see a benefit from using PCC warranties after up to nine years of monitoring.) A review after up to 12 years showed that warranted asphalt pavements over flexible bases (either existing HMA or unbound bases) performed better than non-warranted pavements in terms of PDI and had a lower rate of deterioration. IRI values for warranted pavements were also lower than for non-warranted pavements (Battaglia, 2009).

Changes since the five-year report included (Battaglia, 2009):

- Reducing the amount of the bond from 100–25% of the cost to overlay the entire pavement.
- Moving the requirement to rout and seal cracks from year four to year five.
- Adding a specification for a three-year warranty on functional HMA surface overlays.

WisDOT administration of the warranty program included a contact person in each of the five regions who was responsible for monitoring performance, coordinating with contractors on warranty work, etc. One person at the central office was responsible for managing the specifications, tracking the program and other issues. Decisions to require warranties on specific projects were made at the regional level (Battaglia, 2009).

Bid prices for non-warranted pavements included separate prices for mix, binder and tack plus prices for quality testing (materials and nuclear density) and incentive, but for warranted pavements, only one bid item for mainline HMA and one for ancillary pavement were included. Median bid prices were significantly lower (about \$5 to \$7 per ton) for warranted pavements in 2005, 2006 and 2007. In prior years and 2008, the median bid prices were also lower in most cases, but the differences were not significant. WisDOT concluded that the lower bid prices might have resulted from (Battaglia, 2009):

- More efficient mix designs,
- More efficient paving operations,
- Better estimates of the amount of binder needed when the contractor does mix design versus using the engineer's estimated quantities (would not apply for INDOT, which pays per ton of mix),
- More efficient quality testing, including reduced frequencies of testing when things are running smoothly.

After 12 years, there had still not been a need for conflict resolution, however about two projects each year did call for additional field reviews and meetings (Battaglia, 2009).

Total WisDOT staff time was estimated to be less for warranted than non-warranted pavements, resulting in a cost savings estimated to be over \$8 per ton, or 17%. Overall, WisDOT's warranty program was deemed successful and cost-effective (Battaglia, 2009).

A 2011 review of WisDOT's warranty and QA programs by the State's Legislative Audit Bureau (LAB) called the warranty program into question because of cost and management issues. That report recommended a reevaluation of the cost effectiveness of the program. Specific concerns expressed in the LAB report were that the costs to the department for repairs if the contractor was exempted from warranty work were not included, nor were long-term maintenance costs. In addition, it stated that the number of special inspection requests for warranted pavements had increased at high cost to the department (Battaglia, 2012).

Therefore, a new study reanalyzed the program by comparing the costs and performance of 38 warranted projects constructed between 2002 and 2006 to those of 37 conventional projects. That represented half of the warranty projects constructed during that time frame. The time period was selected for a number of reasons, including the fact that several warranty projects during this time period had experienced early distress. The projects were on US and state trunk highways and included new construction, reconstruction and overlays (Battaglia, 2012).

The costs evaluated included materials and construction, construction staff charges for DOT and consultants, maintenance and repairs, regional administration, and Pavement Data Unit (PDU) costs for performing routine and special inspections. The conclusion regarding costs was that the overall costs to the department were similar for the two types of contracts. The costs for maintenance and repair on the warranted pavements were lower but administration and monitoring costs (PDU) were higher. Only the costs for regional administration, routine surveys and special requests were statistically significant, but these costs were very low in comparison to the other costs (less than 1% of the total project cost) (Battaglia, 2012).

To reduce staff time devoted to administration of the warranty program, a contract was let for a consultant to manage the program centrally. Regional staff time was not completely eliminated. The cost appeared to be slightly higher with the consultant, but not a great deal higher (Battaglia, 2012).

The evaluation of the performance of this set of projects showed no consistent difference in performance. The ride qualities for pavements constructed under both types of contract were very good, with warranted pavements being significantly lower. The anticipated rehabilitation schedule was found to be similar for both types of contracts (Battaglia, 2012).

Although this report also indicated warranty contracting was a cost effective contracting mechanism (Battaglia, 2012), by 2013 the department had placed a moratorium on the use of warranties (WisDOT, 2013). In a personal conversation, a contractor from Wisconsin revealed that this was due in part to industry concerns, including the perceived inequity between asphalt paving, which could require a warranty, and concrete paving, which did not; inappropriate project selection; lack of a base course density specification until 2014, among other issues. The contractor also indicated the Department and industry were considering revisiting the warranty project.

2.3 Previous Indiana Research on Warranties

INDOT let its first warranty contract in 1996 using an A+B+C bidding concept. In this contracting method, the contractors bid on the cost of labor and materials (A) plus time (B). The time component included the contract days (at \$2,000/day), peak period lane closures (at \$13,800 each) and non-peak period lane closures (at $4,600 each); these costs represented the user delay costs. These costs were summed, and the contract was awarded to the lowest bidder. The C component was a five-year performance warranty (FHWA, 1996). A $500,000 bond was required, which represented about 20% of the cost of the warranted pavement.

The rehabilitation project (R-22232) was located on I-70 east of Indianapolis. Minimum standards were set for the materials (minimum PG 64-28 binder and Superpave-compliant aggregates), but the contractor had the option of using better materials and which mix design procedure to use; Superpave was still relatively new at the time. Milestone Contractors LLC was the low bidder and elected to use Superpave to design the mixes. In addition, they used Superpave mixture testing to get some assurance that the mixtures would perform well.

As the time incentives and warranty were inter-related, INDOT credited the contracting technique with encouraging early completion of the work. Incentives were provided for faster completion with disincentives for additional lane closures or construction days. The project was completed 55 days ahead of schedule with one-third fewer lane closures than anticipated. Based on this favorable result, as well as overall interest in innovative contracting, INDOT planned to let additional warranty contracts (FHWA, 1996).

It is important to note that a great deal of planning and communication preceded this contract award. In fact, deliberations began in 1994 between agency and industry partners (FHWA, 1996). A working group discussed the contract requirements, distresses to warrant and threshold limits. The INDOT PMS was used to analyze pavement performance of existing roadways to set the limits at which remediation would be required so that at the end of the five-year warranty period, the pavement would be in such a condition that it would be expected to perform for ten more years (the design life was 15 years (FHWA, 1996)). INDOT and contractors took a tour of existing roadways to gain an understanding of the practical significance of the threshold limits and to show that meeting the limits was feasible (Stephens et al., 1998).

The distresses covered by the warranty included ride quality (IRI), rut depth, longitudinal cracking and friction. As noted in preceding sections of this report, many other distresses could be considered, but the working group felt that ride quality would capture the effects of many of these distresses and would be more objectively and efficiently measured (using automated equipment). Annual surveys were conducted to monitor the performance.

As mentioned earlier, INDOT's contract included an "escape clause" for the contractor. The warranty would be waived if the traffic level exceeded a certain limit (Class 5 trucks 50% above the estimate), if the base thickness was thinner than expected (by 50 mm) or if the subgrade density was too low (less than 90% of optimum) (Stephens et al., 1998). These three factors could have significant effects on pavement performance.

During the warranty period, problems with the pavement friction did arise, which compelled the contractor to mill and repave the surface in 1998. The low friction values were attributed to the loss of macrotexture, which in turn was related to low mixture stiffness. Although the rut depths had not exceeded the threshold limit, they were increasing, hence the decision to mill and fill rather than apply a microsurface. In a later warranty project by this contractor, stiffer binder was used and there was even more attention to detail, resulting in excellent performance (Huber, 2000). After 14 years, this second project had an average rut depth of 0.08 in. and IRI values of 30 in./mi or less (Huber, 2000).

INDOT did, in fact, let additional warranty contracts including nine more warranted asphalt projects between 1996 and 2005. (Warranties have also been used in Indiana for portland cement concrete pavements, microsurfacing, erosion control and bridge painting.)

In 2004, Gallivan et al. (2004) published a TRB paper in which they evaluated the performance and cost effectiveness of Indiana's asphalt pavement warranty projects. At the time, three of the warranty projects they evaluated had outlived the five-year warranty period and four remained under warranty. All of the projects were overlays over cracked and seated or rubblized concrete pavement on interstate routes. Two of the warranted pavements had experienced low friction numbers necessitating surface replacement during the warranty period, including the first project on I-70.

The authors explained that the INDOT warranty provisions were established by statistically analyzing data from the Pavement Management System (PMS). The criteria for smoothness (IRI), rutting, cracking and friction were set at two standard deviations above the mean for five-year-old pavements that were performing well. PMS data was used to monitor the performance of the warranted pavements to ensure that objective measurements were used. In this paper, the warranted pavement performance was compared to that of four- to six-year-old interstate pavements. Friction data was available at 1.6 km (1-mi) increments, except for the warranted pavements where special friction testing was conducted at 0.16 km (0.1 mi.) increments. The remaining condition data was analyzed in 0.16 km (0.1 mi.) segments (Gallivan et al., 2004).

The results indicated that the warranted pavement sections were smoother and less variable than the conventional pavements. In addition, the warranted pavements had less rutting and less variability than the other interstate projects. Using average deterioration curves developed using the PMS data, the service lives of the different types of pavements were estimated at about 15 years for the conventional pavements and about 24 years for the warranted pavements. That is, the warranted pavements would be expected to reach roughness and rut depth values similar to those of conventional 15-year-old pavements when they reached an age of about 24 years (Gallivan et al., 2004).

The authors went on to explore the cost effectiveness of warranty contracts by looking at capital costs to maintain the system for 25 years under warranty and conventional rehabilitation scenarios. The analysis suggested that using warranties to rehabilitate the network resulted in about a 27% cost savings over the 25-year period while the increased initial costs of the warranty projects were estimated to be about 10%. The ultimate conclusion of the study was that warranties provided "smoother and safer pavements with fewer defects over a longer period of time, which reduces delays and congestion" (Gallivan et al., 2004).

By pairing five of INDOT's asphalt warranty contracts with conventional projects and exploring the agency and user costs as well as pavement performance, Oh et al. (2006) evaluated the medium- (five year) and long-term (treatment service life) cost effectiveness of warranties. The five comparison sets consisted of contracts with similar traffic, type of project, location, length, number of lanes, thickness and year of construction. The costs were estimated in terms of equivalent uniform annual costs. Agency costs included initial construction costs and maintenance costs. For warranty projects, the contractors carried the maintenance costs during the warranty period. User costs considered delay costs during lane closures and traffic disruptions. Pavement performance was measured in terms of IRI. The service life was the time until the IRI value signifying a need for rehabilitation was reached; this is not the same as the warranty threshold, which was set lower to ensure the pavement would perform for some time after the warranty ends (Oh et al., 2006).

The results of the analysis showed that the warranty pavements had significantly lower roughness values than traditional pavements in the medium term. Agency costs for the initial construction were higher, but user costs were lower due to shorter work-zone durations. Incentives, typically included in warranty contracts, encouraged faster construction. [Incentives without warranties may also be effective in accelerating construction, but incentives without warranties were not investigated in this study]. The agency did not incur maintenance costs for the duration of the warranty. Overall, the warranty projects were 27–30% less cost-effective in the medium term (Oh et al., 2006).

Over the longer term, however, services lives were significantly longer for the warranty vs. conventional pavements (25 vs. 15 years on average). Warranty projects were found to be significantly more cost-effective over the long term; approximately 70–90% more cost effective in terms of service life and 58–65% more effective when both service life and pavement condition (IRI) were considered (Oh et al., 2006).

Warranty projects had lower roughness values at the time of construction (Oh et al., 2006); roughness has been shown in other research to have a major impact on service life with smoother pavements performing better longer (Smith et al., 1997).

The remainder of this report extends the evaluation of the performance of all ten warranted projects constructed in Indiana. The warranty period has now expired for all of the projects, and six were still in service in 2014.

3. PERFORMANCE OF INDIANA'S WARRANTED ASPHALT PAVEMENTS

3.1 Effectiveness of Warranted Pavements

This section summarizes the results of examination of the data from Indiana's ten asphalt pavement warranty projects. There were several approaches to analyzing the data. The first, reported here, compared the overall performance of the warranted pavements to the overall performance of non-warranted interstate projects. Specific pairwise comparisons of warranted and conventional pavements are presented in the next section.

3.1.1 Analysis Approach

The INDOT uses IRI, rut depth, cracking, and friction as the criteria to measure the performance of warranted asphalt pavements. These criteria are considered reliable indices to evaluate the pavement condition since they are aligned with public priorities for highway improvement, which include smoother pavement, better safety and less traffic congestion (Gallivan et al., 2004; NCI Steering Committee, 1996). The threshold levels specified in the warranty provisions were set by analyzing data in the pavement management database. The intent was to set the five-year performance criteria such that the pavement would continue to perform well for at least ten more years. Thus, the data for well-performing five-year-old pavements were analyzed and the thresholds were set at the mean value plus two standard deviations (Gallivan et al., 2004).

In reviewing the available data, IRI and rut depth were the two factors easily found that could be used to evaluate the performance and service lives of warranted asphalt pavements. These data were from the INDOT pavement management system database. While cracking and friction data do exist, the spatial locations of the data are reported differently, and so it is problematic to assign cracking and friction data to the same locations as IRI and rutting data. Also, cracking data was not readily available for all of the years of interest. However, as a measure of smoothness, the IRI values are affected by cracking, so that cracking is somewhat represented in the analyses, if only by a surrogate. Friction data was obtained from special friction testing on the warranted pavements for five years after construction. Additional years of friction data on the warranted pavements and all of the friction data for the non-warranted pavements were pulled from the friction inventory. An attempt was made to be conservative in selecting the data to use to ensure that the data was collected within the projects' limits.

Contract number, length, year of construction, and warranty period for each of the ten warranted asphalt

TABLE 3.1
Indiana's warranted asphalt pavement projects..

Contract Number	Location	Length(km)	Construction Year	Warranty Period (yrs.)
R-22925	I-69, DeKalb County	14.50	1997	5
R-22854	I-65, Bartholomew/Shelby County	6.45	1997	5
R-22232	I-70, Hancock County	7.95	1996	5
R-23500	I-65, Tippecanoe/ White County	27.57	1999	5
R-23390	I-74, Shelby County	17.66	1998	5
R-23898	I-74, Hendricks County	7.77	1999	5
R-24327	I-65, Marion County	8.13	2002	5
R-25142	I-64, West of Owensville Rd	14.50	2002–2003	5
R-25808	I-64, near Illinois state line	17.72	2002–2003	5
R-27533	I-465, From I-65 to W 86PthP St.	4.83	2007	5

pavements placed in Indiana since 1996 are shown in Table 3.1.

To evaluate the performance of warranted asphalt pavements and compare them to data from non-warranted asphalt pavements, the data from a set of non-warranted asphalt pavements were also taken from the INDOT pavement database. The set of non-warranted pavements were selected from similar types of projects and traffic levels as the warranted pavements. In order to minimize bias in analyses, the non-warranted pavement sections were selected to have the same age distribution as the warranted pavement sections. The average age for both contract types (warranted and non-warranted) was 11 years with a standard deviation of 3 years, and a minimum and maximum age of 5 and 15 years (6 and 16 years for friction data), respectively. Any concrete sections, such as bridge approaches, were eliminated from both the warranted and non-warranted datasets.

3.1.2 Results and Discussion

3.1.2.1 Pavement Performance and Smoothness. Histograms of the IRI and rutting performance data and friction numbers for warranted and non-warranted pavements were developed to graphically compare their distributions (Figure 3.1, Figure 3.2 and Figure 3.3).

As shown in Figure 3.1, the IRI data for the warranted pavement sections is shifted slightly more to the left than is the data for non-warranted sections, indicating that, in general, warranted asphalt pavements have slightly lower IRI values than do non-warranted asphalt pavements. The data in Figure 3.1 indicate that 96% of the warranted sections had IRI values less than or equal to 1.9 m/km (120 in./mi), whereas only 87.5% of non-warranted pavement sections had IRI values this low. Additionally, 6% of the non-warranted sections had IRI values greater than 2.8 m/km (180 in./mi), while only 1% of warranted sections' IRI values were greater than 2.8 m/km (180 in./mi).

The average IRI values for the warranted and non-warranted asphalt pavement sections are 0.90 m/km (56.9 in./mi) and 1.19 m/km (75.1 in./mi) with standard deviations of 0.41 m/km (25.9 in./mi) and 0.65 m/km (41 in./mi), respectively. A Student's t-test (α=0.05) was used to test the difference of the means and it was found that the warranted and non-warranted means are significantly different. Thus, on average, IRI values were improved approximately 24% by implementation of asphalt pavement warranties. IRI data variability was also decreased by 37% with the implementation of the warranties.

The rutting data suggests that INDOT has done a good job of limiting the amount of rutting in asphalt pavements. Figure 3.2 shows the rutting data for the warranted pavements is again shifted slightly more to the left than is the data for non-warranted pavements, indicating that, in general, warranted asphalt pavements have slightly lower rut depths than do non-warranted asphalt pavements. The data indicate that 84.5% of the warranted sections had rut depths less than or equal to 3 mm (0.125 in.), whereas only 80% of non-warranted pavement sections had rut depths this low. Additionally, approximately 3% of the non-warranted pavement sections had rut depths of 6 mm (0.25 in.) or greater, while only 1% of warranted pavement section rut depths fell into this range.

The average rut depth of the warranted asphalt pavements was 2.13 mm (0.08 in.) with a standard deviation of 1.10 mm (0.04 in.). The average rut depth for the non-warranted asphalt pavements was 2.3 mm (0.09 in.) with a standard deviation of 1.4 mm (0.05 in.). Again, a Student's t-test (α=0.05) was used to determine if the mean rut depths of the two contract types (warranted and non-warranted) were significantly different. In general, rut depth was improved by 7% with the use of warranty

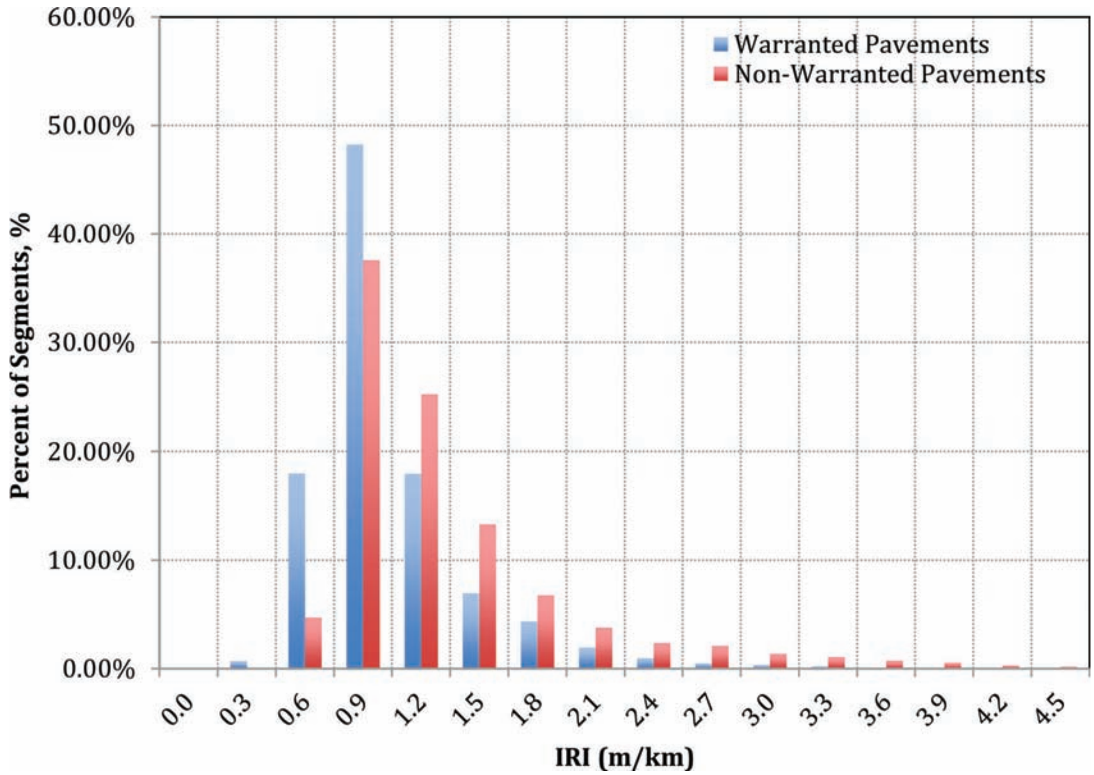

Figure 3.1 IRI distribution.

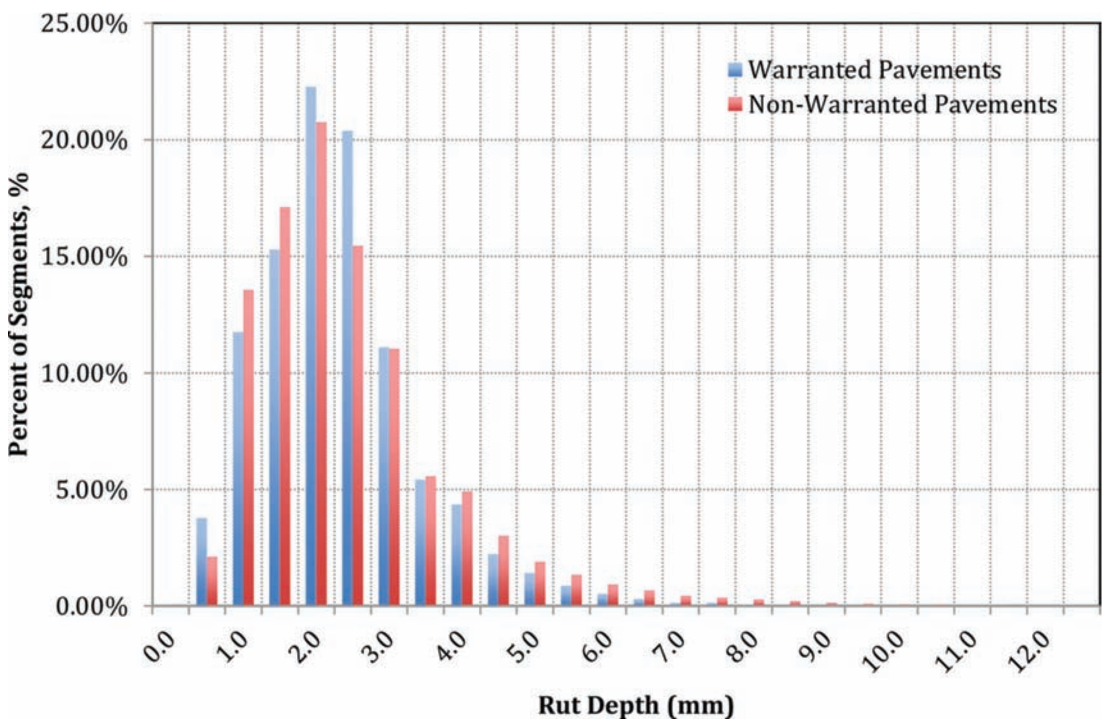

Figure 3.2 Rut depth distribution.

contracts while rut depth variability decreased by 20%. While the mean rut depth for the warranted asphalt pavement sections was only 7% less than that of the non-warranted sections, it is important to consider that, as a whole, the rut depths for all the pavement sections, both warranted and non-warranted, are minimal.

The distribution of the friction numbers at 40 mph is shown in Figure 3.3. The histogram indicates that 92%

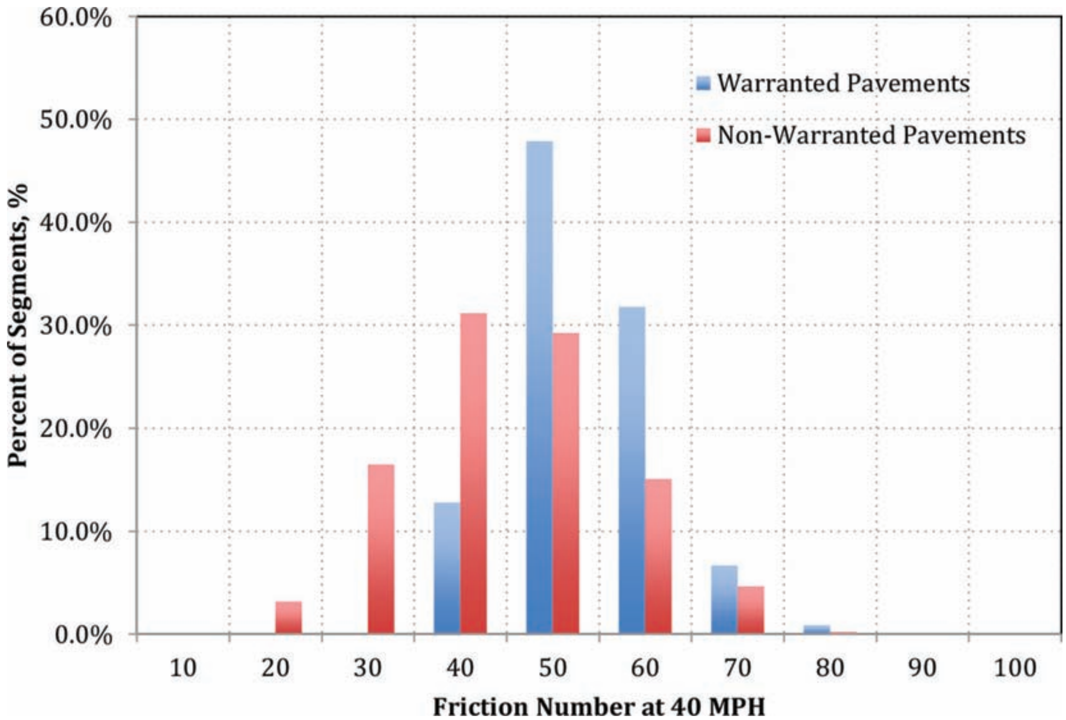

Figure 3.3 Friction number at 40 mph distribution.

of the warranted sections' friction numbers fall between 40 and 60, whereas only 75% of the non-warranted sections' friction numbers are in this range. In fact, 20% of the non-warranted segments have friction numbers less than 35 which require remedial activities.

The average friction numbers of the warranted and non-warranted pavements were 48.43 and 40.23, respectively. The standard deviations were 7.72 for warranted pavements and 11.37 for non-warranted sections. A Student's t-test (α=0.05) showed the difference between the mean friction numbers of the two contract types was statistically significant. This implies that the friction numbers of the warranted section was higher than the other contract type projects.

3.1.2.2 Deterioration Rate and Service Life. The IRI and rut depth data were used to develop deterioration curves for both warranted and non-warranted asphalt pavement sections to project what the expected service lives and performance levels would be in the absence of other distresses. In Figure 3.4 and Figure 3.5, each square represents the average non-warranted sections' IRI value or rut depth at the corresponding pavement age. The circles represent the same data for warranted pavement sections. Exponential curves were fitted to the data points in both Figure 3.4 and Figure 3.5 using the least squares method. Although an exponential curve gave the best fit in each case, the regression fit of the IRI data is poor. This is likely due to the wide variability in asphalt pavement IRI values. While the wide variability in as-constructed IRI values can be high, the analysis should consider the initial IRI values since the initial IRI values affect the short- and long-term performance of the pavement. While the regression fit for the warranted sections' rut depths is also poor, the non-warranted rut depth data have a very good fit with an exponential curve.

While the exponential best-fit curves are less than desirable, comparison of the data can be used to make some general observations. For example, Figure 3.4 clearly shows that, at every age, the warranted asphalt pavement sections had better IRI performance than the non-warranted sections.

To compare the service lives of the two contract types, the 15-year IRI values were calculated from the regression equations. The 15-year IRI of non-warranted asphalt pavement sections was 16% higher than that of the warranted sections, 1.21 m/km (76.7 in./mi) versus 1.02 m/km (64.2 in./mi). Also, the regression curves indicate that it would take an additional 14 years for the IRI of the warranted pavement sections to reach the same level as the 15-year-old non-warranted sections (1.21 m/km (76.7 in./mi)).

The data in Figure 3.5 show the rut depth differences between warranted and non-warranted asphalt pavement sections is less than 0.5 millimeter (less than 0.02 in.) over the first 6 years of pavement life and is never very great. However, the rate of deterioration for non-warranted sections does appear to be higher than for warranted pavement sections, meaning that non-warranted pavements may develop rutting more quickly than do warranted asphalt pavements. The regression curves indicate that it would take an additional 10 years for warranted asphalt pavements to reach the same rut depth as 15-year-old non-warranted asphalt pavements.

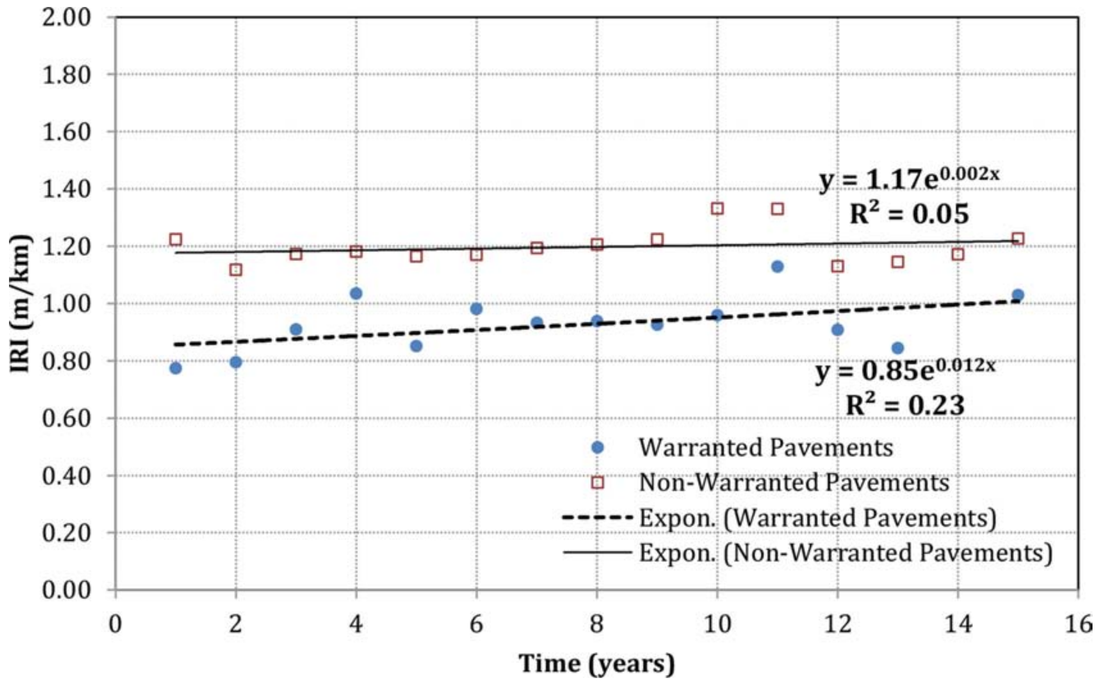

Figure 3.4 IRI deterioration trend.

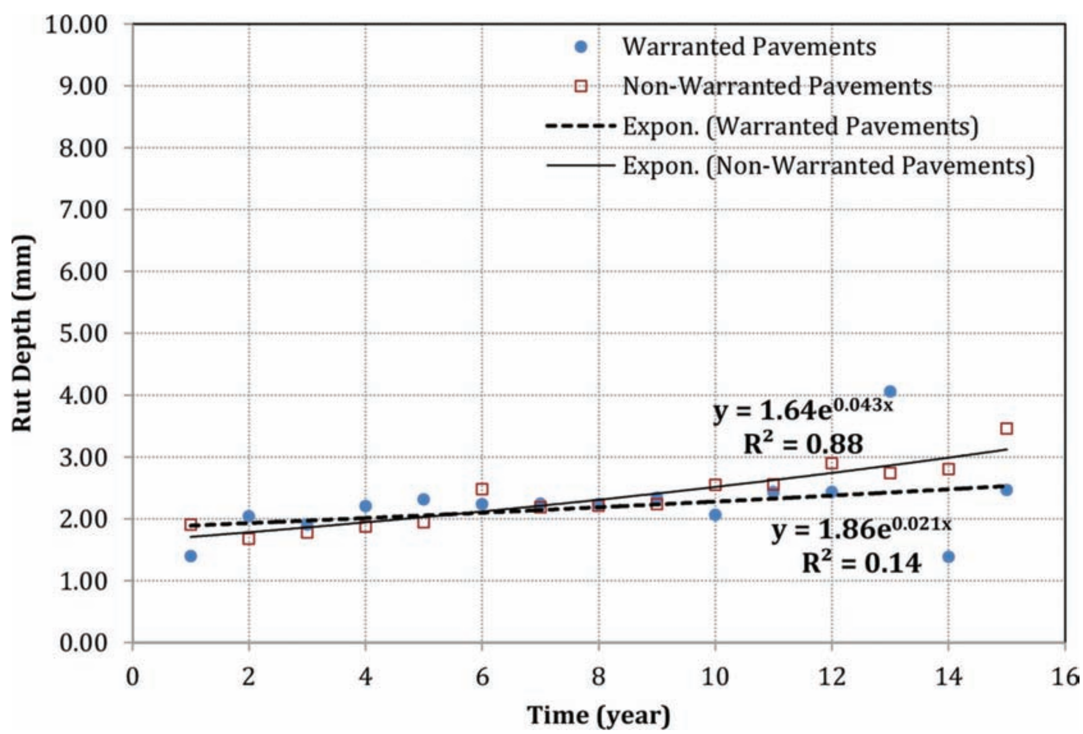

Figure 3.5 Rut depth deterioration trend.

3.1.2.3 Construction and Maintenance Cost Comparison. Although warranted asphalt pavements appear to perform better than non-warranted asphalt pavements, the non-warranted pavements are on average 5–10% less expensive than warranted asphalt pavements in terms of initial capital costs (Gallivan et al., 2004). Thus, cost effectiveness of warranted asphalt pavements can be determined only after evaluating the maintenance and initial costs simultaneously. INDOT has set threshold values of 1.4 m/km (90 in./mi) for IRI and 6 mm (0.25 in.) for rut depth. If the IRI or rut depth of any 100 m segment (325 ft.) exceeds one or both of the thresholds, the section receives remedial action. By determining the number of 100 m segments at or above

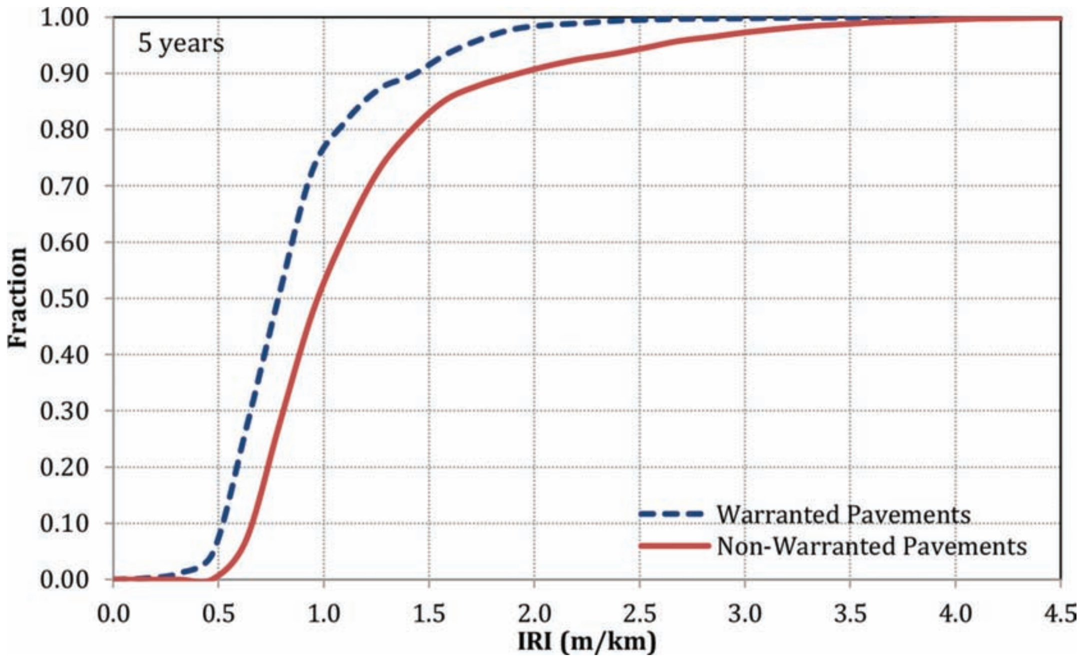

Figure 3.6 Cumulative distribution functions for short-term IRI performance.

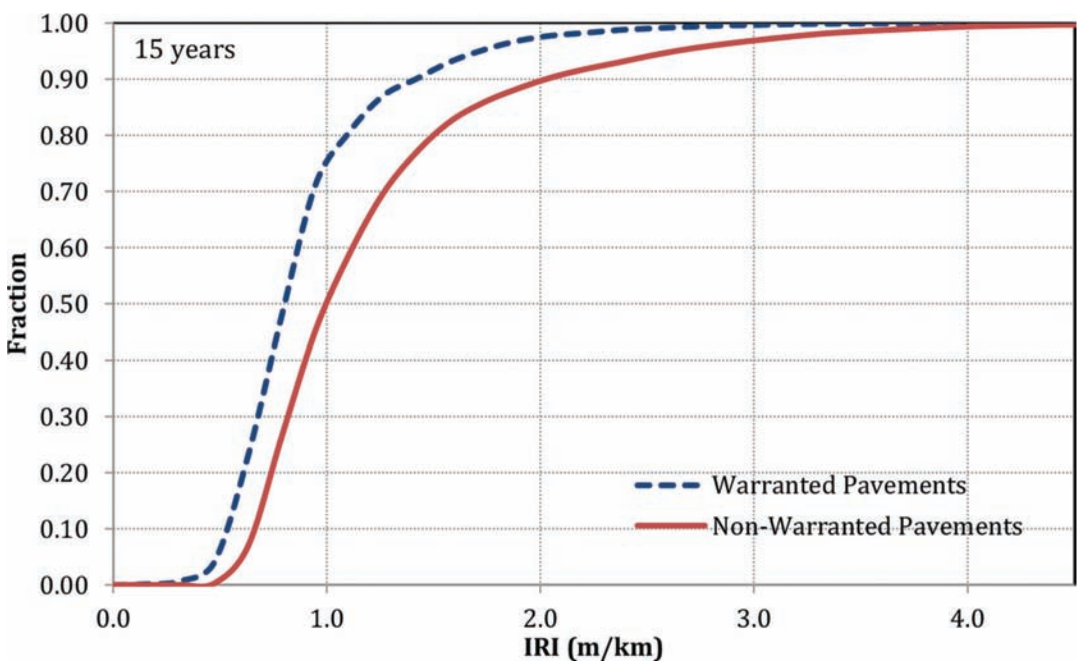

Figure 3.7 Cumulative distribution functions for long-term IRI performance.

these criteria, the maintenance costs can be established for both warranted and non-warranted asphalt pavements.

Figure 3.6 through Figure 3.9 display the cumulative distribution functions (CDF) for IRI and rut depths over short (5 years) and longer (15 years) terms. The use of CDF makes it possible to find the percentage of the 100 m segments having IRI values or rut depths equal to or less than a specific IRI or rut depth value.

In the both short and longer terms, 90% of the warranted asphalt pavement sections had IRI values equal to or less than 1.4 m/km (90 in./mi); thus only 10% of the warranted segments would have needed remedial action over a 15-year life. On the contrary, in the short-term, 20% of the non-warranted pavement sections and 23% in the long-term would have needed remedial action regarding IRI criteria (Figure 3.6 and Figure 3.7). In other words, maintenance costs for the warranted asphalt pavements were reduced by 50% (10% rather than 20%) in the short-term and 57% (10% rather than 23%) in the long-term regarding IRI criteria.

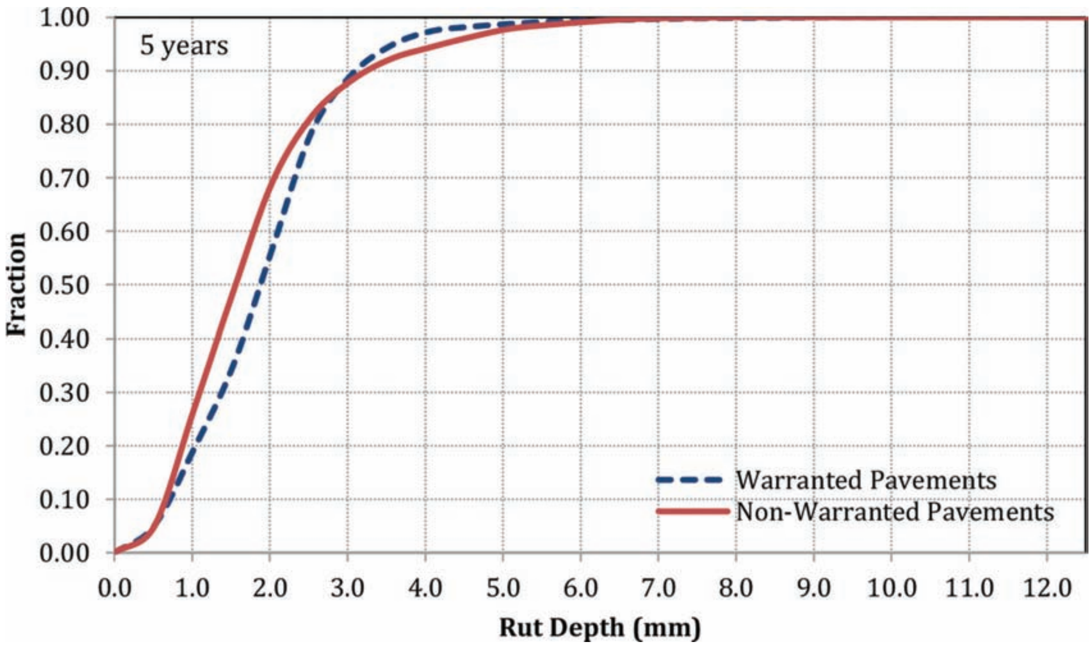

Figure 3.8 Cumulative distribution functions for short-term rutting performance.

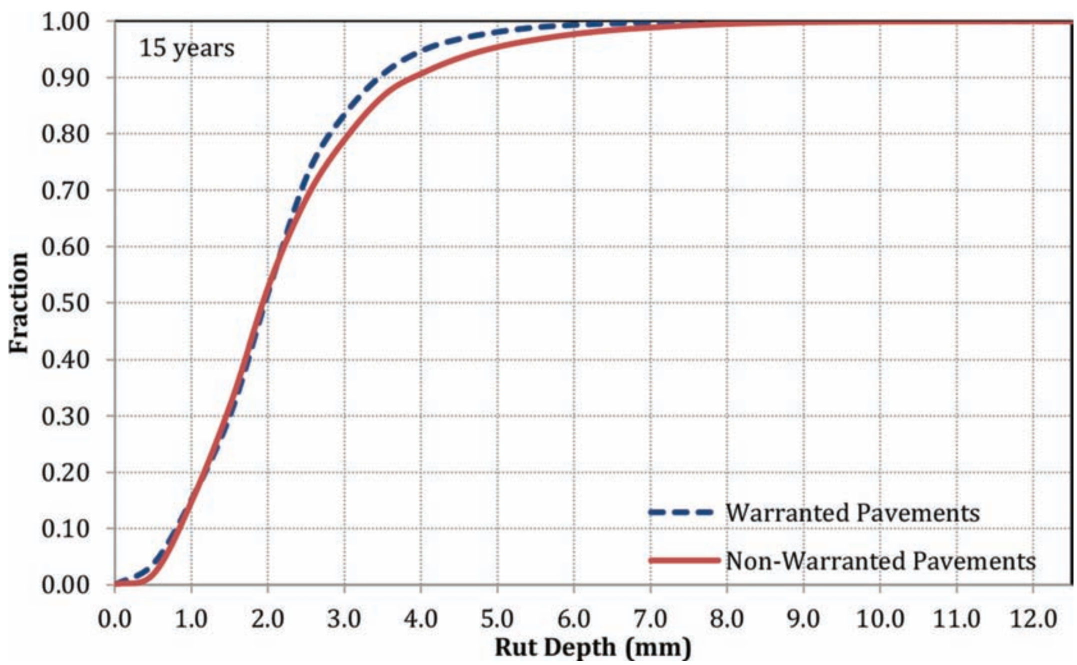

Figure 3.9 Cumulative distribution functions for long-term rutting performance.

In similar fashion, the percentage of warranted asphalt pavements that exceeded the rut depth threshold were 0.6% in both the short- and long-term, whereas 0.8% and 2.1% of the non-warranted sections exceeded the threshold in the short- and long-term, respectively. Accordingly, the maintenance costs for remediating rutting problems could be potentially reduced by 25% (0.6% rather than 0.8%) in the short term and 71% (0.6% rather than 2.1%) in the long term by implementation of asphalt pavement warranties (Figure 3.8 and Figure 3.9).

3.2 Comparison Sets

In 2004 Singh et al. evaluated the cost effectiveness of asphalt pavement warranties by comparing five warranty projects to similar non-warranted projects constructed in the same year with similar designs and traffic levels (Singh et al., 2005). At the time of that study, three to five years of performance data was available for the pairwise comparisons. These same comparison sets are used again in this study to examine the performance trends with additional years of data.

TABLE 3.2
Warranted and non-warranted contracts used in comparison sets.

Comparison Set	Warranted Project		Non-Warranted Project	
	Contract	Service Life	Contract	Service Life
1	R-22232	16	R-21607	11
2	R-22854	17	R-21602	10
3	R-22925	14	R-22912	11
4	R-23390	12	R-21607	11
5	R-23898	>16	R-22923	14

These projects are compared in terms of projected service lives based on regression analysis of the performance data as well as actual service lives based on reported rehabilitation work.

3.2.1 Analysis Approach

In this section, the five comparison sets, including a warranted project and a comparable non-warranted project, used by Singh et al. (2005) were analyzed and re-evaluated with more data. The non-warranted projects were designed and built in traditional way with similar properties to the warranted projects, such as construction year, thickness of the pavement, traffic volume and geographical location. This approach enables comparing the performance, smoothness and service lives of the pavements since the other affecting factors are similar.

Table 3.2 indicates each comparison set including the warranted project and the paired conventional project. The service lives for each project were estimated by years from the original contract award date to the award of subsequent construction work (according to district information or the contract history database). Warranty project R-23898 is still in service. The surface of warranty project R-22232 was milled and replaced in 1998 during warranty period because of low friction; using that date would shorten the service life by two years. Table 3.2 shows that all the warranted projects actually performed longer and outlasted the similar conventional pavements by one to seven years. The pavement performance and smoothness for each comparison set is compared and discussed in the following sections.

3.2.2 Comparison Set 1

Warranted Project R-22232 is compared to the conventional project R-21607 in Comparison Set 1. Warranted project R-22232 was built on I-70 in Hancock County from 0.7 mile east of SR-9 to 5 miles east of SR-9. The paired conventional project R-21607 was placed on I-69 from the SR-67 intersection at Daleville to 0.25 mile north of SR-32 in Delaware County. Both projects have similar functional classes, construction years, contract lengths and pavement structures (overlays over cracked and seated concrete). The annual average daily traffic (AADT) and percentage of trucks for the warranted pavement were 14% and 1% more than those of the non-warranted pavements in 2002 (Singh et al., 2005). The warranted project was overlaid in the final year of the warranty at the contractor's expense (Singh et al., 2005).

Figure 3.10 displays the IRI comparison for both warranty and non-warranty projects during their service lives. Each data point represents the average value of the sections' IRI at the corresponding age. The plot shows overall that the warranted pavement performed with lower IRI values during its service life and provided a smoother pavement compared to the non-warranted pavement.

The exponential curves were fitted to the data points based on least square method and extended to 25 years, which is the service life of the warranted pavements predicted by Singh et al. (2005). They predicted that after 25 years, the warranted pavements' IRI would reach 200 in./mi, which defines terminal serviceability. Based on their model and five years of data, it would take 15 years for traditional pavements' IRI to reach 200 in./mi (Singh et al., 2005). In fact, based on ten more years of data, Figure 3.10 indicates that the IRI of the non-warranted pavement would reach 200 in./mi after 24 years, while the warranted pavement's IRI would be less than 200 in./mi after more than 25 years. Although the service lives of both warranted and non-warranted pavements have ended, the predictive curves help us to understand how long the pavements could have performed if reasons other than IRI had not led to them being resurfaced.

Figure 3.11 displays the rutting performance comparison for both the warranted and non-warranted pavements in Set 1 during their service lives. In the first two years, the rut depth of non-warranted pavement was less than that for warranted project. However, the difference was not significant (less than 0.04 in.). Rut depths for both the warranted and non-warranted pavements were minimal over their service lives, while the variability in rutting of the non-warranted pavement was higher.

Comparison of friction numbers for both warranted and non-warranted projects in Set 1 is shown in Figure 3.12. In the first ten years, the friction numbers for both warranted and non-warranted pavements ranged from 36 to 59. Friction numbers increased after the tenth year for warranted pavement to a maximum value of 66.

Based on the actual service lives, the warranted pavement lasted five years longer than the non-warranted pavement. Although the traffic loads and truck percentages were higher for the warranted pavement, the warranted pavement performed longer and more cost-effectively compared to the similar non-warranted pavement.

3.2.3 Comparison Set 2

The second comparison set includes warranted project R-22854 and the comparable conventional pavement

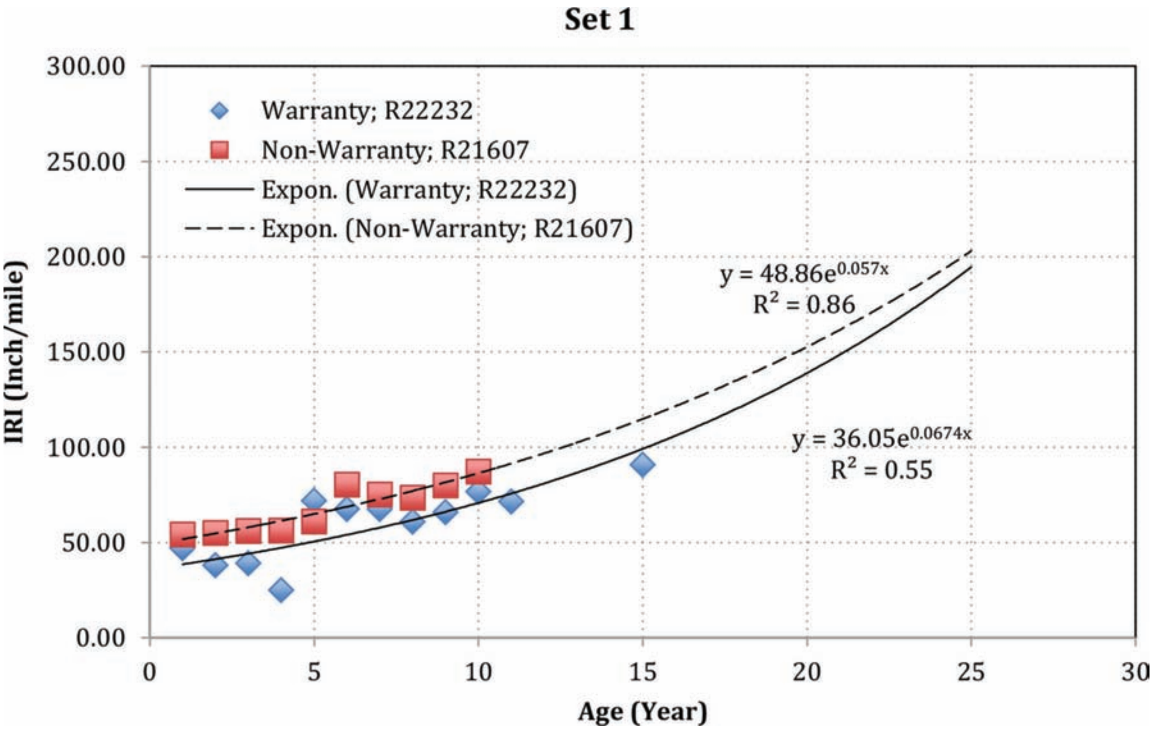

Figure 3.10 IRI performance comparison for Set 1.

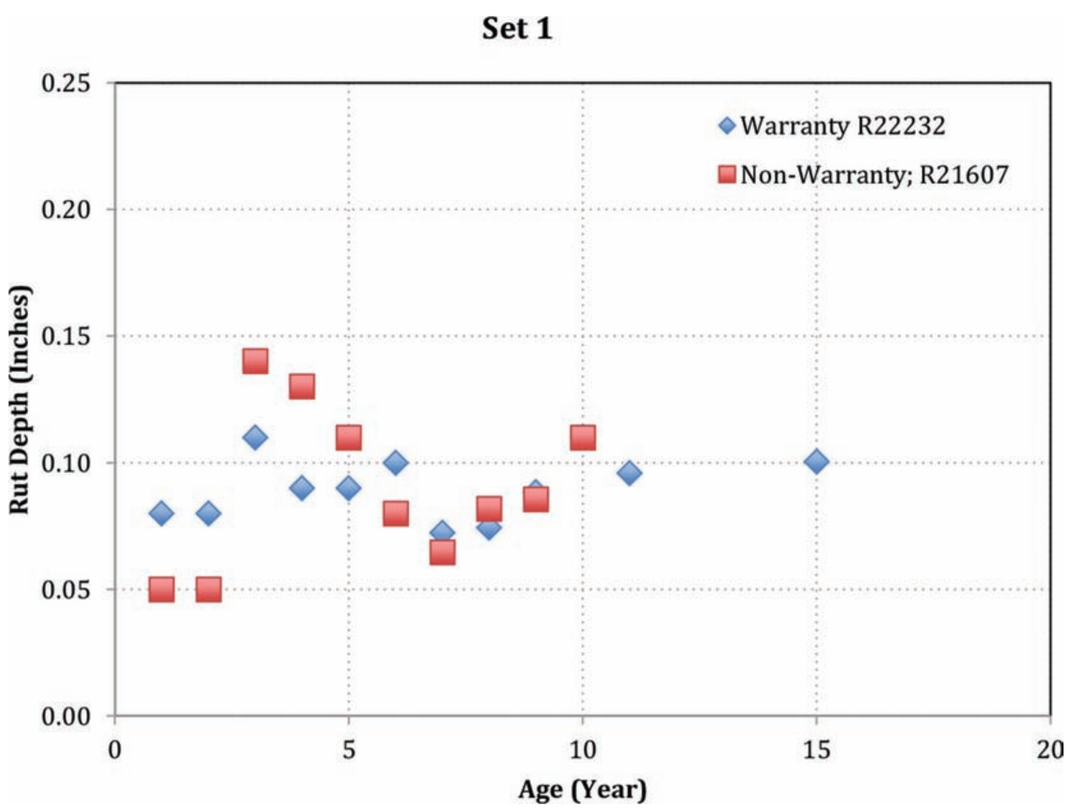

Figure 3.11 Rutting performance comparison for Set 1.

R-21602. R-22854 is located on I-65 from 0.26 mile north of US-31 to 0.5 mile north of SR-252 in Bartholomew County. The non-warranted pavement R-21602 is located from a point 0.26 mile north of US-31 in Huntington County and ends at a point 0.5 mile north of SR-252. Both projects have similar functional class, pavement

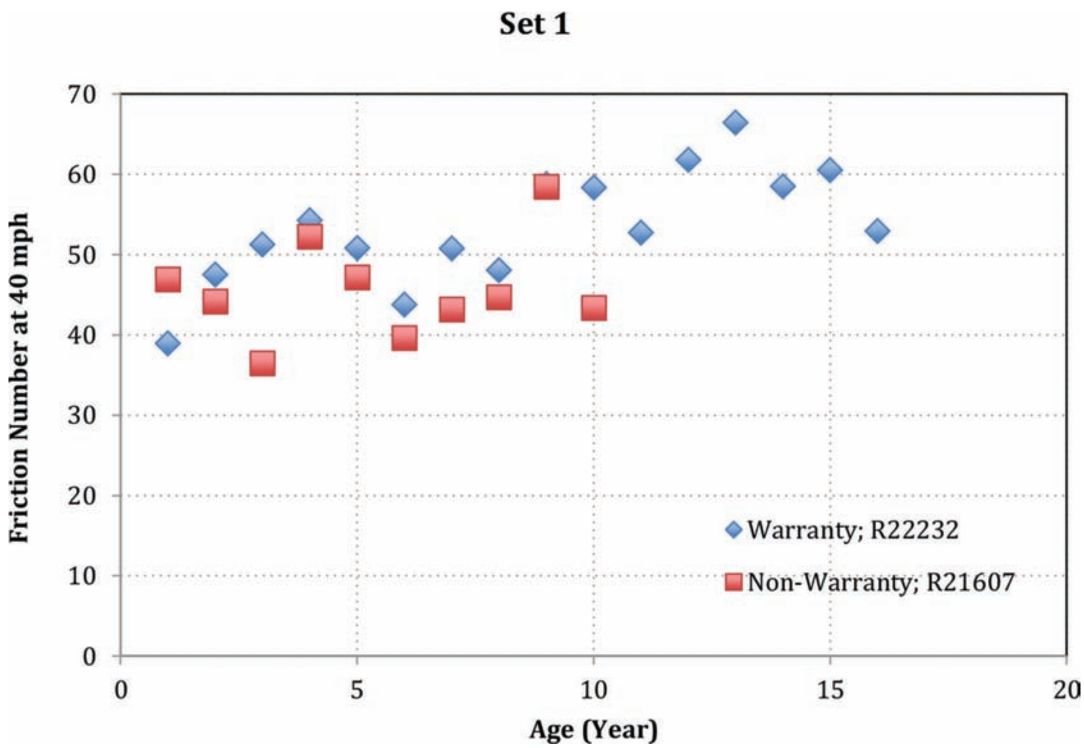

Figure 3.12 Friction number comparison for Set 1.

structure (overlay over cracked and seated concrete) and construction year. The AADT was 35% higher for the warranted pavement in 2002, while the truck percentage for the non-warranted pavement was 4% greater. In addition, the thickness of the overlay on the warranted pavement was 3 inches thicker than that for non-warranted pavement (Singh et al., 2005).

IRI and rutting performance for the two contract types are shown in Figure 3.13 and Figure 3.14, respectively. The IRI of the warranted pavement ranged from 34 to 57 in./mi over its service life, whereas the IRI of the non-warranted project ranged from 51 to 82 in./mi and is greater than the IRI of warranted project at all ages with higher variability. The exponential curve shows that the IRI of the non-warranted pavement would have reached 200 in./mi after about 22 years. Although the correlation observed for the exponential curve of the warranted project data points is very weak, the plot implies that the warranted pavement's IRI did not increase significantly over its service life and remained in the same range over 16 years.

Rut depth data points vary between 0.06 and 0.13 in. for both contract types, as shown in Figure 3.14. There is a slight increase in rut depths of the warranted project in the last two years of its service life. Both warranted and non-warranted pavements had minimal rutting.

Figure 3.15 demonstrates the variation of the friction numbers for both the warranty and non-warranty projects during their service lives. Overall, the friction numbers observed for the non-warranty project were lower than those of the warranty project in the first nine years. However, the numbers for both projects are in the range that does not need remedial action. The friction numbers of the warranted pavement increased after the tenth year with the highest value of 64 in the twelfth year of its service life.

Although both projects were constructed in the same year and higher traffic loads passed over the warranted pavement, the actual service life of the warranted pavement was seven years longer than the traditional pavement, and it performed more cost-effectively during its service life. The additional overlay thickness no doubt contributed to this performance, but presumably there was a need for the extra thickness identified at the pavement design stage, possibly because of the traffic level, subgrade and/or base conditions and condition of the concrete pavement.

3.2.4 Comparison Set 3

Comparison Set 3 includes warranted project R-22925 and non-warranted project R-22912. R-22925 was located on I-69 in DeKalb County. The control project, R-22912, started 1.97 miles north of SR-5 and ended 0.38 mile south of US-224 in Huntington County. The structure of the pavements (6 in. overlay over cracked and seated concrete), years of construction and their functional classes are the same. The AADT on the warranted pavement was 24% higher than the non-warranted pavement in 2002. However, the truck percentage was 3% higher for non-warranted project.

Figure 3.16 through Figure 3.18 show the performance and smoothness comparison between the two contract types. The IRI values of both projects were

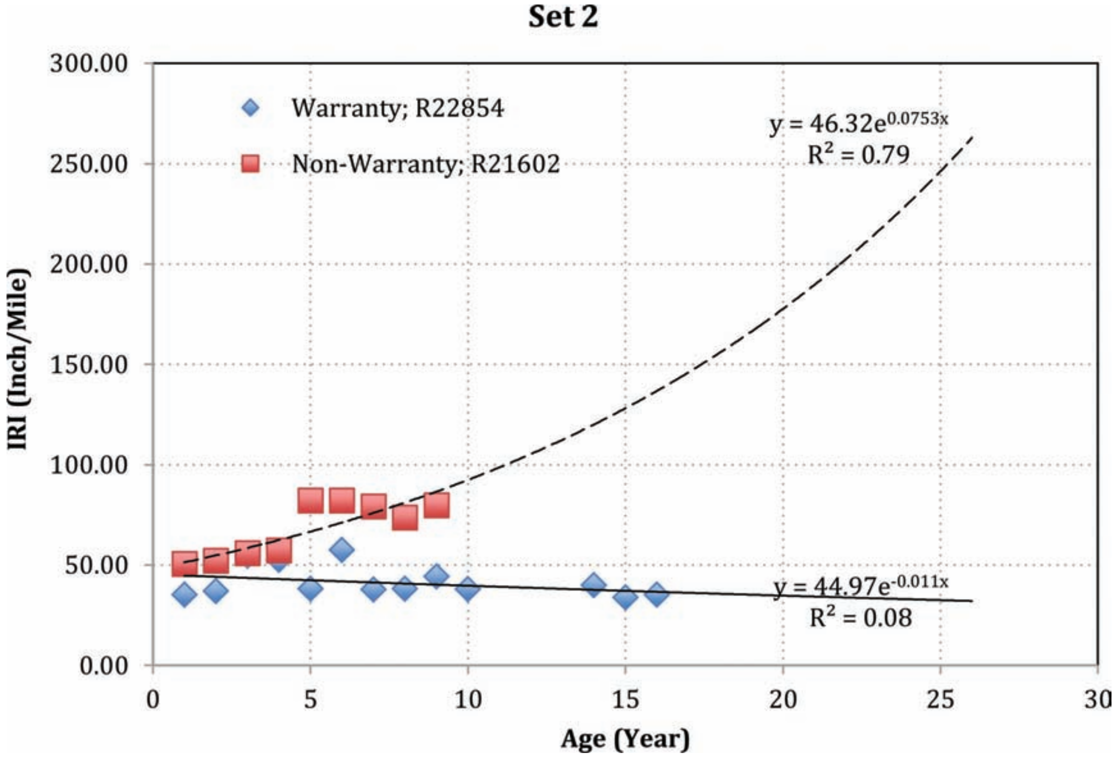

Figure 3.13 IRI performance comparison for Set 2.

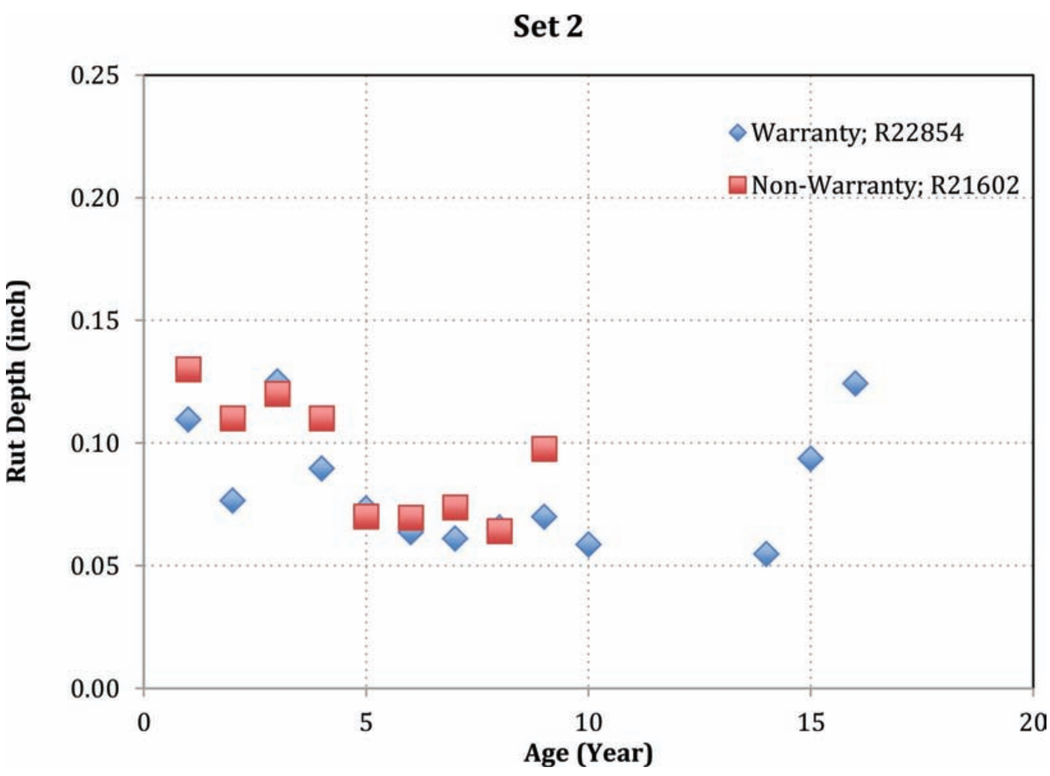

Figure 3.14 Rutting performance comparison for Set 2.

satisfactory since neither would have reached 200 in./mi after 25 years according to the exponential curves although the correlation is not very strong. In addition, during their service lives, on average, neither exceeded the threshold of 90 in./mi that would have triggered remedial activities. At 25 years, the projected IRI for the warranted pavement approached 100 in./mi, while the non-warranted pavement's IRI was less than 100 in./mi. This difference

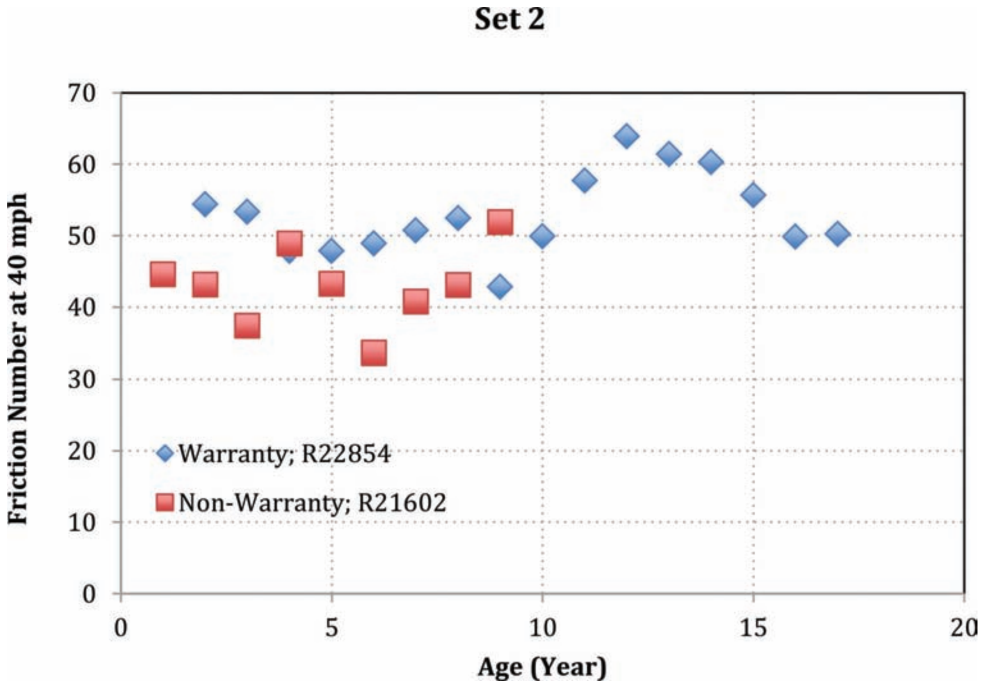

Figure 3.15 Friction number comparison for Set 2.

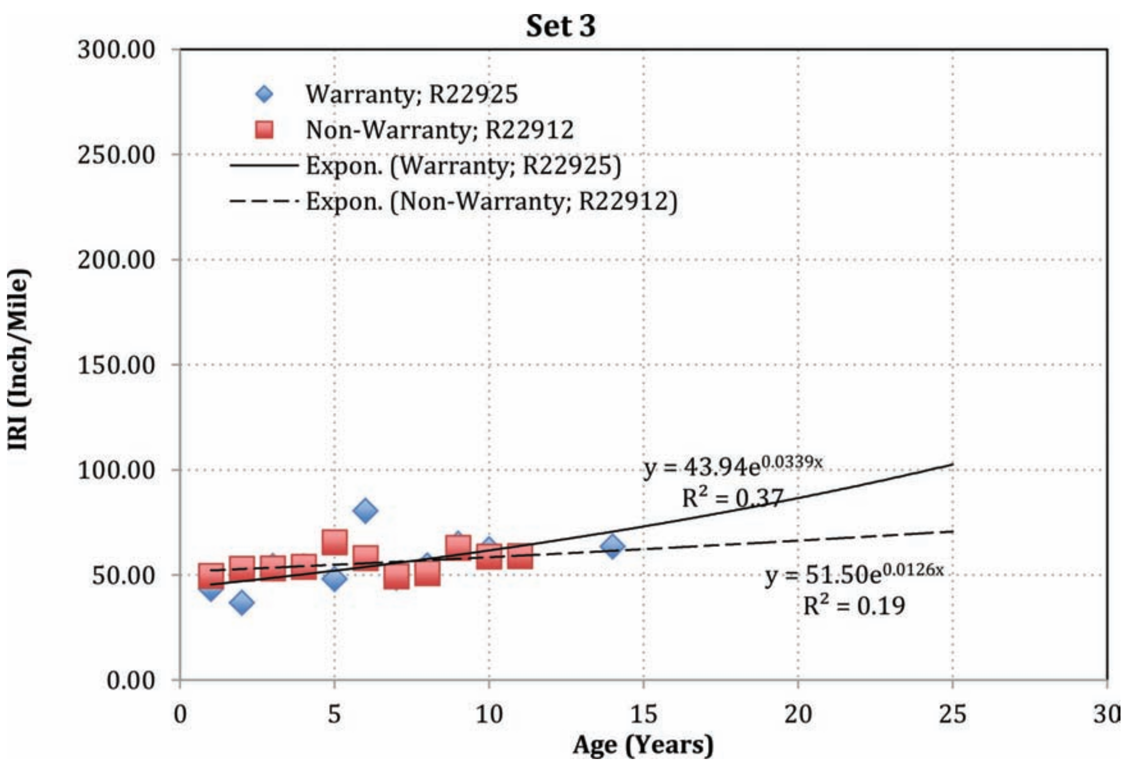

Figure 3.16 IRI performance comparison for Set 3.

may be due to the higher traffic loads on the warranted pavement.

Although the IRI values during the service life of the projects were very similar, the rut depth of the warranted project was significantly less than that for the non-warranted project at all ages (Figure 3.17), though again the rut depths were quite low.

Friction numbers, compared in Figure 3.18, demonstrate that except for the first and third years, the friction numbers of the non-warranted pavement were lower on average than the friction numbers of the warranted pavement at the corresponding age. At 5, 6, 9 and 11 years, the average friction numbers of the non-warranted pavement dropped below 35, which

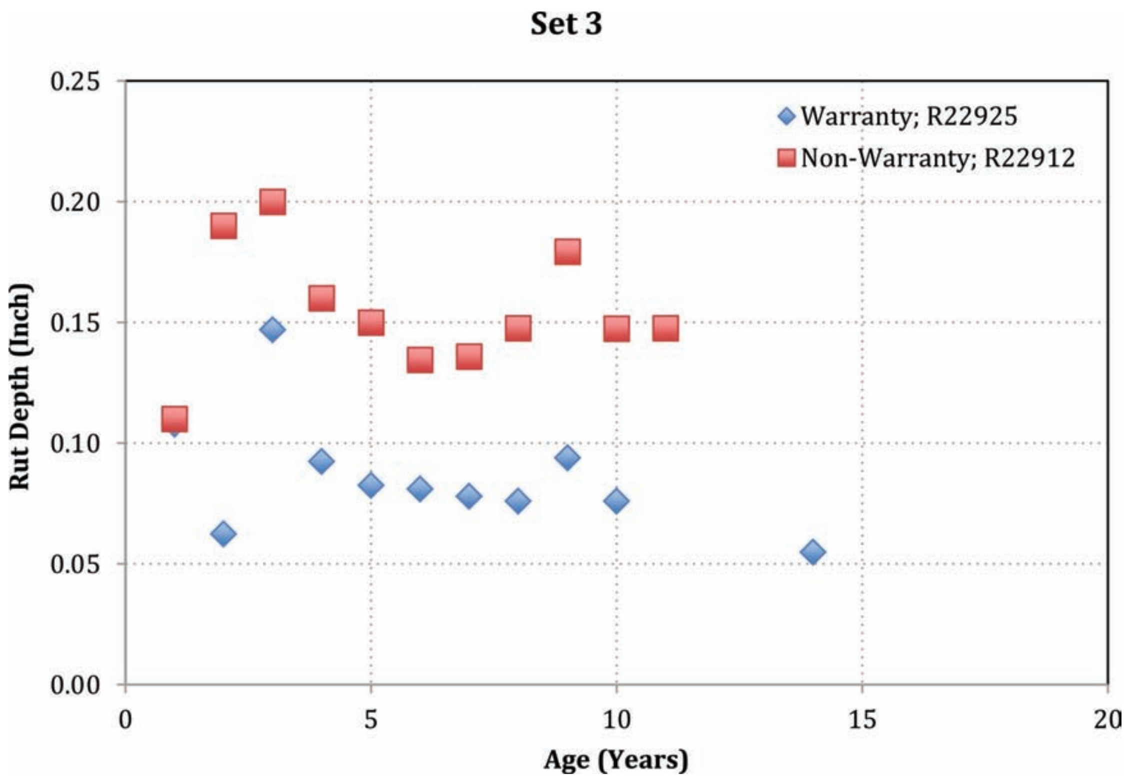

Figure 3.17 Rutting performance comparison for Set 3.

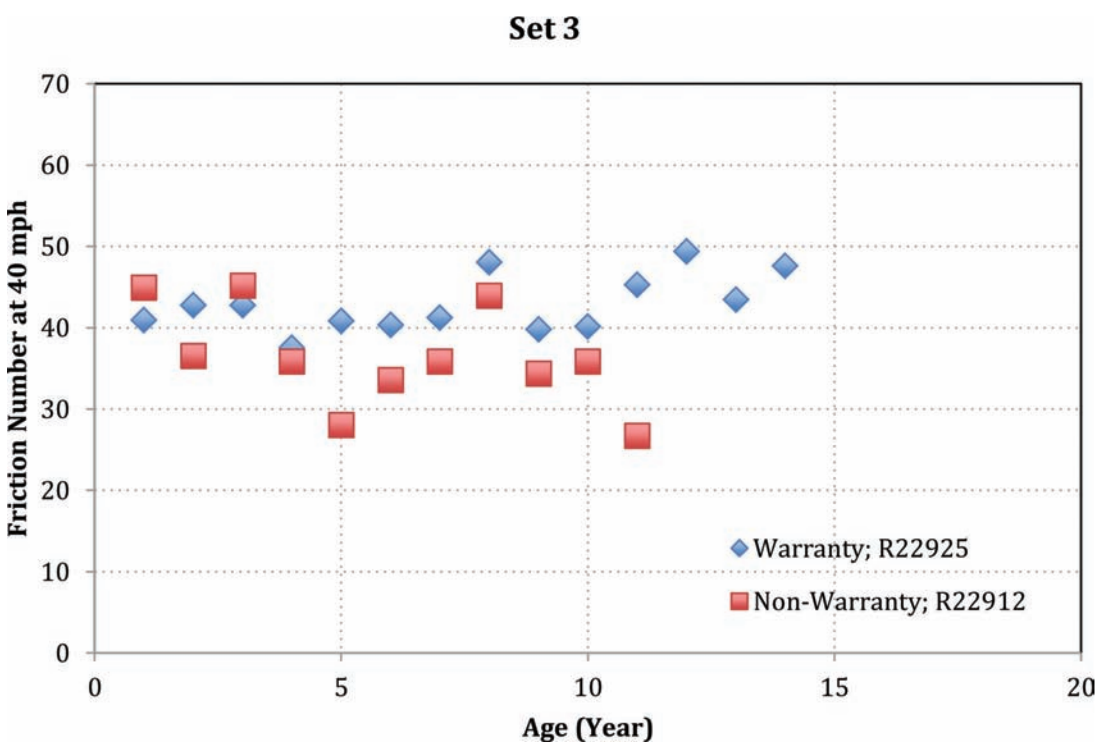

Figure 3.18 Friction number comparison for Set 3.

implies that the number of sections that would have needed remediation for friction increased in those years for the non-warranted project. By contrast, this issue is not observed for the warranted section's friction numbers.

It is noteworthy to mention that considering all of the similarities between the construction and condition of these two projects, the warranted pavement lasted three years longer than the paired non-warranted

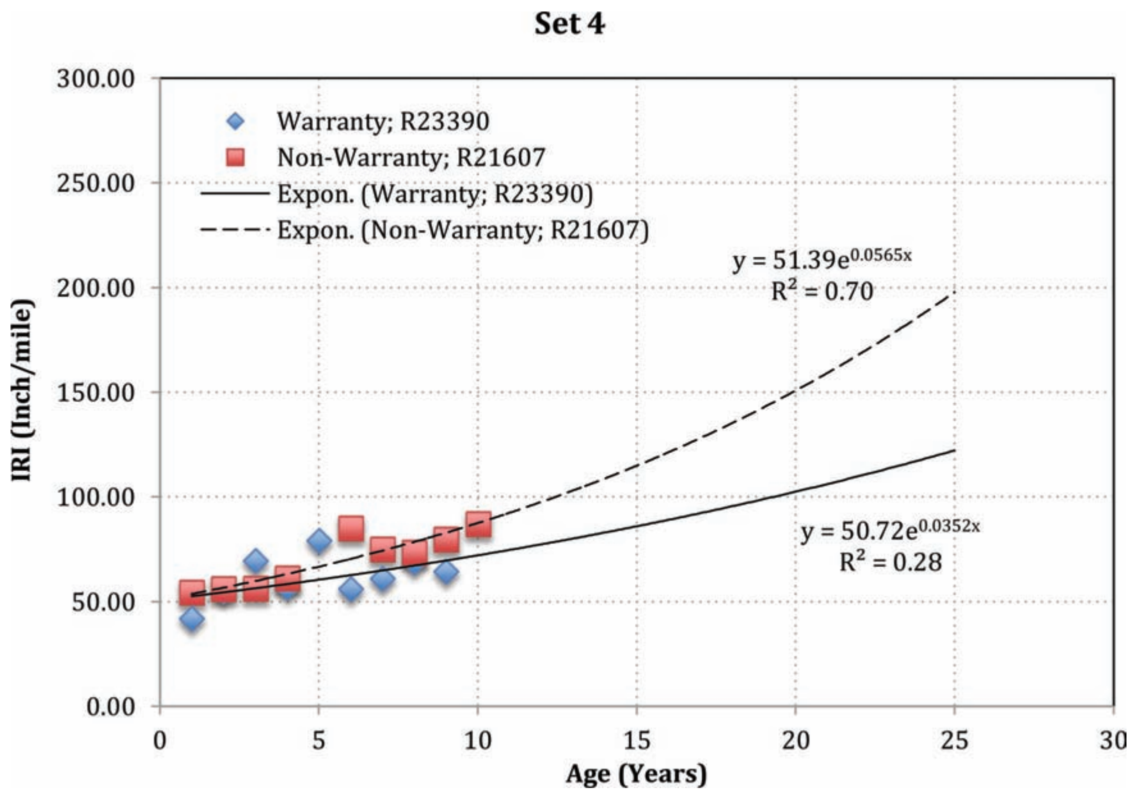

Figure 3.19 IRI performance comparison for Set 4.

pavement although higher traffic loads passed over the warranted pavement.

3.2.5 Comparison Set 4

The warranted pavement R-23390 is compared to the same conventional pavement used in Set 1, R-21607, in this comparison set. R-23390 was located on I-74 in Shelby County from SR-9 to Middleton. Both projects are similar regarding the pavement structure (overlay over cracked and seated concrete) and functional class. AADT and truck percentages were 35% and 1% higher in 2002 for the non-warranted pavement (Singh et al., 2005).

Figure 3.19 through Figure 3.21 show the performance comparisons between these two contract-type projects. The IRI comparison in Figure 3.19 demonstrates that, in general, the non-warranted pavement's IRI was greater than that of the warranted pavement at the same age. The non-warranted pavement's exponential curve reached 200 in./mi at 25 years. On the contrary, the IRI of the warranted pavement is less than 150 in./mi at 25 years. Except for the significant difference in the first year rut depths of the two projects, the average rut depths for both projects are similar (and low) for the observed data during their service lives.

Friction numbers for both contract types ranged from 36 to 59. However, on average the friction number of the warranted pavement was 15% higher with 34% less variability (Figure 3.21).

In this comparison set, the actual service life of the non-warranted pavement was 11 years and the service life of the warranted pavement is one year longer.

3.2.6 Comparison Set 5

Warranted pavement R-23898 is compared with the paired non-warranted pavement R-22923 in Comparison Set 5. Warranted R-23898 is located on I-74 in Hendricks County and is still in service. The comparable conventional pavement R-22923 was located on I-74 in Hancock County from Sugar Creek to 0.4 mile east of Brandywine Creek. Both projects have similar structures (overlays of cracked and seated concrete), construction years and functional classes. The AADT is 20% higher for the non-warranted pavement but the truck percentage is 5% higher for the warranted pavement (Singh et al., 2005).

IRI and rutting performance are plotted in Figure 3.22 and Figure 3.23, respectively. It is observed that overall the warranted pavement's IRI is lower than the non-warranted pavement's IRI throughout their service lives. The non-warranted pavement has been out of service since 2011, while the warranted pavement is still in service. The exponential curve fitted to the warranted pavement data points demonstrates that projected IRI barely reaches 100 in./mi after 25 years, while the non-warranted comparison section actually reached that level within about the first three years of service and exceeded it after ten years.

In addition to the better IRI performance of the warranted pavement, the rut depths of the warranted

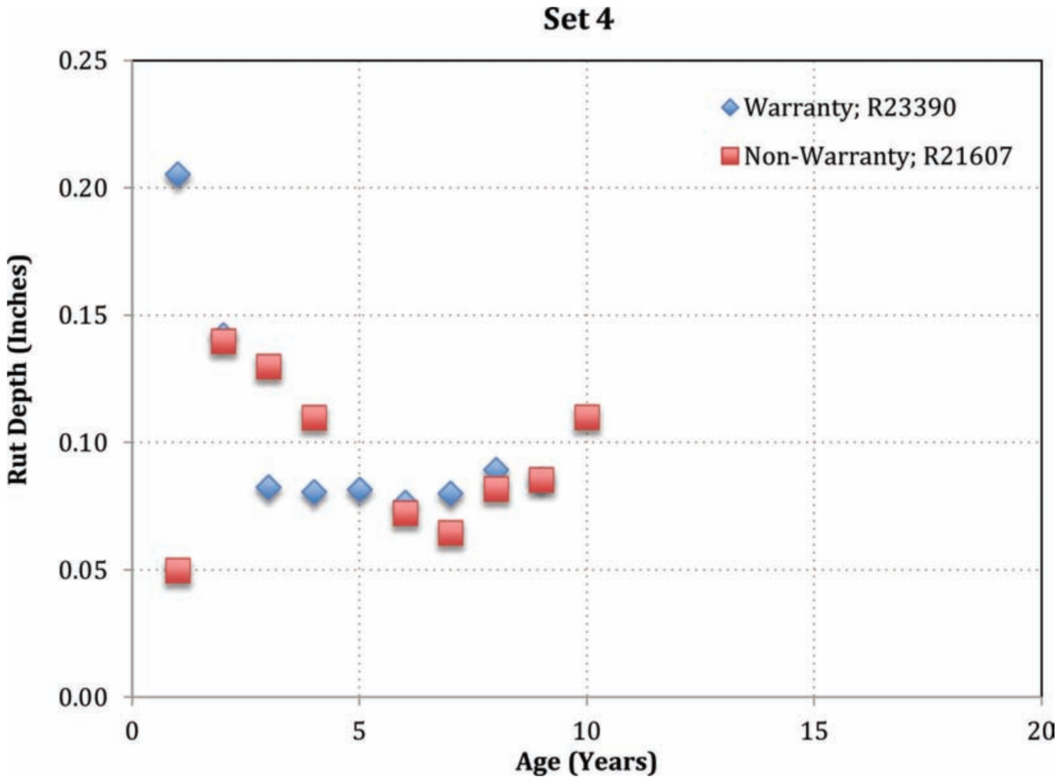

Figure 3.20 Rutting performance comparison for Set 4.

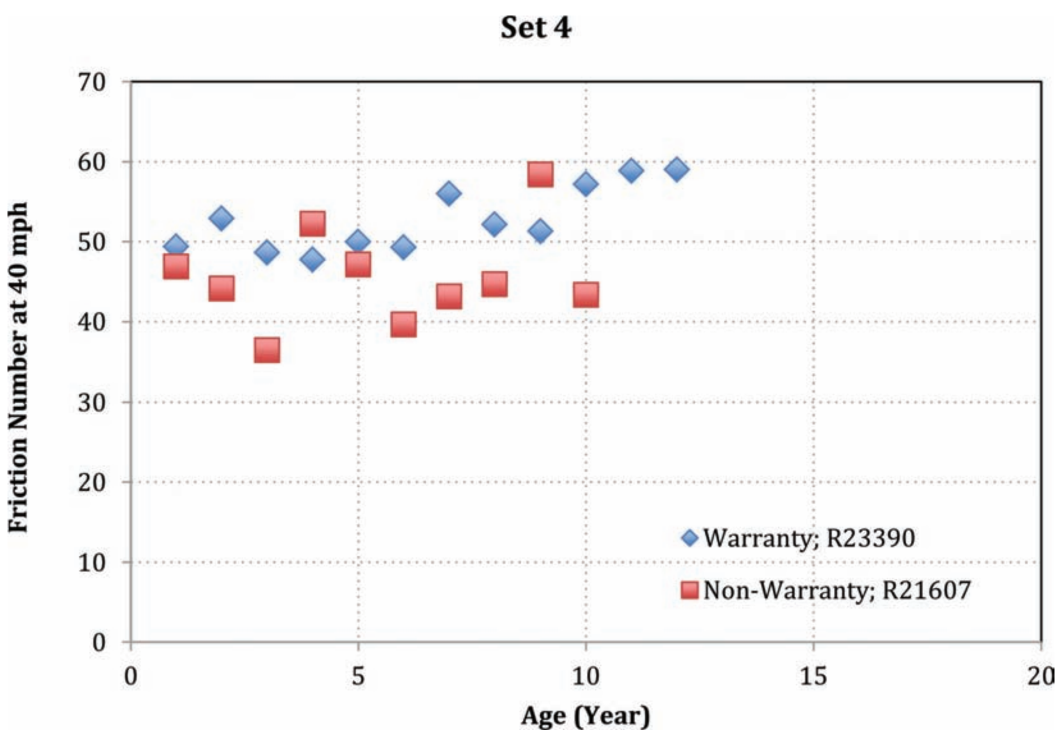

Figure 3.21 Friction number comparison for Set 4.

pavement are lower than those of the non-warranted pavement at the same age, except for the last year when the warranted data point does not seem to fit the previous trend (Figure 3.23).

Figure 3.24 displays the friction numbers at different ages for both the warranted and non-warranted pavements. The warranted pavement's friction numbers ranged from 46 to 61, while the friction numbers of the

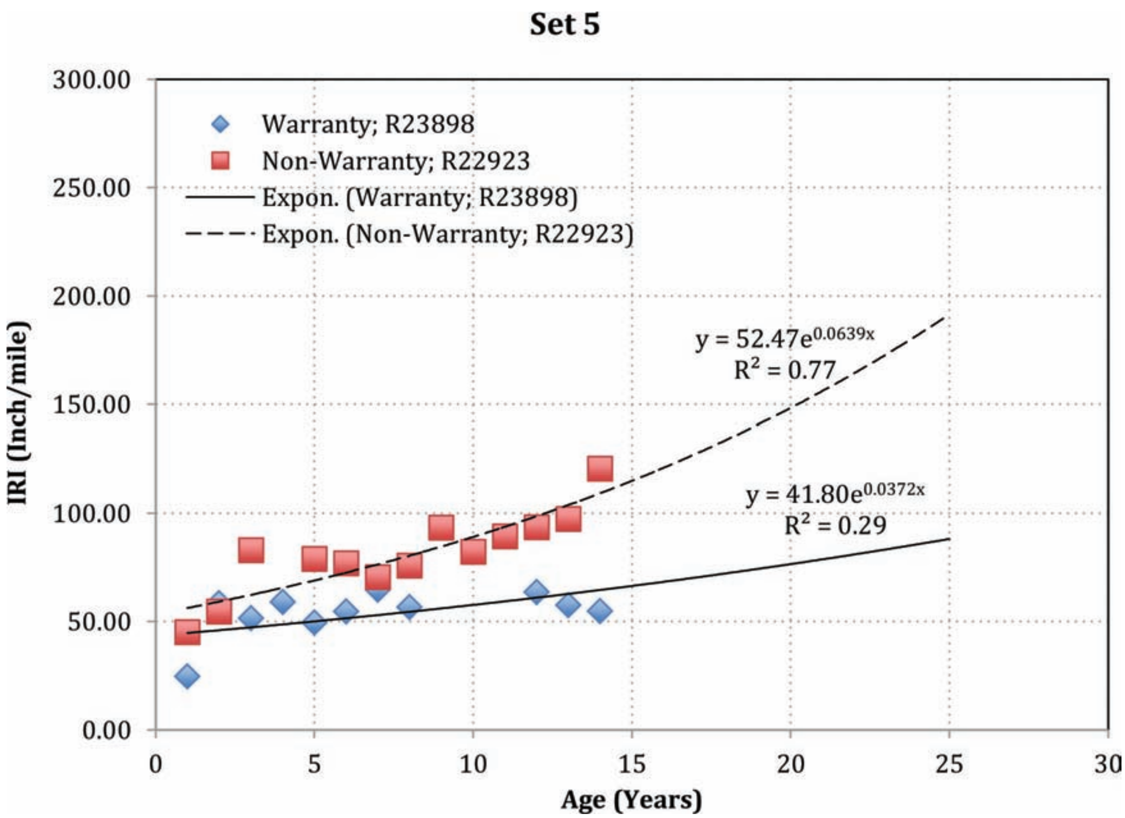

Figure 3.22 IRI performance comparison for Set 5.

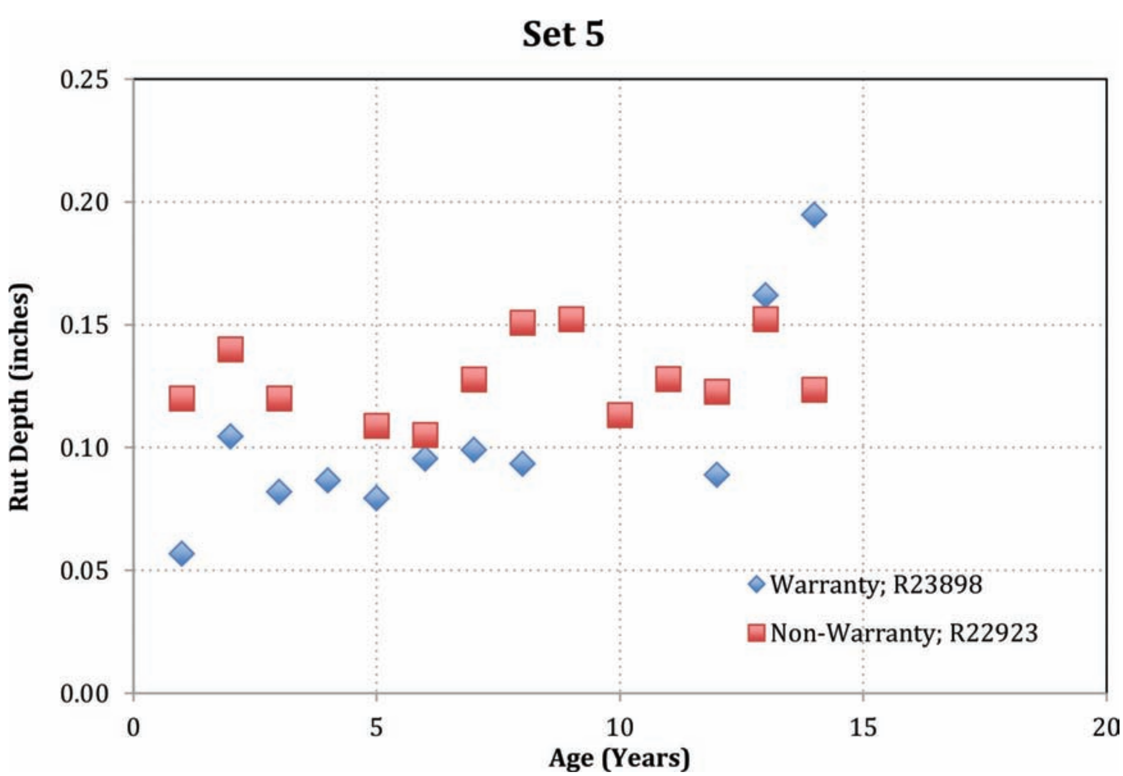

Figure 3.23 Rutting performance comparison for Set 5.

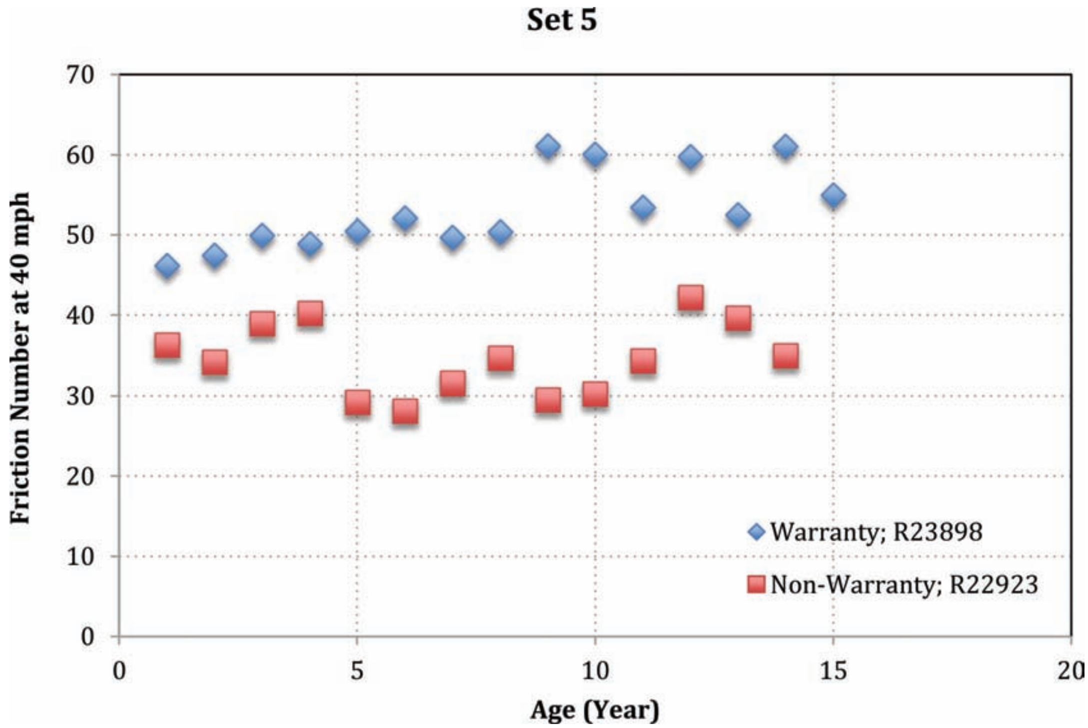

Figure 3.24 Friction number comparison for set 5.

non-warranted pavement were from 28 to 42, indicating the fact that there are more segments in the non-warranted project having friction numbers lower than the threshold set by INDOT for friction number, 35, that would have required remediation under a warranty contract. At all ages, the friction numbers of the warranted pavement were significantly higher than for the non-warranted pavement.

These plots prove that the warranted pavement performed better than the paired conventional pavement regarding IRI, rutting and friction. That is to say, less maintenance activities were needed for the warranted pavement and thus less expenditure was required to maintain the pavement.

3.2.7 Bid Price Comparison

In this section, the asphalt-associated bid prices for warranted and non-warranted pavements are compared for each comparison set. The complete bid tabulations for each project were evaluated to find the contractor with the lowest total bid price who won the project. Then, the asphalt-associated bid prices were extracted for comparison on a price-per-ton basis. It was interesting that for all five warranted projects, the contractor with the lowest total bid price had the lowest bid price for the asphalt mixtures, while this was not true for all the non-warranted pavement projects. In the absence of detailed information on the structure of the warranted and non-warranted pavements, it was assumed that the pavement surface mixes constituted about 20% of the total thickness; this was verified for those projects where the cross sections were available.

Table 3.3 through Table 3.7 show the comparison of the asphalt associated bid prices for the non-warranted and warranted pavement projects for five comparison sets. The price is based on the current dollars in year of

TABLE 3.3
Cost comparison for Set 1.

	Comparison Set 1	
	Warranty Project R-22232	**Non-warranty Project R-21607**
Asphalt mixture price per ton, $	34.25	33.76
Service life	16	11
Asphalt mixture price per ton per years, $	2.14	3.07

TABLE 3.4
Cost comparison for Set 2.

	Comparison Set 2	
	Warranty Project R-22854	**Non-warranty Project R-21602**
Asphalt mixture price per ton, $	32.00	25.60
Service life	17	10
Asphalt mixture price per ton per year, $	1.88	2.56

TABLE 3.5
Cost comparison for Set 3.

	Comparison Set 3	
	Warranty Project R-22925	**Non-warranty Project R-22912**
Asphalt mixture price per ton, $	35.27	31.55
Service life	14	11
Asphalt mixture price per ton per year, $	2.52	2.87

TABLE 3.6
Cost comparison for Set 4.

	Comparison Set 4	
	Warranty Project R-23390	**Non-warranty Project R-21607**
Asphalt mixture price per ton, $	32.5	33.76
Service life	12	11
Asphalt mixture price per ton per year, $	2.71	3.07

TABLE 3.7
Cost comparison for Set 5.

	Comparison Set 5	
	Warranty Project R-23898	**Non-warranty Project R-22923**
Asphalt mixture price per ton, $	34.00	34.08
Service life	>16	14
Asphalt mixture price per ton per year, $	2.13	2.43

letting. Regardless of the superior pavement performance and the longer service lives of warranted pavements, the initial price per ton for warranted project in comparison sets 1, 2 and 3 was 1%, 25% and 12% more expensive than the comparable non-warranted pavement projects, respectively. By contrast, the initial cost per ton for the warranted pavement in comparison set 4 was 4% less expensive and there was not a significant price difference in comparison set 5.

The last row of the tables shows the asphalt mixture price per ton per years of service life of the projects to evaluate the cost effectiveness of warranted pavements in the longer term. Figure 3.25 and Figure 3.26 visualize the comparison for asphalt mixture price per ton and asphalt mixture price per ton per year for the five comparison sets. The comparison indicates that warranted pavements are 12–30% less expensive than the non-warranted pavements regarding the initial cost per ton and their service lives in the long-term. Also, it is interesting to note that the same contractor constructed both the warranted and non-warranted pavements of comparison set 2. Although the initial cost per ton for the warranted pavement was 25% more expensive, the pavement lasted seven years longer and gave superior pavement performance than did the comparable non-warranted pavement and thus, the warranted pavement was at least 26% more cost effective in the long-term comparison.

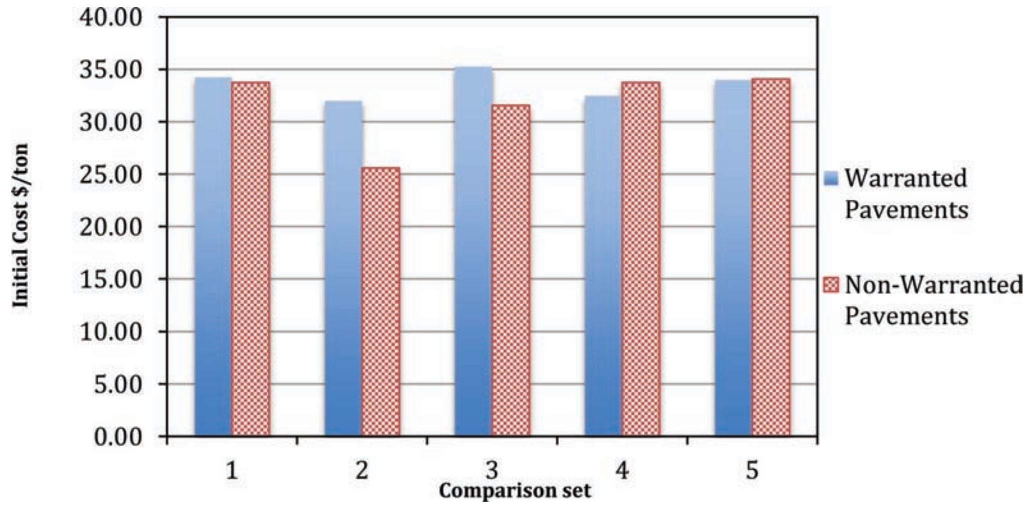

Figure 3.25 Initial cost per ton for five comparison sets.

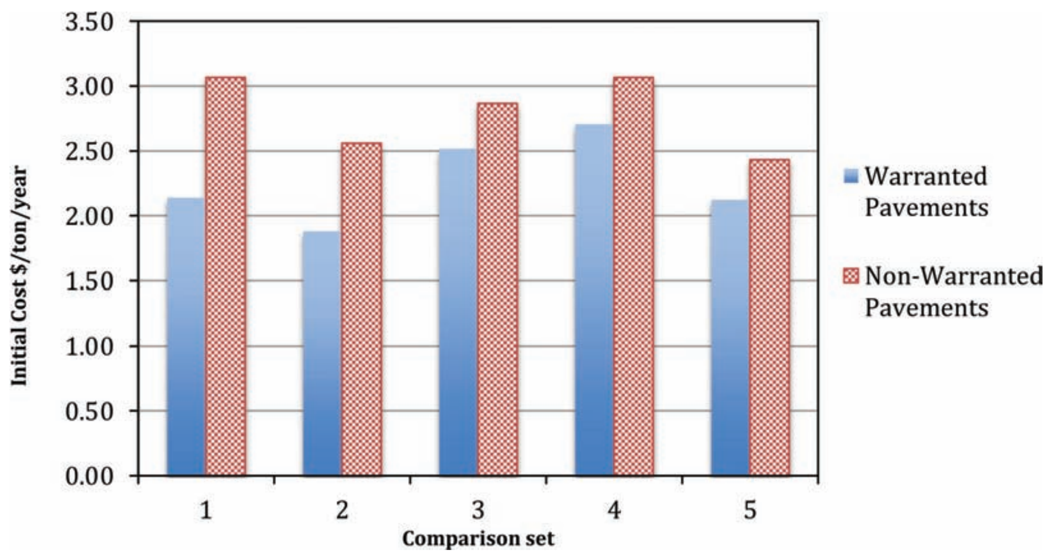

Figure 3.26 Initial cost per ton per year for five comparison sets.

4. CONCLUSION AND RECOMMENDATIONS

4.1 Summary of Findings

The literature review revealed that not all warranty programs are successful, but also provided many lessons learned that can help to ensure success and cost-effectiveness of a warranty program. These lessons are incorporated in the recommendations provided in 4.2. The findings, based on review of INDOT pavement management data and special testing are summarized here.

4.1.1 Overall Performance Comparisons

Overall performance comparisons of Indiana's warranted and non-warranted asphalt pavements indicate that warranted asphalt pavements tend to perform more effectively than do non-warranted asphalt pavements. On average, warranted asphalt pavement sections had lower IRI values and rut depths than did non-warranted sections. The variability in IRI values and rut depths was also found to be less for warranted pavement sections than for the non-warranted sections. In terms of service life based on changes in IRI and rut depth, analyses indicate that warranted asphalt pavements could last 10 to 14 years longer than non-warranted asphalt pavements. In other words, considering 15 years as a typical pavement design life for an asphalt pavement in Indiana, pavements built under warranty specifications could last 67 to 93% longer than traditional pavements. When both initial capital costs and maintenance expenditures are considered, warranted asphalt pavements appear to be 15 to 40% more cost effective over a 5-year (short-term) period and 47 to 61% more cost effective over a 15-year (long-term) period. These savings do not include potential benefits of reduced user costs nor reduced INDOT inspection costs.

Variability observed in the friction numbers of the warranted pavements was found to be 32% less than that in non-warranted pavements as 92% of the warranted pavements' friction numbers ranged from 40 to 60, while only 75% of the non-warranted sections were in this range. Twenty percent (20%) of the non-warranted section had friction numbers less than 35.

The results presented herein indicate that warranty projects result in asphalt pavements that provide a smoother ride (lower IRI values), less rutting, and are more cost-effective than traditional non-warranted asphalt pavements.

4.1.2 Pairwise Comparisons

Comparison of warranted pavements vis-à-vis comparable conventional pavements proves that the warranted pavements lasted 1 to 7 years longer than the non-warranted pavements according to the actual service lives. However, the projected service lives based on the IRI trends reveals that non-warranted pavements' IRI values (except for Comparison Set 3) reached 200 in./mile by about 20 to 25 years, while none of the warranted pavements' IRI values reached 200 in./mile by 25 years.

In all comparison sets except Set 3, on average, the IRI of the warranted pavements was 12 to 40% lower than the non-warranted pavements. In Comparison Set 3, both types of contracts performed similarly on average. Rut depth comparison for Sets 2, 3 and 5 revealed that rut depths of the warranted pavements were on average 13 to 45% lower than those of the non-warranted pavements. In Sets 1 and 4, rut depths were 13% and 9% lower for the non-warranted pavements. In all cases, however, the rut depths were quite low.

The minimum average friction numbers at different ages for warranted pavements during their service lives ranged from 34 to 53, and the average was from 42 to 54. The minimum values for non-warranted pavements varied from 27 to 36, and the average ranged from 37 to 46. This implies that the number of sections needing remedial activities is greater under non-warranty contracts. Overall, the friction numbers of the warranted pavements were greater than those of the similar non-warranted pavements.

Results of this report revealed that warranted pavements perform superior to and more cost effectively than similar non-warranted pavements. Both projected and actual service lives were found to be greater for warranted pavements.

4.2 Recommendations for Implementation

This section outlines the recommendations for implementation of the research findings for INDOT's consideration. These recommendations are based on the literature review and the analysis of the performance of Indiana's previous asphalt pavement warranties.

4.2.1 Lessons Learned

In short, the literature review showed that not all warranty programs have been successful and even those that were considered model programs had issues to overcome. On the other hand, the literature also indicates that warranties can be effective tools for preventing premature failures, providing a means of redress if early distresses appear, reducing maintenance costs during the warranty period and increasing the service life of the pavement, which can reduce life cycle costs. In some cases, warranties have also been credited with reducing construction delays and reducing agency costs for inspection and testing. These benefits come at an increased initial cost to the agency in the range of 5–10% and increased risk to the contractors.

The most successful warranty programs are those that are built upon partnering efforts within the agency and with industry. Buy-in is critically important from both the agency and the industry. Warranted distresses must be within the control of the contractor, and their threshold levels must be set at attainable levels. Contractors must be prepared to pay more attention to detail in order to be successful. Agencies must commit to monitoring traffic and distresses during the warranty period. When all of the pieces come together, warranties can be very effective tools.

4.2.3 Considerations for Implementing an Asphalt Pavement Warranty Program

Based upon this research effort, it is recommended that INDOT revisit its warranty program for asphalt pavements and consider reinstituting the previous program or a modification of it. The previous program did serve to improve pavement performance, extend the service life of asphalt pavements, reduce construction delays, provide insurance against early failures and reduce maintenance costs during the warranty period, which all contribute to increased cost effectiveness. Some specific recommendations for consideration include the following:

- Florida's approach to warranties is worthy of consideration since it has proven to be effective and successful for many years. By obviating the need for a bond, a contractor's bonding capacity is not affected and the cost of securing a bond is avoided, making the economics even more favorable. The risk of losing the ability to bid on Department work is a strong incentive to the industry to perform well.
- If INDOT choses to require a warranty bond, the cost of the bond could be a separate pay item in the contract, which would allow the bonding costs to be re-evaluated in the future. If the cost of the bond is included in the bid price for the mixture(s), it is more difficult to examine the bonding expense to see if it is reasonable or if changes can be made to the program to reduce the cost. These changes could include such things as a decreasing bond value over time, an annually renewable bond, an optional bond in the case of suspect materials and construction practices, or other options.
- It would be advisable to implement a warranty program over time, rather than wholesale. Warranties have not been used for asphalt pavements for a decade in this state, so an incremental approach would help to re-familiarize the industry and agency with the concept and application, while also giving time for re-evaluation and revision (tweaking) of the warranty specifications.
- A clear plan for management of the warranty program should be developed before reinstituting the program. Decisions need to be made on who will be responsible for overseeing the program, ensuring that inspections are performed at the appropriate times, reviewing the condition data and communicating the results to the contractor, and many other details.
- A database should be developed and used to track the location and important milestones for the warranty projects. The database should record the beginning and ending dates of the warranty period, when inspections or data collection efforts are due and the results of inspections and data analysis. This is especially important since different segments of the roadway may have different beginning and ending dates for the warranty; the most common example of this is when one direction is paved and completed before work in the other direction is initiated. The same database could be used to document when the contractors have been informed of the results, when remediation is required and when the work has been completed.
- Specific positions in the Central Office and possibly the Districts should be responsible for ensuring that the warranty projects are monitored, documented and reported on as required.
- The distresses to be warranted should be those that can be monitored using automated equipment to the extent possible. This will help to reduce the subjectivity of the measurements, facilitate routine data collection and reduce redundancy of inspections by making use of the Pavement Management System. The capabilities of the automated equipment have improved over the last decade, so this data maybe even more reliable and informative than that previously available.
- Measuring the pavement condition on an annual basis may help to avoid some of the problems experienced in Michigan by making the review process a routine, recurring event. One could speculate that the irregular inspection intervals Michigan used could have contributed to the fact that some reviews were late or missed entirely. Using the PMS data for this purpose would simplify the inspection process.
- Decisions must also be made regarding project selection. Does INDOT eventually want to have widespread implementation on most asphalt paving projects, like Florida has, or does the department prefer to use warranties on particular types of projects?
- Warranties are, perhaps, easier to implement – or at least less risky – on new construction, but that is a fraction of the construction program in the state. For warranties on overlay or mill and fill projects, the existing pavement condition is a critical consideration. The existing pavement should be structurally sound to reduce the chances that underlying problems cause pavement distresses that the contractor cannot control. If there is poor quality concrete to be overlaid, cracking and seating or rubblization could be considered.
- The department must commit to providing reliable traffic data to the contractor for design purposes and must monitor traffic over the duration of the warranty period to ensure the projections are not exceeded, which would void the warranty.
- Quality assurance testing by the department is still important but the level of inspection could be reduced on warranty projects. Contractors should still be required to produce a quality control plan and provide the data to the department.
- There must be good communication within INDOT so that all the relevant divisions, offices and units are aware of the location and provisions/restrictions of the warranty projects. These groups include Highway Design and Technical Support, Operations, Program Development, Research, and the Districts. The maintenance units responsible for the roads where warranty projects have been constructed need to know their locations and understand that they are not to perform maintenance activities that would affect the pavement performance in those locations; erecting signs to mark the project limits might be worthwhile to reduce the chances of performing maintenance on a warranted pavement.
- Communication with the asphalt paving industry is also critical. Industry should be involved in the development and refinement of the program. Without industry cooperation and acceptance, the program will not be successful.

TABLE 4.1
Distresses, threshold levels and remediation from 2004 warranty contract.

Distress	Threshold	Remediation
Alligator Cracking	NA/IRI	Remove and replace 150% of distressed area to a depth not to exceed the warranted pavement.
Flushing	NA	Remove and replace 150% of distressed surface full lane width.
Longitudinal Cracks	0 m severity 2 or greater	Rout and seal.
Transverse Cracks	5.5 m (18 ft)	Rout and seal.
Longitudinal Distortion	IRI 1.4 m/km (90 in./mi)	Remove and replace 110% of distressed area to a depth not to exceed warranted pavement.
Potholes, Slippage Areas, Raveling, Segregation or other disintegrated areas	NA/IRI	Remove and replace 150% of distressed area to a depth not to exceed warranted pavement.
Rutting	6.0 mm (0.25 in.)	Remove and replace distressed layers full lane width.
Low Friction	FN = 25 (FN must average 35 with no three consecutive sections with individual values <25	Remove and replace or overlay distressed layers full lane width.

4.2.4 Review of Previous INDOT Warranty Specification

INDOT's previous warranty specification (example in Appendix A) required the contractor to be responsible for ensuring the pavement performance met or exceeded the specified threshold values for a period of five years after opening the roadway to unrestricted traffic. The design life was established (20 years, typically) and the estimated design traffic level was provided. In addition, minimum material requirements for aggregates and binders were specified. The warranty clearly applied to the mainline pavement, while ancillary pavements (shoulders, ramps, acceleration and deceleration lanes, etc.) were to be constructed under standard specifications; this is reasonable since collecting condition data on theses ancillary pavements is more difficult and not automated. These features of the warranty provisions seem appropriate and should be retained.

The previous warranty provisions did require a performance bond. The intent of the bond was to provide resources for repairing or replacing the pavement if it failed to perform. Typical bond amounts used across the country range between 25 and 50% of the cost of the warranted pavement or the cost to mill and replace the surface. If INDOT choses to require a bond, the face value and whether the amount of the bond should decrease over time if the pavement performs well should be discussed and established in consultation with the industry.

The previous specification also outlined a Conflict Resolution Team and its responsibilities. This feature should also be retained.

The pavement distress indicators, threshold levels and remedial actions were enumerated in the warranty provisions. These are summarized in Table 4.1. These appear to be reasonable starting points for a discussion of warranty implementation, especially in light of the good performance of the previous warranted pavements. PMS data could be analyzed to determine if the same threshold levels should be retained.

The warranty provision did include an escape clause relieving the contractor of responsibility if:

- The existing (or rubblized) pavement thickness is less than 50 mm thinner than the plan thickness,
- The subgrade density is less than 90% of optimum,
- Or the actual number of Class 5 and higher trucks is 50% above the projected five year truck volume.

In addition, if alligator cracking resulted in smoothness issues, the contractor would be relieved of responsibility to remediate the IRI. These limitations on liability seem reasonable, at least as starting points.

The previous warranty provision appears to be a reasonable starting point for discussions. No specific changes are recommended at this time, but the provisions should be discussed with the Pavement Warranty Committee and threshold levels could possibly be adjusted based on recent PMS data.

In summary, then, asphalt pavement warranties do appear to be effective tools for improving the performance of asphalt pavements, insuring against premature failures and extending service lives in a cost effective manner over the long term. A number of options exist for reinstituting a warranty program that should be considered by the department in cooperation with industry.

REFERENCES

Anderson, S., Blaschke, B., Trejo, D., & Erbatur, C. (2006, January). *Development of warranty-based specifications for construction* (Report No. 0-4498-3). College Station, TX: Texas Transportation Institute.

Anderson, S. D., Russell, J. S. (2001). *Guidelines for warranty, multi-parameter, and best value contracting* (NCHRP Report 451). Washington, DC: Transportation Research Board.

Battaglia, I. (2012, January). Report to the Joint Legislative Audit Committee on the cost effectiveness of warranted HMA pavements (Report No. WI-01-12). Madison, WI: Wisconsin Department of Transporation.

Battaglia, I. K. (2009, June). *Pavement warranty program in Wisconsin: 12-year evaluation* (Report No. WI-03-09). Madison, WI: Wisconsin Department of Transportation.

D'Angelo, J., Whited, G., Molenaar, K., Bower, S., Russell, J., Huber, G., … Rice, J. (2003, November). *Asphalt pavement warranties technology and practice in Europe* (Report No. FHWA-PL-04-002). Washington, DC: Federal Highway Administration.

Egan, P. (2014, January 3). Michigan driven to maximize warranties on roads. Detroit Free Press. http://www.freep.com/article/20131222/NEWS06/312220059/ (accessed 7/13/2015).

Federal Highway Administration (FHWA). (1996, October). Indiana asphalt pavement project as easy as ABC. https://www.fhwa.dot.gov/publications/focus/96oct/106inabc.cfm (accessed 7/30/2015).

Federal Highway Administration (FHWA). (2015a). Background for pavement warranties: What are they and why should they be used? https://www.fhwa.dot.gov/pavement/warranty/backgrnd.cfm (accessed 7/7/2015).

Federal Highway Administration (FHWA). (2015b). Management of pavement warranties. www.fhwa.dot.gov/pavement/warranty/mangment.cfm (accessed 3/3/15).

Federal Highway Administration (FHWA). (2015c). Selection procedures for pavement warranties. www.fhwa.dot.gov/pavement/warranty/selction.cfm (accessed 3/3/2015).

Florida Department of Transportation (FDOT). (2015). *Standard specifications, Section 338, Value added asphalt pavement*. http://www.fdot.gov/programmanagement/Implemented/SpecBooks/July2015/Files/715eBook_Revised.pdf (accessed 3/19/2015).

Gallivan, V. L. (2011). *Development of warranty programs for hot-mix asphalt pavements* (Transportation Research Circular E-C154). Washington, DC: Transportation Research Board.

Gallivan, V. L., Huber, G. V., & Flora, W. F. (2004). Benefits of warranties to Indiana. *Transportation Research Record: Journal of the Transportation Research Board*, 1891, 221–228.

Goldbaum, J. E. (2012, March). *Cost-benefit evaluation of short-term warranties for hot mix asphalt pavements* (Report No. CDOT-2012-1). Denver, CO: Colorado Department of Transportation, Research Branch.

Hancher, D. E. (1994). *Use of warranties in road construction* (NCHRP Synthesis of Highway Practice No. 195). Washington, DC: Transportation Research Board.

Hastak, M., Minkarah, I. A., Cui, Q., & Bayraktar, M. W. (2003, November). *The evaluation of warranty provisions on ODOT construction projects* (Report No. FHWA/OH-2003/019). Cincinnati, OH: University of Cincinnati.

Hinkley, J. A. (2015, September 8). MDOT improves warranty oversight. Lansing State Journal. http://www.lansingstatejournal.com/story/news/local/capitol/2015/09/04/mdot-improves-warranty-oversight/71697270/ (accessed 9/9/15).

Hinkley, J. A., & Reed, S. R. (2015, April 20). After 18 years, MDOT "still learning" troubled oversight program. Lansing State Journal. http://www.lansingstatejournal.com/story/news/local/watchdog/2015/04/19/years-mdot-still-learning-troubled-oversight-program/25947137/ (accessed 9/9/15).

Huber, G. (2000). *Performance warranties on asphalt pavement: Effect on performance*. Paper presented at the Southeastern Association of State Highway and Transportation Officials, August 2000.

Huber, G. (2012). *Building asphalt pavements that perform.* Presentation to NCAT Applications Steering Committee, December 6, 2012.

Kennedy, K. (2005, October). Warranty administration in the Michigan Department of Transportation's capital preventative maintenance program. In *Roadway pavement preservation 2005: Papers from the First National Conference on Roadway Pavement Preservation* (Transportation Research Circular E-C078; pp. 114–119). Washington, DC: Transportation Research Board.

Krebs, S. W., Duckert, B., Schwandt, S., Volker, J., Brokaw, T., Shemwell, W., & Waelti, G. (2001, June). *Asphaltic pavement warranties: Five year progress report.* Madison, WI: Wisconsin Department of Transportation.

Martinez, M. (2012, April). *Implementation of warranties in state contracts for highway construction* (Report No 00-2P). Baton Rouge, LA: Louisiana Transportation Research Center.

Michigan Department of Transportation (MDOT). (2002, December, 13). *Bureau of Highway instructional memorandum 2002-23, Contract administration and oversight guidelines for projects containing warranty work.* Lansing, MI: Michigan Department of Transportation.

Michigan Department of Transportation (MDOT). (2008, February). *Guidelines for administering warranties on road and bridge construction contracts.* Lansing, MI: Michigan Department of Transportation Construction and Technology Division. Retrieved from http://www.michigan.gov/documents/mdot/MDOT_WarrentyGuide_225426_7.pdf

Minnesota Department of Transportation (MnDOT). (2005, December). *Innovative contracting guidelines*. Minnesota Department of Transportation, Office of Construction and Innovative Contracting. Retrieved from https://www.dot.state.mn.us/const/tools/documents/Guidelines_004.pdf

New York State Department of Transportation (NYSDOT). (2010, September). *Warranty requirements for hot mix asphalt (HMA) top course* (Materials Procedure MP402-01). Albany, NY: New York State Department of Transportation.

NQI Steering Committee. (1996). *National highway user survey*. Washington, DC: Federal Highway Administration.

Oh, J. E., Singh, P., Labi, S., & Sinha, K. C. Warranty practice in pavement construction: An assessment of the costs and benefits. *TRB 2006 annual meeting CD-ROM* (Paper No. 06-2869). Washington, DC: Transportation Research Board.

Page, G. (2015). Effect of new asphalt technologies in Florida, (discussion). *Asphalt Paving Technology 2015: Journal of the Association of Asphalt Paving Technologists*, *84*, 615–617.

Qi, Y., Wang, F., El Gendy, A., & Li, Y. (2013). Evaluation of the effectiveness of Mississippi's pavement warranty program. *Transportation Research Record: Journal of the Transportation Research Board*, *2366*, 98–109.

Scott III, S., Ferragut, T., Syrnick, M., & Anderson, S. (2011). *Guidelines for the use of pavement warranties on highway construction projects* (NCHRP Report 699). Washington, DC: Transportation Research Board.

Scott, S., Ferragut, T., & Anderson, S. (2007). *Use of warranties in highway construction* (NCHRP Project 20-07, Task 201). Washington, DC: Transportation Research Board.

Sharma, D., Cui, Q., Baldwin, R., & Arkle, D. (2009). *Big or small, does warranty contracting provide equal opportunities to all?* Paper presented at the First International Conference on Transportation Construction Management, February 9–12, 2009, Orlando, FL.

Shuler, S., Aschenbrener, T., & DeDios, R. (2007). Effect of performance warranties on cost and quality of asphalt pavements. *Transportation Research Record: Journal of the Transportation Research Board*, 2040, 100–106. http://dx.doi.org/10.3141/2040-11

Singh, P. S., Labi, S., McCullouch, B. G., & Sinha, K. C. (2005). *An evaluation of the cost-effectiveness of warranty contracts in Indiana* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2004/34). West Lafayette, IN: Purdue University. http://dx.doi.org/10.5703/1288284313394

Smith, K. D., Hoerner, T. E., & Darter, M. I. (1997). Effect of initial pavement smoothness on future smoothness and pavement life. *Transportation Research Record: Journal of the Transportation Research Board*, *1570*, pp. 60–69.

Stephens, J. E., Johnson, D. R., Wangsmo, M., & Schillings, P. (1998, August). *Use of warranties on in-service performance for roadway construction projects* (Report No. FHWA/MT-98-003/8131). Bozeman, MT: Montana State University.

Wienrank, C. J., (2004, June). *Demonstrating the use of performance-based warranties on highway construction projects in Illinois* (Report No. FHWA/IL/PRR-146). Springfield, IL: Illinois Department of Transportation.

Wisconsin Department of Transportation (WisDOT). (2013, June, 19). *Facilities development manual*. Madison, WI: Wisconsin Department of Transportation.

APPENDIX

2004 INDOT WARRANTY PROVISION

CONTRACTOR LIABILITY AFTER CONTRACT ACCEPTANCE

Upon the acceptance of the project, the contractual obligations of the contractor are satisfied as long as the pavement continues to meet or exceed the warranted values as defined herein.

HMA PAVEMENT, WARRANTED

1. DESCRIPTION: This work shall consist of the construction of warranted HMA pavement in conformance with the lines and grades shown on the plans as directed by the Department and as follows.

   The Contractor shall be responsible for the warranted HMA pavement for a period of five (5) years after the date all warranted HMA pavement is complete and open to unrestricted traffic. The pavement shall be designed for a 20 year life with an anticipated 13,400,000 ESAL loading [*contract specific value*] over the design life.

   The Contractor shall establish the Job Mix Formula (JMF) and select all materials. Aggregates must meet the minimum requirements of AASHTO MP 2 that are as follows:

   Mixtures within 100 mm of the pavement surface:

% crushed one face	100% min.
% crushed two faces	100% min.
Fine aggregate angularity	45% min.
Clay content (sand equivalent)	45 min.
Flat and elongated particles	10% max.

   Mixtures below 100 mm of the pavement surface:

% crushed one face	95% min.
% crushed two faces	90% min.
Fine aggregate angularity	40% min.
Clay content (sand equivalent)	45 min.
Flat and elongated particles	10% max.

For coarse aggregates the following additional requirements apply:

Los Angeles abrasion[1]	40% max.
Soundness (AASHTO T 103, Procedure A)	12% max.

Deleterious:

Clay lumps / friable (AASHTO T 112)	0.2% max.
Non-durable[2]	4.0% max.
Coke and iron[3]	
Chert[4]	3.0% max.

For fine aggregates the following additional requirements apply:

Soundness (AASHTO T 103, Procedure A)	10% max.
Acid Insoluble Content (ITM 202)	
Sand	40% min.
Blast Furnace Slag	25% min.

1 Los Angeles abrasion (AASHTO T 96) requirements shall not apply to blast furnace slag.

2 Includes soft particles as determined by ITM 206 and other particles that are structurally weak, such as soft sandstone, shale, limonite concretions, coal, weathered schist, cemented gravel, ocher, shells, wood, or other objectionable material. Determination of non-durable particles shall be made from the total weight of material retained on the 9.5 mm sieve.

3 Air cooled blast furnace slag and steel slag coarse aggregate shall be free of objectionable amounts of coke and iron.

4 The bulk specific gravity of chert shall be based on the saturated surface dry condition. The amount of chert less than 2.45 bulk specific gravity shall be determined on the total weight of material retained on the 9.5 mm sieve.

Alternately aggregate can be used which meet Indiana Class A aggregate requirements.

The minimum grade of asphalt binder to be used on the top 100 mm of the finished surface shall be PG 70-22. Below the top 100 mm of the finished surface, the minimum grade of binder shall be PG 64-22. The mixture within the top 32 mm of the finished surface shall have a maximum top size aggregate of 12.5 mm.

The contractor shall develop a Quality Control Plan that meets the requirements as outlined in Section 10 for Warranted HMA Pavements that is to be submitted to the Department.

The provisions of the warranty work shall apply to all HMA mixtures placed as mainline pavement including the construction joint between the mainline pavement and adjacent materials (shoulders, tapers, and ramps). Section 400 and Section 900 of the

Standard Specifications are exempted except 401.18 and 904.03. Shoulders, ramps, acceleration lanes and deceleration lanes are not included in the warranty requirements and shall be constructed under standard specifications. The finished surface of the warranted HMA pavement shall meet the profilograph requirements in accordance with 401.18 before the warranted HMA pavement is opened to traffic. Milling of the finished surface is not an acceptable corrective action to achieve the surface tolerance.

2. WARRANTY: Upon completion of all warranted HMA pavement and opening of the warranted pavement to unrestricted traffic, the Warranty Bond shall be in effect for a total of five (5) years. The warranty bond must be properly executed by a surety company satisfactory to the Department and be payable to the State of Indiana and submitted with the bid.

    The warranty bond is $1,500,000.00 [*contract specific value*] for the warranted HMA pavement. The bond is intended to insure completion of required warranty work, including payments for all labor, equipment, materials and closure periods used to remediate any warranted pavement distresses.

    Upon the final acceptance of the project, the contractual obligations of the contractor are satisfied as long as the pavement continues to meet or exceed the warranted values as defined herein.

    All warranty work shall be in accordance with Section 5. At the end of the warranty period, the Contractor will be released from the further warranty work or responsibility, provided all previous warranty work has been satisfactorily complete and accepted by the Department.

3. CONFLICT RESOLUTION TEAM (TEAM): The scope of the Team includes all issues concerning the warranted pavement relative to: material selection, quality control plan, distress rate, and remediation.

    The Team will consist of two Contractor representatives, two Department (District & Central Office) representatives, and a fifth person mutually agreed upon by both the Department and the Contractor. Any costs for the fifth person will be equally shared between the Department and the Contractor.

    The Team members shall be identified in writing at the preconstruction meeting and will be knowledgeable in the terms and conditions of this warranty and the methods used in the measurement and calculation of pavement distress. Should any impasse develop, the Team will render a final recommendation to the Chief Engineer by a majority vote. Each member has an equal vote.

4. WARRANTY WORK: during the warranty period remedial work shall be performed at no cost to the Department and shall be based on the results of pavement distress surveys. Remedial work to be performed and materials to be used will be the joint decision of the Contractor and the Department. Prior to the proceeding with any warranty work or monitoring, a Miscellaneous Permit shall be obtained from the Department.

    Costs for closure periods will be applied using the closure period rates contained in this contract.

    During the warranty period, the Contractor may monitor the warranted HMA pavement using nondestructive procedures. All proposed remedial action(s) shall be coordinated with the Department.

    Coring, milling, or other destructive procedures may not be performed by the Contractor, without prior consent of the Department. If the Contractor elects to conduct any independent testing, both destructive and non-destructive, the equipment shall be calibrated and correlated with the department's equipment.

    The Contractor shall not be responsible for damages to the pavement as a result of coring, milling or other destructive procedures conducted by the Department.

    The Contractor shall have the first option to perform the remedial work. If, in the opinion of the Department, the problem requires immediate attention for safety of the traveling public and the Contractor has not performed the remedial work within twenty-four (24) hours, the Department has the option to have the remedial work performed by the other forces. The Contractor shall be responsible to pay for all the cost incurred. Remedial work performed by other forces shall not alter the requirements, responsibilities, or obligations of the warranty.

5. PAVEMENT DISTRESS INDICATORS, THRESHOLDS AND REMEDIAL ACTION: The Department will use the following pavement distress indicators:

    - International Roughness Index (IRI)
    - Rut Depth
    - Friction Number
    - Longitudinal Cracking
    - Transverse Cracking

The Department procedures contained in the manual “Measurement and Calculation of Pavement Distress Indicators for Warranted HMA Pavements” will be used for distress measurements and calculation of pavement distress indicators.

The Department will conduct pavement condition surveys annually between April 15 and May 30 at no cost to the Contractor. The Contractor will be advised of the survey schedule and the results will be made available to the District, Central Office, Contractor and FHWA within 14 days after completion of the survey. If the Contractor disputes the survey findings, written notification of the dispute shall be provided within 30 days. Any such dispute must be based on appraisals of data supplied or additional information performed by a licensed professional engineer in the State of Indiana.

The final condition survey will occur by August 15, 2009 [*contract specific value*]. Remedial work, if required, shall be completed by October 1, 2009 [*contract specific value*]. Written acceptance by the Department will be given following completion of any remedial work.

If any of the threshold levels are met or exceeded, the Contractor shall recommend remedial action. After the Department approves the remedial action, the Contractor shall perform the remedial work according to the following minimum standards:

Alligator Cracks:

Remove and replace distressed layer(s). The removal area to be 150% of the distressed area to a depth not to exceed the warranted pavement

Flushing:

Remove and replace distressed surface layer full lane width. The removal area to be 150% of the distressed area.

Longitudinal Cracks:

Rout and seal all cracks with rubber crack filling material, or agreed upon equal

Transverse Crack:

Rout and seal all cracks with rubber crack filling material, or agreed upon equal

Longitudinal Distortion:

Remove and replace distressed layer(s). Removal area to be 110% of the distressed area to a depth not to exceed the warranted pavement

Potholes, Slippage Areas, Raveling, Segregation and Other Disintegrated Areas:

Remove and replace distressed area(s). The removal area to be 150% of the distressed area to a depth not to exceed the warranted pavement

Rutting:

Remove and replace distressed layers full lane width

Low Friction:

Remove and replace, or overlay distressed layers full lane width with HMA.

Warranty requirements for all remediation work will be limited to the life of the original contract warranty.

If any of the threshold levels are met or exceeded and the Contractor does not agree to the pavement distress survey results or, the Department does not agree with the proposed remedial action, the Team will provide a recommendation within 30 days.

Remedial action shall be performed on all segments of the project where the threshold levels are met or exceeded. If areas of warranted pavement which are not within the measured area are suspected of meeting or exceeding a threshold level, the Department will conduct a distress survey to see if a threshold level has been met or exceeded.

Remedial action shall be taken by October 1 of the same calendar year as the survey that indicated the threshold level is met or exceeded. If, anytime during the warranty period, 30% or more of the project segments require, or have received remedial action, then the entire project shall receive a remedial action as determined by the Contractor and the Department. If an impasse develops, the Team will make a final recommendation.

If remedial action work or elective/preventive action work performed by the Contractor necessitates a corrective action to the pavement markings, adjacent lane(s) or roadway shoulders, then such corrective action to the pavement markings, adjacent lane(s) and shoulders will be the responsibility of the Contractor.

The threshold values for each 100 meter evaluation section are as follows:

International Roughness Index	1.4 m/km (90 in/mi)
Rut Depth	6.0 mm (0.25 in)
Longitudinal Cracking (Severity 2 or greater)	0 m
Friction Number	25

The friction number must average 35 with no three consecutive sections with individual value less than 25. Friction numbers will be measured in each lane.

Transverse Cracking	5.5 m (18 ft)

Transverse cracks will be monitored for 152.5 m (500 ft) beginning at each reference post.

The Contractor will not be held responsible for distresses that are caused by factors beyond the control of the Contractor. For example, the Contractor will be relieved of the responsibility for IRI remedial action if caused by alligator cracking. The Contractor shall provide proof that the warranted pavement in question is of proper thickness (not thinner than 15 mm from plan thickness) and the recovered binder is of acceptable stiffness and one of the following are true: The rubblized concrete pavement is less than 50 mm thinner than plan thickness, the subgrade density is less than 90% of optimum, or the actual number of Class 5 and above trucks are 50% above the projected five year number of Class 5 and above trucks. The five year projected number of Class 5 and above trucks for this project is 11,500,000 [*contract specific value*].

The rutting threshold level is waived when the accumulated number of Class 5 and above trucks is 50% above the projected fifth year accumulated number of Class 5 and above trucks. The Contractor shall only be responsible for mixture and placement problems.

6. ELECTIVE/PREVENTIVE ACTION: Elective/preventive action shall be the Contractor's option with the concurrence of the Department. For elective/preventive actions, closure periods are not charged.

7. DEPARTMENT MAINTENANCE: The Department will perform routine maintenance during the warranty period such as snow plowing, applying de-icing chemicals, repairs to safety appurtenances, pavement markings, mowing and sign maintenance.

8. METHOD OF MEASUREMENT: Warranted HMA pavement will be measured for payment by the megagram of mixture based on the quantity of mixture placed in accordance with 109.01(b) of the standard specifications.

9. BASIC OF PAYMENT: The accepted quantities of HMA pavement mixtures will be paid for at the contract unit price per megagram for HMA Pavement Mixture, Warranted, which payment will be full compensation for furnishing, preparing, hauling, mixing and placing all materials and compacting the mixtures. The Warranty Bond, warranty work, Job Mix Formula, Quality Control Plan and all testing, record keeping, sampling and traffic control are included in the contract unit price.

   Payment will be made under:

Pay Item	Pay Unit
HMA Pavement Mixtures, Warranted………………………………	Mg (ton)

10. QUALITY CONTROL PLAN FOR WARRANTED HMA PAVEMENTS: This section covers the preparation of the QCP by a Contractor. The QCP shall be provided, maintained, and followed to assure all materials furnished and placed for acceptance are in accordance with the contract requirements.

    10.1 STANDARDS. AASHTO, ASTM, ITM, and other referenced standards will be identified.

10.2 GENERAL REQUIREMENTS

10.2.1 The QCP shall be contract specific and state how the Contractor proposes to control the materials, equipment, and production methods on the project.

10.2.2 The QCP shall contain the name, qualifications, telephone number, duties, and employer of all quality control personnel necessary to implement the QCP. The minimum number of quality control functions shall be as follows:

10.2.2(a) QCP Manager—the person who is responsible for the overall administration of the QCP.

10.2.2(b) QCP Site Manager—the person who is responsible for the execution of the QCP and liaison with the Engineer.

10.2.2(c) Quality Control Technician—the person who is responsible for conducting quality control tests and inspection to implement the QCP. There may be more than one quality control technician.

10.2.3 One quality control person may perform the duties of any of the other functions listed in 10.2.2(a), 10.2.2(b), or 10.2.2(c).

10.3 The QCP shall contain, but not be limited to, the proposed methods of sampling, testing, calibration, construction control, monitoring, and anticipated frequencies.

10.4 Placement operations shall not begin before the QCP has been accepted.

10.5 The ACP shall be signed and dated by the Contractor’s representative at the time it is submitted to the Engineer.

10.6 The Department will review the QCP contents for compliance with the requirements as stated herein.

10.7 The QCP shall be maintained to reflect the current status of the operations, and revisions shall be provided in writing prior to initiating the change. The change shall not be implemented until the revision has been received and reviewed by the department.

10.8 MIX DESIGN METHODOLOGY: The mix design methodology used for the design of the HMA and how the design shall be developed. As a minimum the mix design shall be based on:

(a) Voids in the Mineral Aggregate (VMA);
(b) Voids in the Total Mix (VTM); and
(c) Voids Filled with Asphalt (VFA).

10.9 LABORATORY: The location of the laboratory for production quality control testing. The Engineer shall be permitted access to the laboratory to witness quality control activities, and review quality control results.

10.9.1 The laboratory testing equipment shall meet the requirements of the test methods identified for the QCP's mix design methodology and required sampling and testing procedures.

10.9.2 The Contractor shall list the laboratory equipment proposed for quality control testing and the respective procedures for calibration. The AASHTO Materials Reference Laboratory (AMRL) requirements for laboratory accreditation shall be used as guidelines. The Contractor shall maintain a record of all equipment calibration results at the laboratory.

10.10 MATERIALS: A list of all materials proposed to be used in the HMA including specific properties of each. The Contractor shall also supply sufficient documentation to demonstrate that all materials meet standard quality requirements for the application. The Contractor shall be responsible to certify to the Department that all products used during HMA production meet the quality requirements as originally specified in the QCP.

10.11 MIXING PLANT: The minimum requirements for control of the HMA mixing plant shall include the following:

(a) Plant inspection (Form TD-444);
(b) Calibration results of all meters, scales and other measuring or recording devices; and
(c) Plant calibration for the mixtures(s).

10.12 MATERIALS SAMPLING AND TESTING: The proposed sampling procedures and size of samples necessary for testing, and controlling as a minimum of VMA and VTM. The test methods and minimum frequencies of the quality control tests shall also be included.

10.12.1 The Contractor shall outline proposed methods to protect the sample from the loss of temperature, binder hardening, and/or binder absorption from the time of sampling the mixture at the project site to the time of testing of the mixture at the laboratory.

10.13 QUALITY CONTROL CHARTS: A statement that control charts shall be maintained at the laboratory. The charts shall include as a minimum VMA, VTM, and other quality control properties as identified in the QCP. All quality control results shall be recorded and included on the control charts within 24 h of testing.

10.13.1 The Contractor's intention to use their own quality control chart design or the Department's furnished charts shall be included. The chart design characteristics, which shall include, as a minimum, material control and specification limits, shall be designated.

10.14 HMA VARIABILITY: A list of the quality control parameters that shall be used to control the mixture and the test tolerances to be used during production. The acceptable tolerances for single test and multiple test results, as well as corrective action to be taken if the results fall outside acceptable tolerances, shall be included.

10.15 IN-PLACE DENSITY TESTING: The method to be used to achieve target densities, and the method of monitoring in-place densities. The Contractor shall be responsible for certifying to the Department that the number of in-place density tests is in accordance with the frequencies as originally specified in the QCP.

10.16 INDEPENDENT ASSURANCE PROGRAM: Acknowledgment of the Independent Assurance Program and the proposed methods to ensure compliance with the minimum frequencies as noted in the Department's Manual for Frequency of Sampling and Testing. The requirements for the Independent Assurance Program shall apply to Contractor's personnel conducting quality control testing.

10.17 DOCUMENTATION: A statement that all material certification, production test reports, quality control charts, test equipment certifications and calibrations, and any other material and/or design or production related records shall be maintained for a period to include the terms of the warranty. The records, either electronic and/or hard copies, shall be maintained in a readily accessible location for access by the Department at any time. Upon completion of the placement, and the opening of the warranted HMA pavement to traffic, a copy of all records shall be provided to the Department.

WARRANT BOND

Know all persons by these presents that we, ___________________________________ as principal and ___________________________________ as surety, are held and firmly bound unto the State of Indiana (hereinafter referred to as oblige) in the full and just sum of $1,500,000.00 [*contract specific value*], lawful money of the United States of America, for the payment of which, well and truly to be made, we bind ourselves, our heirs, administrators, executors, successors, and assigns, jointly and severally, firmly by these presents.

The condition of the above obligation is that for five (5) years after the date all warranted asphalt pavement is complete and opened to unrestricted traffic, the principal is to maintain the travel lanes for the work covered by the contract; such warranty is to be in accordance with the special provisions in this contract (which is made a part of this bond) for warranted asphalt pavement. If the principal satisfactorily fulfills the above condition, then this obligation shall be null and void; otherwise such obligation is to remain in full force and effect.

It is agreed that no modifications, omissions, or additions in or to the terms of the contract or in or to the plans or specifications shall affect the obligation of the surety on its bond.

In witness whereof, we hereunto set our hands and seal.

Name ________________________________

Address ______________________________

By ___________________________________

Signature Surety Title

____

(Printed or Typed) Surety

State of Indiana, County of ___________SS:

Personally appeared before me,

As surety and acknowledge the executions

Of the above bond

This _____ day of ____________, 20 ____

By

____

Signature Notary Public

____

(Printed or Typed) Notary

My Commission Expires _________, 20___

____

(County of Residence)Name

____

Address ______________________________

By ___________________________________

Signature Surety Title

____

(Printed or Typed) Surety

State of Indiana, County of ___________SS:

Personally appeared before me,

As surety and acknowledge the executions

Of the above bond

This _____ day of ____________, 20 ____

By

____

Signature Notary Public

____

(Printed or Typed) Notary

My Commission Expires _________, 20___

____

(County of Residence)

About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,500 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at: http://docs.lib.purdue.edu/jtrp

Further information about JTRP and its current research program is available at: http://www.purdue.edu/jtrp

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