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FINAL REPORT

Effectiveness of various public private partnership pavement rehabilitation treatments: A big data informatics survival analysis of pavement service life

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16. Abstract

Past research efforts have used a wide variety of methodological approaches to analyze pavement performance indicators, pavement rehabilitation treatments, and pavement service life. Using big data informatics methods, the intent of this study is to conduct a detailed, statistical assessment of pavement rehabilitation treatments by PPP type, by studying their performance in terms of pavement indicators (International Roughness Index, rutting depth, and Pavement Condition Rating) and in terms of extending pavement lives. In order to model and forecast pavement performance, a three-stage least squares (3SLS) approach is used. For the pavement service life, the elapsed time until the pavement crosses a threshold is investigated, using random parameters hazard-based duration models. The model estimation results show that several influential factors such as traffic characteristic, weather characteristics, pavement characteristics, and drainage condition, affect pavement performance and pavement service life; and these factors differ among pavement rehabilitation treatments and PPP types.

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TransInfo Research Project Final Report

Effectiveness of Various Public Private Partnership Pavement Rehabilitation Treatments: A Big Data Informatics Survival Analysis of Pavement Service Life

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ABSTRACT

Past research efforts have used a wide variety of methodological approaches to analyze pavement performance indicators, pavement rehabilitation treatments, and pavement service life. Using big data informatics methods, the intent of this study is to conduct a detailed, statistical assessment of pavement rehabilitation treatments by PPP type, by studying their performance in terms of pavement indicators (International Roughness Index, rutting depth, and Pavement Condition Rating) and in terms of extending pavement lives. In order to model and forecast pavement performance, a three-stage least squares (3SLS) approach is used. For the pavement service life, the elapsed time until the pavement crosses a threshold is investigated, using random parameters hazard-based duration models. The model estimation results show that several influential factors such as traffic characteristic, weather characteristics, pavement characteristics, and drainage condition, affect pavement performance and pavement service life; and these factors differ among pavement rehabilitation treatments and PPP types.

CHAPTER 1 INTRODUCTION

1.1 Background and Motivation

Sustaining roadways at an acceptable level has always been a significant issue in the United States. A report card is made every four years to provide a comprehensive assessment of the nation's major infrastructure. This report card is prepared by the American Society of Civil Engineers (ASCE). The report card utilizes a very simple but convenient way to understand grading. It ranges from A (exceptional) to F (failing). According to the report card, United States is overall ranked a D+ grade, and a D grade specifically for the roads. In 2013, ASCE found that 42 percent of United States' major urban highways were congested, which annually costed approximately 101 billion dollars in terms of time and fuel. Although improvements have been made, these cannot be considered as adequate. To upgrade the road condition and performance, a capital investment of approximately 170 billion dollars would be needed (Herrmann, 2013). This, to some extent, is due to significant increases in vehicle miles traveled (VMT). Safety is another significant concern, since roadway conditions are responsible for approximately one-third of all USA traffic fatalities (Herrmann, 2013). These crashes cost the USA about $230 billion each year (Herrmann, 2013). The infrastructure report card provides certain solutions to improve such conditions. ASCE suggests an increase on investments for rehabilitation of roadways, which would optimize highway capacity. It would be crucial to implement performance-based investment strategies and boost the use of asset management programs. Other proposals include applying freight movement efficiency and continue supporting the highway safety improvement program while assuring the sustained sufficiency and reliability of the highway trust fund.

The Federal Highway Administration (FHWA) provides support to the state Department of Transportation (DOT), which seeks to improve or expand their pavement preservation programs. The Pavement preservation programs maintain or repair the roads. A good pavement preservation approach can reduce the cost and time of project for the State Transportation Agencies (STA), which can be translated to more traffic. A pavement preservation strategy has three components, illustrated in Figure 1.1.

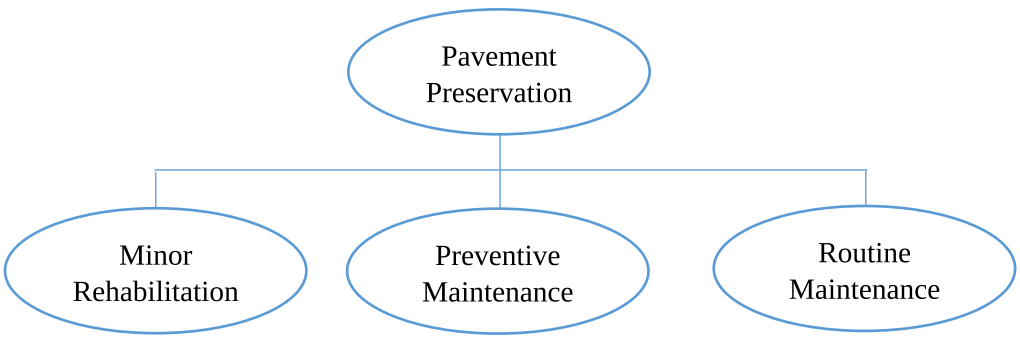

Figure 1.1 Pavement preservation components (FHWA, 2005)

According to FHWA, an improvement in safety and mobility with reduction in congestion and smoother, long-lasting pavement for the public, is the true goal of pavement preservation.

Over 4 million miles of public road have been constrcuted over the years in the USA. As mentioned earlier, a significant increase in vehicle miles traveled has been noticed over the last several decades. For reparation and maintenance, an alternative has been observed. Using a public-private partnership (PPP) often results in an increase of the money available for highway projects. They also complete the work more quickly or at a lower cost, as compared to other methods (Kile, 2014). The term public-private partnership can be associated with transferring more of the risk related to the control of the project to a private associate.

1.2 Research Objectives

Using big data informatics methods, the intent of this study is to conduct a detailed, multivariate statistical assessment of pavement treatments by PPP type, by evaluating their performance in terms of extending pavement lives. Such pavement treatments include: functional treatments [2-course hot-mix asphalt (HMA) overlay with or without surface milling; and concrete pavement restoration], and structural treatments [3-course HMA overlay with or without surface milling; 3-course HMA overlay with crack and seat of PCC Pavement; 3-R (resurfacing, restoration and rehabilitation) and 4-R (resurfacing, restoration, rehabilitation and reconstruction) overlay treatments; and 3-R/4-R pavement replacement treatments]. Pavements may be considered to be in need of such treatments when their International Roughness Index (IRI) or rutting depth (RUT) exceeds certain threshold values, or when their Pavement Condition Rating (PCR) falls below some pre-specified threshold value. This Study utilizes literature-based thresholds, indetified by Sarwar (2016). The way these three critical pavement performance indicators deteriorate over time is investigated, by estimating a three-stage least squares (3SLS) model of IRI, RUT, and PCR by PPP approach and by rehabilitation type, in an effort to account for possible interdependences and cross-equation error correlation.

Furthermore, the elapsed time until the pavement crosses a specific threshold that is considered critical is investigated, using hazard-based duration models; specifically, the pavement service life is modeled by PPP contract type and by rehabilitation type. This task identifies influential factors that increase or reduce pavement life by rehabilitation treatment type and PPP approach. The ability of various pavement rehabilitation treatments and PPP approaches to extend the time it takes for pavements to cross one of these thresholds under various traffic, weather, and initial pavement conditions, is critical for determining the most effective treatments, and thus the efficient allocation of pavement-management resources.

To fulfill this work, cost and project specific data were available from previous conducted studies in the broad area of pavement rehabilitation and PPP cost effectiveness (see for example, Anastasopoulos, 2009; and Anastasopoulos et al., 2009, 2010a-d, 2011a-c, 2012a-c, and 2014a-b). The available data that are used for this study include 1,247 pavement segments that were rehabilitated through various PPP types (performance-based contracting, cost-plus-time, incentives/disincentives, design-build and their derivatives, warranties, and lane rentals) and that were let or completed in the United States (812 segments) and abroad (435 segments) between 1996 and 2011. Out of the 812 USA pavement segments, 200 were from New York, 104 from Texas, 138 from Virginia, 195 from Indiana, 45 from Minnesota, 91 from Florida, and 39 from Alaska. The data were collected and collated from the corresponding Departments of Transportation, and from other resources (for detailed data description and list of data sources, see Anastasopoulos et al. 2014a).

1.3 Organization

The remainder of this study is organized as follows. First, a literature review is conducted, with a focus on PPP and pavement rehabilitation types. Next, the data and methodological framework are presented. The model estimation results are then presented and discussed, categorized by PPP and rehabilitation type. Finally, the findings of this study are summarized, and the conclusions, limitations, and direction for future work are discussed.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

Transportation Agencies spend significant amount of money for pavement rehabilitation. However, the effectiveness of various pavement rehabilitation treatments or their effects on pavement life is not completely understood. The issue can become more complex with the relatively recent abundance, in terms of quantity and quality, of available data. At the same time, public-private partnerships (PPPs) in pavement rehabilitation have been gaining considerable popularity, due primarily to their cost-related benefits. These benefits are typically in terms of cutting costs for the Agencies, and reducing cost-related discrepancies, such as cost overrun, time delay, change orders. Some of the PPP types that are frequently used in pavement rehabilitation include the following (Anastasopoulos, 2007; Anastasopoulos et al. 2010a, 2010b, 2010c, 2010d, 2011d, and 2014a; Nahidi et al., 2017):

i. Performance-based contracting (PBC)
ii. Cost-plus-time contracting (A+B)
iii. Incentives/disincentives (I/D)
iv. Design-build-operate-maintain (DBOM) and their derivatives
v. Warranties (WARR)

vi. Lane-rentals (LR)

Also, some of the most common pavement rehabilitation treatments are as follows (those are as well used for this study):

i. 2-course Hot Mix Asphalt (HMA)
ii. Concrete pavement (PVM) restoration
iii. 3-course Hot Mix Asphalt (HMA) overlay with or without surface milling
iv. 3-course Hot Mix Asphalt (HMA) with crack and seat of Portland cement concrete (PCC) pavement (PVM)
v. 3R & 4R overlay treatments
vi. 3R/4R pavement (PVM) replacement treatments

This chapter includes concepts and definitions regraridng the pavement rehabilitation and maintenance and the different PPP contract types. It also includes a review of the past work.

2.2 Principal Concepts and Definition for Pavement Rehabilitation Treatments

2.2.1 Flexible Pavements

Flexible pavements are made from a thin surface of hot-mix asphalt (HMA) over one or more unbound base courses resting on a subgrade. The water and the moisture constitute crucial factors, which can result in deterioration of the flexible pavements. The water penetrates through cracks in the pavement. To prevent this outcome to happen, popular flexible pavement treatments are described below:

- According to Pavement Interactive (2008), bituminous surface treatment (BST) consists of a thin and protective layer that is applied to a pavement or base course. It can act as a waterproof layer to protect the pavement and increases the skid resistance, while it can act as a filler for cracks or raveled surface. This surface is a great preventive from the sun and the water which is the main deterioration factor for flexible pavement. The surface also increases the friction of the pavement since it has a good gripping texture.
- Cracks sealing products are used to fill each pavement cracks individually. It aims at preventing water to enter the underlying of the pavement. Sand, dirt and rocks can be used for filling (Sarwar, 2015). It is a type of preventive maintenance treatment.
- Micro-surfacing is another treatment that used a homogenous mixture of emulsified asphalt, water, fine aggregate and mineral filler with advanced polymer additives (Sarwar, 2015). It is an advanced form of slurry sealing. Micro-surfacing has benefits such as improving the surface texture and sealing surface cracks. The pavement condition and traffic loads are critical to micro-surfacing. The aforementioned factors determine its success (Sarwar, 2015)
- Rejuvenators are products that are used for restoration of the originals properties to aged asphalt binder. Their use will retard deterioration and can reduce the formation of cracks (Pavement Interactive, 2008).

- A fog seal is also a preventive maintenance treatment. It has for purpose to restore an HMA pavement surface (Pavement Interactive, 2008).
- Patching is an appropriate method for an area of localized distress. HMA is used for permanent patches, whereas, for temporary repairs, cold mix is the most common treatment. Pothole patching is probably the most well-known procedure since it is easily identified by the majority of drivers (Pavement Interactive, 2008).

2.2.2 Rigid Pavement

Rigid pavements performance can be categorized as functional and structural. A functional performance can be related to the surface or profile characteristic and their interactions with vehicles, while the structural performance can be related to the pavement's ability to carry loads (Labi and Sinha, 2003). Some popular rigid pavement preventive maintenance treatments are as follows:

- Diamond grinding is used to restore pavement smoothness and its frictional characteristic by shaving off surface defects that develop on the basis of traffic loads and environmental condition (Sarwar, 2015). Findings show pavement friction can be enhanced by diamond grinding, because it can adjust the surface in such way that allows for plenty of channels of water to escape fromt the surface; this property results in reduced hydroplaning potential. (Anastasopoulos et. al, 2009). It has the potential to reduce the IRI from an older pavement to 63-126 in/mile (Pavement Interactive, 2009).

- The joint and crack sealing is similar to the flexible pavement. Products are used to fill joints and cracks which will prevent water or other substances, resulting in a significant increase of the pavement service life (Sarwar, 2015). Not only is it as important as the sealing of traverse joints, but also it is one of the most cost-effective maintenance techniques used for prevention (Sarwar, 2015). Its service life ranges between 2 and 8 years, depending on its preparation, type and placement of the material used (Anastasopoulos et. al, 2009).
- Undersealing can be defined as filling air-pockets under the concrete slabs. It is done by pumping cement, bitumen or other pozzolanic mixture into the air pocket (Sarwar, 2015).
- The pavement life is greatly increased by underdrain maintenance, which improves the subsurface drainage either for existing or newly constructed pavements (Anastasoupoulos et. al, 2009).

2.2.3 Pavement Condition Indicators

Some commonly used pavement condition indicators, adopted from the vast majority of the Departments of Transportation, include the international roughness index (IRI), the rutting depth (RUT), the pavement condition rating (PCR), the present serviceability index (PSI), and the surface deflection (Anastasopoulos et al., 2013, 2014b, 2016a; Tanaka et al., 2012; Warith et al., 2014, 2015). In this study, and due to data availability, the international roughness index (IRI), the rutting depth (RUT) and the pavement condition rating (PCR) are used to represent the pavement conditions. Those are defined as follows (Anastasopoulos, 2009):

- International roughness index (IRI): The IRI can define a characteristic of the longitudinal profile of a traveled wheel track (Sarwar, 2015). The units used for the IRI are inches per miles or meters per kilometers. The IRI can be calculated using a filtered ratio that is calculated as the average rectified slope of a standard vehicle's accumulated suspension motion, measured in meters/inches, divided by the distance traveled by the vehicle during the measurement time in kilometers/miles (Sarwar, 2015). An IRI of lower value is preferred since it indicates a smoother pavement.
- Rutting depth (RUT): RUT is a depression in the pavement caused by the traversals of vehicles/trucks or by the erosion from water (Sarwar, 2015). The unit used for the RUT is inches. Excessive rutting depth can contribute to vehicle tracking and loss of control during maneuvering (Anastasopoulos et al., 2008).
- Pavement condition rating (PCR): The PCR is based on a visual inspection, made by the engineer, of the pavement distress. The PCR can be expressed by a rating ranging from 0 to 100, with 0 representing a poor pavement condition and 100 an excellent pavement condition (Sarwar, 2015). The engineer decision on the rating is affected by the overall distress and condition of the pavement.

2.3 Principal Concepts and Definition for different PPP types

2.3.1 Performance-based contracting (PBC)

The performance-based contracting approach significantly differs from the method-based contracts, which are considered as the most applied approach for roadway management and maintenance. Using PBC, the clients are not specifying methods or material requirements, but they focus on performance indicators; these indicators constitute requirements of the contracting agreement that must be met by the contractor, while performing maintenance services (Stankevich, et al., 2005). In contrast, under the traditional method, the time period, technologies and material are explicitly specified by the agency. Furthermore, the payment of the contractor is based on the work hours “in situ”, the cubic meters of the pavement completed, etc.

PBC is gaining populatity over the last years. According to Stankevich et al. (2005), it offers multiple advantages:

(a) Road asset management and maintenance cost savings.

(b) More certainty for road agency expansion.

(c) Less demand for agency staff to manage the road network.

(d) Increased customer satisfaction rates involving road service and conditions.

(e) Multi-year financial stability for maintenance.

PBC is not only used in United States; it is used at a global level. It has also provided significant benefits wherever it has been used. Table 2.3.1 shows the major cost savings in many countries from using PBC over the traditional method.

Table 2.3.1 Cost savings of different countries under PBC contracts (Source: Pakkala, 2005)

Cost saving of different countries under PBC over the conventional contracts	
Country	Cost saving, %
Norway	About 20-40%
Sweden	About 30%
Finland	About 30-35%; about 50% less cost/km
Holland	About 30-40%
Estonia	20-40%
England	10% minimum
Australia	10-40%
New Zealand	About 20-30%
USA	10-15%
Ontario, Canada	About 10%
Alberta, Canada	About 20%
British Columbia, Canada	Some, but might be in the order of 10%

Many other results have been observed using PBC. For example, a greater road user satisfaction has been reported. Agencies have noticed that complaints decrease when PBC is being implemented. Cases where pavement does not require treatment, allow for unexpected orders to be managed by the contractor themselves, fact that saves money for the Agency.

In addition to the PBC advantages, a number of challenges have also emerged. According to Stankevich et al. (2005), the challenges can be summarized as follows:

a) Adequate allocation of risks between parties.
b) Contractor and client relationship establishment.
c) Higher demand for new skills and expertise.
d) Agency downsizing.
e) Defining and identifying appropriate performance specifications.
f) Design of an incentive payment mechanism.
g) Assurance for multi-year PBCs regarding long-term funding.
h) Liability and indemnity between the contractor and client determined.

2.3.2 Cost-plus-time contracting (A+B)

The Cost-plus-time contracting is an approach that considers the bid cost and the time to finish the project as pre-specified in the contractor's bid. Using these two criteria (time and cost), agencies select the best contractor under a bi-criteria optimization approach. Since both criteria have different units, it is may be challenging to compare. The solution to this issue, according to Anastasopoulos et al. (2011b-c), is to convert time into dollars by calculating a road-user cost for each day of the contract duration (in dollars/day). Then, it is multiplied by the required number of days for completion for every individual bid. The contractor with the best cost and time offer will be granted the right for this project. Also, many variables can be included in the optimization, such as safety, air quality, noise, etc., which make the problem having a multiple-objective optimization nature. Such contracts are, thus, named multi-parameter contracts (Carpenter et al. 2003; Herbsman et al, 1998).

The A+B contracts have a risk of increasing the construction cost. The faster the project is completed, the more overall traffic control cost will be saved. However, to reduce the time of construction, the initial cost might be higher. This initial cost is covered by the contractor. The contractor will not profit from the savings associated with traffic control. Having that in mind, many contractors do not prefer to reduce the construction project time but instead, to increase it, which can increase significantly the cost of the construction project (Washington State DOT, 2016).

2.3.3 Incentives/Disincentives (I/D)

For incentives/disincentives contracts, the agencies will reward the contractor for an early completion of the project. On the other hand, contractors are penalized in case of delay in project completion. Since time has a different unit then money, a road-user cost is created. In other words, the longer the delay, the higher the cost of the penalty will be (Anastasopoulos et al., 2011).

The advantages of the I/D are very similar to the cost-plus-time contract. As previously mentioned, there are incentives to finish a contract early for both the public agencies and for the contractor. However, incentives come with certain liabilities, if the project is failed to be completed within time. This contingency will diminish the competition since some public agencies and contractors cannot afford to pay the penalties. This process gives an advantage to companies with higher budgets, which are more likely to be awarded the contract, since they can take the aforementioned risk (Anastasopoulos et al., 2015).

2.3.4 Design-build-operate-maintain (DBOM) and their derivatives

In the design-build-operate-maintain method, the responsibility of the four phases (design, build, operation and maintenance) is now undertaken by one contractor or a team of contractors with a lead contractor (Dahl et al., 2005; Anastasopoulos et al., 2015). According to Carpenter et al. (2003), there are 3 levels in the design-build projects. First of all, the low end level is a project that has no room for innovation and is simply basic construction or reconstruction. It is efficient for projects that need to be finished quickly. The second level is the mid-level. In this level, innovation is what makes the decision of using it so attractive. Using innovations to complete the project faster is the main goal. There are two reasons why these projects are ideal for design-build. One reason is timesaving concerning the project declaration and the other is the demand for outside expertise (Carpenter et al. 2003). The last level is called mega. Those projects are complex and tend to take more time. The agency or the owner are willing to fund the project using the design-builder and the resources of the design-builder and to supplement the staff of the agency for other projects (Anastasopoulos et al, 2011).

2.3.5 Warranties (WARR)

Warranties are established to ensure that the product will meet predetermined standards. If it does not reach minimum standards of quality, the contractor will either have to repair it or replace it (Singh et al., 2004). It enforces the contractor to do a higher quality job since the former will be responsible for the maintenance cost. There are two types of warranties: materials-and-workmanship warranties and performance warranties. The responsibility of the contractor in a materials-and-workmanship warranty is associated with the defects, caused by poor materials and workmanship. In a performance warranty, a contractor is responsible that the final product will meet certain performance standards formerly agreed upon (Carpenter et al., 2003).

There are many advantages in using warranties. Since the contractor is responsible for the quality of the product, the product will most likely be of the highest quality. As previously indicated, the contractor is responsible for the maintenance cost, so by providing a high quality product, the future cost would probably reduce.

The time duration of the warranty contracts can vary generally from 1 to 5 years. If the contract is associated with the improvement of the pavement performance, then the warranty period is generally longer. On the other hand, if it concerns the material itself, the warranty period can be shorter (Anastasopoulos et al., 2015)

2.3.6 Lane-rentals (LR)

Lane-rental contracting allows for renting certain lanes in order to close them and do the assigned work. The fees vary depending on many factors such as, the AADT of the road, the length of the road where construction will be done, the time of the construction, etc. The main goal of the lane-rental contracts is to save time, which leads, in turn, to a reduction in public impact. If the project completion time is shorter, the cost of renting a lane and the interruption of traffic due to construction would decrease. The major limitation of this method can be associated with the lack of experience, in terms of implementation, due to its relatively recent implementation (Anastasopoulos et al., 2015; Carpenter et al., 2003).

2.4 Review of Past Work

Past research efforts have used a wide variety of methodological approaches to analyze pavement performance, pavement rehabilitation, and pavement life. For example, Butt et al. (1987) developed a pavement performance and prediction model based on the Pavement Condition Index (PCR) and the age of the pavement. A combination of homogenous and nonhomogeneous Markov chains were used for this model. In an another study, Smith et al. (1997), using time-series analysis, found that the initial pavement smoothness had a significant effect on the future smoothness of the pavement in both new and overlay construction, and that the added pavement life could be obtained by achieving higher levels of initial smoothness.

Singh et al. (2007) used pavement data from Indiana, and evaluated the cost, effectiveness and cost-effectiveness of warranty and traditional contracts. It was inferred that the long-term cost-effectiveness of warranty contracts is more perceptible when: i) both cost and effectiveness are viewed over the entire life of the pavement treatment and; ii) when both the agency and user cost are used in the cost analysis. Labi and Sinha (2003) also used the data from Indiana, and demonstrated a method for cost-effectiveness evaluation of various levels of preventive maintenance activities over pavement life-cycle, using performance curves. It was found that the relative timing between pavement maintenance and performance monitoring reported for a given year, is crucial in the computation of any measure. Jackson et al. (1996) developed – based on the opinions of pavement experts – pavement performance curves for various new pavement sections, as well as for a range of rehabilitation treatments. Gharaibeh and Darter (2003) conducted a pavement longevity study to assess the longevities and the traffic load carrying capacities of new and rehabilitated pavements, for the Illinois Department of Transportation, using survival curves. Some of their findings show the impact of different pavement types, slab thickness, geographic location, durability cracking and AC overlay thickness.

Prozzi and Madanat (2000) used data from the Road Test sponsored by the American Association of State Highway and Transprotation Officials (AASHTO), and developed duration models that enable the stochastic nature of the pavement failure time to be evaluated, as well as censored data to be incorporated in the statistical estimation of the model parameter. The estimated models showed that the predicted failure times were similar to the observed pavement failure data, and were more accurate than the original equation from the AASHTO. Prozzi and Hong (2008) and Anastasopoulos et al. (2012)

used a fixed and random, respectively, parameters seemingly unrelated equations approach to study the post-rehabilitation performance of pavements, and accounted for the possible interrelationships among the considered pavement rehabilitation treatments.

Past research has also used a variety of methodological approaches to model pavement performance with respect to maintenance and rehabilitation practices. Prozzi and Madanat (2004), Agarwal et al. (2006), Puccinelli and Jackson (2007) used linear regression; while Butt et al. (1987), Abaza et al. (2004), Hong and Prozzi (2006) have used Bayesian models and Markov chains. Nonlinear mixed-effect and joint discrete-continuous models were applied by Madanat et al. (1995) and Archilla (2006a); and more recently, random-effect, mixed-effect, and random-parameter models have been used by Madanat et al. (1997), Archilla (2006b), Lee (2007), Madanat et al. (2010), Aguiar-Moya et al. (2011), Anastasopoulos et al. (2011a, 2012a, and 2012c), Khraibaniet al. (2012), MacKenzie and Barker (2013). Sarwar and Anastasopoulos (2016) used 3SLS models instead of SURE models for pavement performance modeling.

A number of studies performed pavement survival/failure analysis using hazard-based duration models. For example, Gharaibeh et al. (1997) performed a survival analysis to provide feedback on the design of new or original pavements and on overlay design, using data from the Illinois Pavement Feedback System database. Nam and Mannering (2000) applied hazard-based duration models to statistically evaluate the time it takes to detect, report, respond to, and clear highway incidents. Wang et al. (2005) conducted a survival analysis to investigate the relationship between fatigue failure time and various influential factors in flexible pavement test sections of the long-term pavement performance (LTPP) program. Yu (2005) developed a Cox Proportional Hazards model to analyze the effects of various influential factors on pavement remaining life of flexible pavements in Ohio. Loizos and Karlaftis (2005) used a duration model approach for pavement failure times. Yang (2007) used the pavement condition survey data, collected as part of the Florida pavement management system, to develop parametric duration models based on various hazard assumptions. Hensher and Mannering (2007) inferred that in order to model transport-related phenomena that deal with the elapsed time until the occurrence of an event,, hazard-based duration models should be used. Anastasopoulos et. al (2009c) analyzed the duration and prolongation of Performance-Based contracts through hazard-based duration and zero-inflated random parameters Poisson models.

To account for the underlying – across the observations – unobserved heterogeneity, random parameter modeling has been extensively used in several methodological contexts over the last years. Specifically, Anastasopoulos and Mannering (2009) explored the use of random-parameters count-data models as a methodological alternative in analyzing accident frequencies. Anastasopoulos et. al. (2012a) used a hasard-Based Approach with random parameters for the analysis of urban travel times. Anastasopoulos and Mannering (2011) used an empirical assessment of fixed and random parameter logit models for crash- and non-crash-specific injury data. Anastasopoulos et al. (2012) used a random parameters Tobit regression model to account for unobserved heterogeneity in accident rates analysis. Anastasopoulos et al. (2012) used random parameters bivariate ordered probit model for modeling household automobile and motorcycle ownership. Anastasopoulos and Mannering (2014) assessed the effectiveness of pavement overlays and replacements on pavement life for urban roads in Indiana, by estimating random parameter duration models. Anastasopoulos and Mannering (2016) used a random paramete seemingly unrelated equations (SURE) approach to analyze the effect of speed limits on drivers' speed choice. Anastasopoulos (2016) used random parameters multivariate tobit and zero-inflated count data models to address unobserved and zero-state heterogeneity in accident injury-severity rate and frequency analysis. Fountas et. al. (2017) used a dynamic binary random parameters (mixed) logit approach to identify pre-crash stationary and dynamic factors of accident occurrence.

2.5 Chapter Summary

This Chapter provides information regarding popular public-privae partnership (PPP) and pavement rehabilitation types, which are also investigated in this study. Specifically, the PPP types include performance-based contracting (PBC), cost-plus-time contracting (A+B), incentives/disincentives (I/D), cesign-build-operate-maintain (DBOM) and their derivatives, warranties (WARR), and lane rentals; whereas, the rehabilitation types include 2-course Hot Mix Asphalt (HMA), concrete pavement (PVM) restoration, 3-course Hot Mix Asphalt (HMA) overlay with or without surface milling, 3-course Hot Mix Asphalt (HMA) with crack and seat of Portland cement concrete (PCC) pavement (PVM), 3R & 4R overlay treatments, and 3R/4R pavement (PVM) replacement treatments. The Chapter also provides a review of past work regarding the analysis of various attributes of the PPP and rehabilitation types.

CHAPTER 3 METHODOLOGY

3.1 Modeling of pavement performance indicators

To assess the effectiveness of pavement rehabilitation treatments by PPP type, two approaches are employed. The first is to explore how critical pavement performance indicators are deteriorating over time, for each PPP and rehabilitation type. A model such as this could provide valuable information on the effectiveness of various rehabilitation treatments. In fact, recent studies (Prozzi and Hong, 2008, Anastasopoulos et al., 2012c) have provided improvements in the forecasting accuracy of pavement performance modeling, by statistically modeling such pavement performance indicators as a system of seemingly unrelated regression equations (SURE). This approach accounts for cross-equation error correlation as a means to control for unobserved factors that lead pavements in poor condition and to observe poor performance indicators. The most common pavement performance indicators are the International Roughness Index (IRI), the rutting depth (RUT), and the Pavement Condition Rating (PCR). Even though the first two can be accurately measured, the PCR is based on engineers' observations of the pavement surface. Therefore, it is likely that the PCR may be measured as a function of the observable IRI and rutting depth. This will be addressed by estimating a three-stage least squares (3SLS) model of IRI, rutting depth, and PCR (omitting subscripting for individual pavement segment, treatment types, and PPP types) (Sarwar and Anastasopoulos, 2016):

$$\text{IRI}_t = \text{IRI}_{t\text{-}1} + \beta_{\text{IRI}}\mathbf{Z}_{\text{IRI}} + \boldsymbol{a}_{\text{IRI}}\mathbf{X}_{\text{IRI}} + \boldsymbol{\zeta}_{\text{IRI}}$$

$$\text{Rut}_t = \text{Rut}_{t\text{-}1} + \beta_{\text{Rut}}\mathbf{Z}_{\text{Rut}} + \boldsymbol{a}_{\text{Rut}}\mathbf{X}_{\text{Rut}} + \boldsymbol{\zeta}_{\text{Rut}} \qquad (1)$$

$$\text{PCR}_t = \text{PCR}_{t\text{-}1} + \text{IRI}_t + \text{Rut}_t + \beta_{\text{PCR}}\mathbf{Z}_{\text{PCR}} + \boldsymbol{a}_{\text{PCR}}\mathbf{X}_{\text{PCR}} + \boldsymbol{\zeta}_{\text{PCR}}$$

where IRI_t, Rut_t, and PCR_t are the measured pavement performance indicators (International Roughness Index, rutting depth, and Pavement Condition Rating, respectively) on a specified segment at time t, IRI_{t-1}, Rut_{t-1}, and PCR_{t-1} are the measured pavement performance indicators (as previously defined) on a specified segment at time t–1, $\boldsymbol{Z}$ are vectors of pavement section and pavement condition characteristics, $\mathbf{X}$ are vectors of other influential factors affecting the pavement condition (such as soil conditions, weather conditions, traffic characteristics, age of the pavement structure at the time of treatment, and so on), the $\boldsymbol{\beta}$ and $\boldsymbol{\alpha}$ are vectors of estimable parameters, and the ζ represent a set of excluded variables that, in conjunction with the included explanatory parameters, are sufficient to determine the dependent variables. For further details on 3SLS and other relevant system of equation methods, see: Bhargava et al. (2010). Anwaar et al. (2011, 2012), Anastasopoulos et al. (2012g), and Sarwar and Anastasopoulos (2016b).

There are two classes of simultaneous-equation techniques: single-equation estimation methods and system equation methods. Compared to single equation methods, system equation methods take into account possible cross-equation correlation of disturbance terms. Instrumental variables (IV), indirect least square (ILS), two stage least square (2SLS) and limited information maximum likelihood (LIML) are single equation methods. Three-stage least squares (3SLS) and full information maximum likelihood (FIML) are system equation methods (Washington et al., 2011).

The indirect least squares approach (ILS) uses ordinary least square (OLS) of reduced form model. This approach may produce biased results, and multiple estimates of model parameters in the case of over identified equation system (Sarwar, 2016).

The instrumental variables (IV) approach replaces the endogenous variables on the right side of the equation, with an instrument variable. The instrument variables are variables that are correlated with the endogenous variables but are not correlated with the disturbance term. This approach yields consistent parameter estimates (Washington et al, 2011).

The two stage least square (2SLS) extends the procedure of the IV approach, by adding a second stage in the model estimation. It is still replacing endogenous variables by using instruments but it seeks for the best instruments. Stage 1 regresses each endogenous variable on all exogenous variables. Using the regression-estimated values from Stage 1 as instrument, Stage 2 estimates equations with ordinary least squares (Sarwar, 2016; Anastasopoulos et al., 2015).

Limited information maximum likelihood (LIML) maximizes the likelihood function to estimate reduced form models. In case of over identified equations, this approach can introduce parameter restrictions (Washington et al, 2011).

Full information maximum likelihood (FIML) is the extension of LIML, since it accounts for contemporaneous correlation of disturbances. The assumption made in this approach is that the disturbances are multivariate normally distributed. The likelihood function becomes complex in this case, since there is considerable contemporaneous error correlation (Washington et al, 2011).

Three-stage least squares (3SLS) model is used in this study to address how critical pavement performance indicators are deteriorating over time. Stage 1 obtains two-stage least squares (2SLS) estimates of the model system. Stage 2 uses the 2SLS estimates to compute residuals to determine cross-equation correlations. Stage 3 uses generalized least squares (GLS) to estimate model parameters (Washington et. al., 2011). The 3SLS method is used in this project since it takes into account the correlation of disturbance terms across the equations system, arisen from unobserved characteristics commonly shared among the three independent variables, and it also accounts for endoegenity, since the IRI and rutting depth are endogenous variables to PCR (Sarwar and Anastasopoulos, 2016).

3.2 Estimation of the Pavement Service Life

The second goal of this study is to investigate the elapsed time until the pavement crosses a threshold that is considered critical. These thresholds can be defined as being crossed when the pavement's IRI or rutting depth exceed certain threshold values, or when its PCR falls below some specified threshold values. In this study, the literature-based thresholds identified in Sarwar (2016) are used. Data on the time until a threshold is crossed are referred to as survival or failure data. These are best modeled using hazard functions, as has been previously done in pavement-related literature (Prozzi and Madanat, 2000; Wang et al., 2005; Yu, 2005; Yang, 2007; Anastasopoulos and Mannering, 2014). For pavement rehabilitation treatment survival/failure data, hazard-based models can be used to examine the conditional probability of the pavement crossing a critical threshold (such as IRI or Rutting depth exceed, or PCR below a specified value) at some time *t*, given that it has not crossed this threshold until time t. This conditional probability is important because the probability of a pavement's performance indicator crossing some critical threshold will increase as the pavement ages (more on this below). Turning to the statistical description of this approach, the hazard function is (Washington et al., 2011), $h(t) = f(t)/[1 – F(t)]$, where $F(t)$ and $f(t)$ are the cumulative distribution function and the density function of pavement lives, respectively, and $h(t)$ is the conditional probability that the PPP pavement rehabilitation treatment will cross a threshold between time t and $t + dt$, given that it has not crossed this threshold up to time t. In other words, $h(t)$ gives the rate at which the PPP pavement rehabilitation treatment is crossing a specified threshold at time t, given that the treatment has not crossed the specified threshold up to time t. This hazard function can be upward sloping as time passes ($dh(t) / dt > 0$) indicating that the conditional probability that the pavement life will end soon increases as the pavement lasts longer; it can be downward sloping ($dh(t) / dt < 0$) indicating that the conditional probability that the pavement life will end soon decreases as the pavement lasts longer; or it can be constant ($dh(t) / dt = 0$) indicating that the conditional probability of the pavement life ending soon is independent of the length of time the pavement has lasted. And the survivor function, which provides the probability that a PPP pavement rehabilitation treatment will survive a time greater than or equal to some specified time, t, is $S(t) = P(T \geq t)$.

To account for the effect of influential variables will have on the PPP pavement-treatment survival curves (such as soil conditions, weather conditions, traffic characteristics, pavement condition at time of treatment application, etc.), a proportional hazards approach can be used; specifically, the explanatory variables act multiplicatively on some underlying (or baseline) hazard function such that (Washington, et al., 2011):

$$h(t|\mathbf{X}) = h_0(t)EXP(-\beta\mathbf{X}). \qquad (2)$$

where, **X** is a vector of explanatory variables, **β** is a vector of estimable parameters, and $h_0(t)$ is the baseline hazard that denotes the hazard when all elements of the explanatory variables vector are zero. In estimating Equation 2, a common approach is to consider various parametric forms of the underlying hazard function. The most widely used parametric forms involve the exponential, Weibull, Weibull with gamma Heterogeneity and Log-logistic models. The Weibull distribution is a more generalized form of the exponential distribution since it provides a more flexible means of capturing duration dependence, but is still limited because the hazard has to be monotonic over time. The Weibull distribution has a density function f(t) = λP(λt)P-1 EXP[(-λt)P] and the hazard function is h(t) = λP (λt)P-1, λ > 0 & P > 0. It allows for:

- positive duration dependence when P > 1 (hazard is monotonic increasing in duration and the probability of the duration ending increases over time);
- negative duration dependence when P < 1 (hazard is monotonic decreasing in duration and the probability of the duration ending decreases over time); or
- no duration dependence when P = 1 (hazard is constant in duration and the probability of the duration ending is unchanged over time).

In fully-parametric models the most common approach to account for heterogeneity is to introduce a heterogeneity term designed to capture unobserved effects across the population and to work with the resulting conditional survival function. For a Weibull distribution with Gamma Heterogeneity a small modification in the formula is used:

h(t) = λP(λt)P-1[S(t)]θ. Also, if $\theta = 0$, heterogeneity is not present because the hazard reduces to a simple Weibull and the variance of the heterogeneity term is zero.

The log-logistic distribution allows for non-monotonic hazard functions and is often used as an approximation of the more computationally cumbersome lognormal distribution. It can be represented using this formula; f(t) = λP(λt)P-1[1+(λt)P]-2, h(t) = [λP (λt)P-1]/[1+(λt)P], λ > 0 & P > 0. Also, if P<1, then the hazard is monotone decreasing in duration. If P=1, then the hazard is monotone decreasing in duration from parameter λ. If P > 1, then the hazard increases in duration from zero to an inflection point, ti = (P-1)1/P/ λ, and decreases toward zero thereafter. For additional information on the application of hazard-based duration models, see: Anastasopoulos et al. (2009c, 2012e, 2012f, 2017), Anastasopoulos and Mannering (2014), and Irfan et al. (2011).

It is important to note that many of the PPP pavement-treatment data will be right censored, meaning that not all treatments will be observed crossing a threshold over the observation period. These censored data can be readily handled with the hazard-function approach.

For all the developed statistical models, the possibility that the effect of the explanatory parameters may vary across the observations due to unobserved heterogeneity or other data limitations, is explored through the use of random parameters, by letting $\boldsymbol{\beta}_n = \boldsymbol{\beta} + \omega_n$, where $\boldsymbol{\beta}_n$ is a vector of estimable parameters and ω_n is a vector of randomly distributed terms (for example, normally distributed terms with mean zero and variance σ^2) (Sarwar et al., 2016c and 2017; Fountas and Anastasopoulos, 2017). With random parameters modeling, unobserved factors are accounted for, and the models' statistical fit and forecasting accuracy are expected to significantly improve. This is important, as the selection of appropriate rehabilitation treatment types under specific PPP types heavily depend on the accuracy of the pavement deterioration and pavement service life forecasts.

CHAPTER 4 DATA DESCRIPTION

The available data that are used for this study include 812 pavement segments that were rehabilitated through various PPP types (performance-based contracting, cost-plus-time, incentives/disincentives, design-build and their derivatives, warranties, and lane rentals) and that were let or completed in the United States between 1996 and 2011. Of these 812 segments, 200 were from New York, 104 from Texas, 138 from Virginia, 195 from Indiana, 45 from Minnesota, 91 from Florida and 39 from Alaska. The data were collected and collated from the corresponding State Departments of Transportation, and from other resources (for detailed data description and list of data sources, see Anastasopoulos et al., 2014a).

The data include information about: the origin of the contract (continent, country, region, etc.); type of the contract (the six PPP contract types discussed above); contract characteristics (duration, length, and coordinates of the road segment or intersection); road assets/activities included in the contract (specific construction, rehabilitation, preservation, and asset management activities); road functional class (rural and urban interstates, non-interstates of the national highway system, and local roads); cost related information (final cost, in-house cost, engineer's estimate of the cost, cost savings, cost overrun, time delay, change orders, number of bids, highest bid, etc.); roadway geometrics (travel way, shoulder, median, and barrier characteristics and measurements); traffic information (average annual daily traffic, traffic composition, etc.); pavement condition and age (pavement roughness, rutting depth, and pavement condition rating); drainage performance; and weather information (precipitation, snowfall, temperature, etc.).

Summary descriptive statistics of the available key variables, by PPP and rehabilitation type, are presented in Tables 4.1.1 through 4.6.6. For the categorical independent variables, the frequency and the percentage are presented in the indicator variables Tables, whereas for the continuous independent variables, the mean, standard deviation, minimum and maximum values are included in the continuous variables Tables. Some key trends were observed for the dependent variables in the descriptive statistics:

- The IRI value was the poorest (it had the highest values) for the Functional-2 course HMA and the 3-course HMA with cracks and seat of PCC PVM for all PPP types.
- No data trend was identified for the PCR, except for an extremely high value for the PBC and the 3R/4R PVM replacement, and for the Warranty and the Concrete PVM restoration.
- The rutting depth for the Functional- 2course HMA treatment had the highest values for all PPP types.

Table 4.1.1 Descriptive statistics of the indicator variables for the Cost-plus-time contracting with 2-course HMA and Concrete PVM restoration

	2-course HMA		Concrete PVM restoration	
Variable Description	Frequency	Percent	Frequency	Percent
System Type				
Interstate	5	17.24	0	0
Non-Interstate (NHS)	6	20.69	1	25
Non-Interstate (Non-NHS)	18	62.07	3	75
Function Class				
Rural	12	41.38	4	100
Urban	17	58.62	0	0
Drainage Efficiency				
Excessively drained	0	0	0	0
Somewhat excessively drained	2	6.9	0	0
Well drained	7	24.14	1	25
Moderately well drained	4	13.79	1	25
Somewhat poorly drained	9	31.03	2	50
Poorly drained	5	17.24	0	0
Very poorly drained	2	6.9	0	0
Work Description Type				
Functional	29	100	4	100
Structural	0	0	0	0
State				
Florida	5	17.24	0	0
Minnesota	24	82.76	4	100
Texas	0	0	0	0
Virginia	0	0	0	0
Indiana	0	0	0	0
Alaska	0	0	0	0
New York	0	0	0	0
Median				
No median	16	55.17	3	75
Median (no barrier)	3	10.34	0	0
Median (barrier)	10	34.48	1	25
Horizontal Curve				
Presence of horizontal curve	29	100	4	100
No horizontal curve present	0	0	0	0
Vertical Curve				
Presence of vertical curve	29	100	4	100

	2-course HMA		Concrete PVM restoration	
Variable Description	Frequency	Percent	Frequency	Percent
No vertical curve present	0	0	0	0

Table 4.1.2 Descriptive statistics of the indicator variables for the Cost-plus-time contracting with 3-course HMA overlay with and without surface milling or 3-course HMA with crack and seat of PCC PVM

	3-course HMA overlay with or without surface milling		3-course HMA with crack and seat of PCC PVM	
Variable Description	Frequency	Percent	Frequency	Percent
System Type				
Interstate	2	33.33	4	30.77
Non-Interstate (NHS)	2	33.33	3	23.08
Non-Interstate (Non-NHS)	2	33.33	6	46.15
Function Class				
Rural	1	16.67	8	61.54
Urban	5	83.33	5	38.46
Drainage Efficiency				
Excessively drained	0	0	0	0
Somewhat excessively drained	1	16.67	1	7.69
Well drained	2	33.33	4	30.77
Moderately well drained	3	50	2	15.38
Somewhat poorly drained	0	0	2	15.38
Poorly drained	0	0	4	30.77
Very poorly drained	0	0	0	0
Work Description Type				
Functional	0	0	0	0
Structural	6	100	13	100
State				
Florida	0	0	0	0
Minnesota	0	0	0	0
Texas	0	0	0	0
Virginia	0	0	0	0
Indiana	6	100	3	23.08
Alaska	0	0	4	30.77
New York	0	0	6	46.15
Median				
No median	5	83.33	6	46.15
Median (no barrier)	0	0	3	23.08

Variable Description	3-course HMA overlay with or without surface milling		3-course HMA with crack and seat of PCC PVM	
	Frequency	Percent	Frequency	Percent
Median (barrier)	1	16.67	4	30.77
Horizontal Curve				
Presence of horizontal curve	6	100	12	92.31
No horizontal curve present	0	0	1	7.69
Vertical Curve				
Presence of vertical curve	6	100	12	92.31
No vertical curve present	0	0	1	7.69

Table 4.1.3 Descriptive statistics of the indicator variables for the Cost-plus-time contracting with 3R & 4R overlay treatments and 3R/4R PVM replacement treatments

	3R & 4R overlay treatments		3R/4R PVM replacement treatments	
Variable Description	Frequency	Percent	Frequency	Percent
System Type				
Interstate	5	31.25	4	28.57
Non-Interstate (NHS)	8	50	3	21.43
Non-Interstate (Non-NHS)	3	18.75	7	50
Function Class				
Rural	10	62.5	7	50
Urban	6	37.5	7	50
Drainage Efficiency				
Excessively drained	1	6.25	0	0
Somewhat excessively drained	0	0	0	0
Well drained	5	31.25	3	21.43
Moderately well drained	7	43.75	3	21.43
Somewhat poorly drained	2	12.5	5	21.43
Poorly drained	1	6.25	3	35.71
Very poorly drained	0	0	0	0
Work Description Type				
Functional	0	0	0	0
Structural	16	100	14	100
State				
Florida	0	0	0	0
Minnesota	0	0	0	0
Texas	0	0	6	42.86
Virginia	0	0	0	0
Indiana	0	0	8	57.14
Alaska	16	100	0	0
New York	0	0	0	0
Median				
No median	10	62.5	5	35.71
Median (no barrier)	1	6.25	1	7.14
Median (barrier)	5	31.25	8	57.14
Horizontal Curve				
Presence of horizontal curve	14	87.5	14	100

Variable Description	3R & 4R overlay treatments		3R/4R PVM replacement treatments	
	Frequency	Percent	Frequency	Percent
No horizontal curve present	2	12.5	0	0
Vertical Curve				
Presence of vertical curve	15	93.75	14	100
No vertical curve present	1	6.25	0	0

Table 4.1.4 Descriptive statistics of the continuous variables for the Cost-plus-time contracting with 2-course HMA and Concrete PVM restoration

	2-course HMA				Concrete PVM restoration			
Variable Description	Mean	Std. Dev.	Min	Max	Mean	Std. Dev	Min	Max
Average AADT (in 1,000 vehicles)	12.587	12.387	0.64	46.85	3.759	1.945	2.07	6.37
Commercial truck percentage	0.140	0.098	0.00	0.42	0.163	0.184	0.05	0.44
Contract final cost (in millions of dollars)	1.353	0.937	0.06	4.80	0.582	0.424	0.28	1.21
Temperature between October and March year t (°F)								
Average of the high temperature	49.811	2.074	46.55	54.72	49.325	2.185	47.37	52.32
Average of the lowest temperature	31.791	1.854	28.29	37.82	31.370	2.522	28.74	34.46
Average temperature	42.357	2.509	37.38	47.72	43.593	5.048	39.84	50.63
Temperature between October and March year t-1 (°F)								
Average of the High temperature	48.199	2.389	43.94	52.94	47.838	2.897	45.13	51.81
Average of the lowest temperature	32.999	2.000	30.25	39.54	32.568	2.003	30.34	34.61
Average temperature	40.356	2.798	34.62	46.47	41.732	6.146	36.66	49.68
Rain coefficient between October and March year t								
Average amount of rain	3.256	0.585	2.10	4.61	3.105	0.748	2.57	4.18
Average of the min amount of rain	1.440	0.562	0.21	3.01	1.088	0.034	1.04	1.12
Average of the max amount of rain	9.321	1.482	3.49	12.29	9.790	0.577	9.24	10.53
Rain coefficient between October and March year t-1								
Average amount of rain	3.825	0.738	2.26	5.13	3.375	0.875	2.70	4.65
Average of the min amount of rain	1.672	0.372	1.18	2.73	1.295	0.119	1.16	1.40

Variable Description	2-course HMA Mean	Std. Dev.	Min	Max	Concrete PVM restoration Mean	Std. Dev	Min	Max
Average of the max amount of rain	8.465	2.751	2.95	10.24	9.063	0.666	8.27	9.89
IRI (inches/miles)								
IRI year t	116.550	30.674	79.00	211.00	107.750	31.595	71.00	148.00
IRI year t-1	105.586	33.850	42.00	199.00	98.000	33.257	55.00	136.00
Base IRI	86.621	40.871	40.00	196.00	89.750	30.467	54.00	128.00
PCR (0 to 100 rating)								
PCR year t	82.931	8.093	67.00	97.00	88.750	6.131	81.00	95.00
PCR year t-1	88.931	7.146	69.00	100.00	93.000	3.916	89.00	98.00
Base PCR	95.000	5.745	74.00	100.00	97.000	3.559	93.00	100.00
RUT (inches)								
RUT year t	0.177	0.097	0.03	0.49	0.200	0.076	0.10	0.28
RUT year t-1	0.150	0.084	0.02	0.44	0.173	0.084	0.08	0.27
Base RUT	0.128	0.090	0.02	0.42	0.143	0.051	0.08	0.20
Number of miles in contract	177.241	286.448	2.00	780.00	17.500	5.447	12.00	25.00
Number of years	3.241	1.123	2.00	5.00	3.500	1.000	3.00	5.00
Cost of savings (%)	0.103	0.093	-0.18	0.26	0.062	0.043	0.00	0.09
Number of bids	2.862	1.274	1.00	6.00	2.250	0.957	1.00	3.00
Cost of overrun (%)	0.010	0.308	-0.43	0.87	0.034	0.228	-0.20	0.34
Time delay	-0.205	0.290	-0.58	0.39	-0.037	0.221	-0.36	0.16
Change of orders	1.379	0.182	0.00	5.00	1.750	2.363	0.00	5.00
Number of lanes	2.240	0.511	1.00	3.00	2.500	1.000	2.00	4.00
Median width (inches)	28.483	41.644	0.00	133.00	7.750	15.50	0.00	31.00
Shoulder width (inches)								
Interior width	4.214	4.214	0.00	14.70	8.825	4.694	2.10	12.80

Variable Description	2-course HMA				Concrete PVM restoration			
	Mean	Std. Dev.	Min	Max	Mean	Std. Dev	Min	Max
Outside width	10.134	5.212	0.00	16.80	3.175	2.656	0.00	5.70

Table 4.1.5 Descriptive statistics of the continuous variables for the Cost-plus-time contracting with 3-course HMA overlay with or without surface milling and 3-course HMA with crack and seat of PCC PVM

	3-course HMA overlay with or without surface milling				3-course HMA with crack and seat of PCC PVM			
Variable Description	Mean	Std. Dev	Min	Max	Mean	Std. Dev.	Min	Max
Average AADT (in 1,000 vehicles)	9.620	8.251	1.43	24.91	29.441	44.391	0.59	131.07
Commercial truck percentage	0.131	0.125	0.04	0.36	0.165	0.071	0.09	0.32
Contract final cost (in millions of dollars)	0.914	0.616	0.19	1.66	3.109	4.857	0.23	17.45
Temperature between October and March year t (°F)								
Average of the high temperature	49.150	2.811	44.87	51.95	49.135	2.656	45.77	53.66
Average of the lowest temperature	29.618	2.311	26.82	32.20	31.342	2.199	25.43	34.28
Average temperature	42.178	2.541	37.88	44.24	40.238	3.512	29.80	44.11
Temperature between October and March year t-1 (°F)								
Average of the High temperature	47.538	2.887	42.00	50.59	47.332	3.003	42.40	52.43
Average of the lowest temperature	32.207	1.888	29.62	34.72	32.471	1.667	29.80	35.44
Average temperature	40.067	3.240	33.81	42.56	37.728	4.099	26.09	42.54
Rain coefficient between October and March year t (inches)								
Average amount of rain	3.290	0.607	2.40	3.87	3.023	0.707	1.47	4.10
Average of the min amount of rain	1.637	0.780	1.08	3.20	1.412	0.452	0.70	2.64
Average of the max amount of rain	8.123	1.750	5.65	10.39	9.081	1.302	6.77	11.03
Rain coefficient between October and March year t-1 (inches)								
Average amount of rain	3.838	0.656	2.94	4.70	3.569	0.715	2.40	4.81
Average of the min amount of rain	1.367	0.296	0.83	1.71	1.55	0.333	1.08	2.47
Average of the max amount of rain	7.685	1.461	5.59	9.62	8.323	1.184	5.71	10.14

Variable Description	3-course HMA overlay with or without surface milling				3-course HMA with crack and seat of PCC PVM			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev.	Min	Max
IRI (inches/miles)								
IRI year t	115.167	41.590	74.00	192.00	124.615	27.594	80.00	173.00
IRI year t-1	107.833	44.459	69.00	190.00	113.539	25.79	77.00	171.00
Base IRI	95.167	48.779	58.00	188.00	98.615	27.636	48.00	162.00
PCR (0 to 100 rating)								
PCR year t	81.333	4.803	73.00	87.00	79.692	8.985	63.00	93.00
PCR year t-1	85.833	5.947	76.00	93.00	87.231	6.918	74.00	95.00
Base PCR	93.500	4.087	87.00	98.00	92.462	8.53	74.00	100.00
RUT (inches)								
RUT year t	0.192	0.050	0.11	0.25	0.17	0.151	0.04	0.61
RUT year t-1	0.160	0.050	0.10	0.22	0.135	0.106	0.04	0.42
Base RUT	0.145	0.051	0.09	0.21	0.0117	0.103	0.02	0.39
Number of miles in contract	79.167	121.54	6.00	325.00	51.538	80.164	2.00	235.00
Number of years	3.667	1.751	2.00	7.00	3.231	1.013	2.00	5.00
Cost of savings (%)	0.092	0.001	0.09	0.09	0.119	0.067	0.09	0.27
Number of bids	3.833	0.408	3.00	4.00	3.231	0.599	3.00	5.00
Cost of overrun (%)	-0.028	0.182	-0.25	0.22	-0.103	0.2	-0.46	0.35
Time delay	-0.347	0.222	-0.07	0.02	-0.167	0.251	-0.67	0.13
Change of orders	0.000	0.000	0.00	0.00	2.231	1.833	0.00	6.00
Number of lanes	2.000	0.000	2.00	2.00	2.769	1.301	2.00	6.00
Median width (inches)	4.000	9.798	0.00	24.00	19.615	26.155	0.00	66.00
Shoulder width (inches)								
Interior width					4.262	3.819	0.00	12.50
Outside width					8.177	3.798	0.00	15.70

Table 4.1.6 Descriptive statistics of the continuous variables for the Cost-plus-time contracting with 3R & 4R overlay treatments and 3R/4R PVM replacement treatments

	3R & 4R overlay treatments				3R/4R PVM replacement treatments			
Variable Description	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
Average AADT (in 1,000 vehicles)	19.071	21.327	2.27	80.81	24.071	336.989	0.48	108.24
Commercial truck percentage	0.130	0.076	0.03	0.32	0.209	0.119	0.03	0.39
Contract final cost (in millions of dollars)	2.187	2.543	0.12	10.30	4.423	2.495	0.22	9.99
Temperature between October and March year t (°F)								
Average of the high temperature	49.238	1.689	46.72	53.06	50.114	3.019	46.57	56.92
Average of the lowest temperature	30.793	1.479	28.15	33.28	32.029	2.162	28.74	37.82
Average temperature	41.179	3.966	29.80	46.26	43.126	3.322	39.84	50.65
Temperature between October and March year t-1 (°F)								
Average of the High temperature	47.688	1.965	44.54	51.54	48.212	3.310	44.60	55.59
Average of the lowest temperature	32.134	1.385	29.80	34.23	34.250	3.444	30.34	42.91
Average temperature	39.046	4.599	26.17	44.86	40.744	3.802	36.51	49.66
Rain coefficient between October and March of year t								
Average amount of rain	3.034	0.529	2.33	3.81	3.245	0.543	2.62	4.40
Average of the min amount of rain	1.653	0.903	0.21	3.51	1.678	0.639	0.99	3.38
Average of the max amount of rain	8.759	1.733	3.49	11.12	9.724	1.021	7.95	11.10
Rain coefficient between October and March year t-1 (inches)								
Average amount of rain	3.620	0.689	2.30	4.60	3.862	0.624	2.97	4.82
Average of the min amount of rain	1.666	0.062	0.51	2.88	1.728	0.506	1.16	3.00

Variable Description	3R & 4R overlay treatments Mean	Std. Dev.	Min	Max	3R/4R PVM replacement treatments Mean	Std. Dev.	Min	Max
Average of the max amount of rain	8.141	1.602	2.95	10.24	8.938	0.918	7.85	10.29
IRI (inches/miles)								
IRI year t	109.625	39.833	55.00	196.00	133.786	75.908	64.00	320.00
IRI year t-1	98.063	36.763	48.00	186.00	122.857	74.476	46.00	299.00
Base IRI	84.688	27.307	46.00	147.00	103.286	66.945	34.00	276.00
PCR (0 to 100 rating)								
PCR year t	79.813	8.159	69.00	92.00	83.071	8.553	66.00	100.00
PCR year t-1	86.250	8.161	73.00	99.00	90.357	6.246	83.00	100.00
Base PCR	91.875	8.531	73.00	100.00	97.643	2.951	91.00	100.00
RUT (inches)								
RUT year t	0.169	0.072	0.06	0.31	0.163	0.097	0.05	0.37
RUT year t-1	0.133	0.071	0.03	0.30	0.126	0.080	0.02	0.26
Base RUT	0.109	0.064	0.02	0.26	0.112	0.082	0.01	0.26
Number of miles in contract	60.438	93.339	2.00	302.00	19.786	14.588	2.00	47.00
Number of years	3.438	0.964	2.00	5.00	3.214	0.975	2.00	5.00
Cost of savings (%)	0.161	0.087	0.09	0.27	0.176	0.097	0.04	0.27
Number of bids	3.313	0.793	3.00	6.00	2.929	0.730	1.00	4.00
Cost of overrun (%)	-0.072	0.232	-0.33	0.33	0.019	0.209	-0.39	0.30
Time delay	-0.369	0.183	-0.76	-0.12	-0.316	0.262	-0.71	0.20
Change of orders	3.750	2.887	0.00	9.00	2.571	1.742	0.00	5.00
Number of lanes	2.188	0.403	2.00	3.00	2.286	0.469	2.00	3.00
Median width (inches)	20.813	34.512	0.00	119.00	51.214	55.545	0.00	130.00
Shoulder width (inches)								
Interior width	8.763	3.865	2.40	14.20	8.400	4.477	0.00	14.70

Variable Description	3R & 4R overlay treatments				3R/4R PVM replacement treatments			
	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
Outside width	8.288	5.306	0.00	16.60	8.793	5.743	0.00	16.80

Table 4.2.1 Descriptive statistics of the indicator variables for the Design-Build with 2-course HMA and Concrete PVM restoration

	2-course HMA		Concrete PVM restoration	
Variable Description	Frequency	Percent	Frequency	Percent
System Type				
Interstate	9	27.27	9	23.08
Non-Interstate (NHS)	5	15.15	8	20.51
Non-Interstate (Non-NHS)	19	57.58	22	56.41
Function Class				
Rural	12	36.36	23	58.97
Urban	21	63.64	16	41.03
Drainage Efficiency				
Excessively drained	0	0.00	1	2.56
Somewhat excessively drained	3	0.09	1	2.56
Well drained	10	30.30	11	28.21
Moderately well drained	5	15.15	8	20.51
Somewhat poorly drained	8	24.24	14	35.90
Poorly drained	4	12.12	4	10.26
Very poorly drained	3	9.09	0	0.00
Work Description Type				
Functional	33	100.00	39	100.00
Structural	0	0.00	0	0.00
State				
Florida	26	78.79	0	0.00
Minnesota	7	21.21	5	12.82
Texas	0	0.00	33	84.62
Virginia	0	0.00	1	2.56
Indiana	0	0.00	0	0.00
Alaska	0	0.00	0	0.00
New York	0	0.00	0	0.00
Median				
No median	19	57.58	14	35.90
Median (no barrier)	2	6.06	6	15.38
Median (barrier)	12	36.36	19	48.72
Horizontal Curve				
Presence of horizontal curve	32	96.97	38	97.44
No horizontal curve present	1	3.03	1	2.56
Vertical Curve				
Presence of vertical curve	33	100.00	38	97.44
No vertical curve present	0	0.00	1	2.56

Table 4.2.2 Descriptive statistics of the indicator variables for the Design-Build with 3-course HMA overlay with or without surface milling and 3-course HMA with crack and seat of PCC PVM

Variable Description	3-course HMA overlay with or without surface milling		3-course HMA with crack and seat of PCC PVM	
	Frequency	Percent	Frequency	Percent
System Type				
Interstate	7	10.29	14	31.11
Non-Interstate (NHS)	20	29.41	15	33.33
Non-Interstate (Non-NHS)	41	60.69	16	35.56
Function Class				
Rural	18	26.47	24	53.33
Urban	50	73.53	21	46.67
Drainage Efficiency				
Excessively drained	2	2.94	2	4.44
Somewhat excessively drained	4	5.88	3	6.67
Well drained	17	25	10	22.22
Moderately well drained	15	22.06	7	15.56
Somewhat poorly drained	18	26.47	13	28.89
Poorly drained	9	13.24	7	15.56
Very poorly drained	3	4.41	3	6.67
Work Description Type				
Functional	0	0	0	0
Structural	68	100	45	100
State				
Florida	0	0	0	0
Minnesota	0	0	0	0
Texas	0	0	0	0
Virginia	27	27	0	0
Indiana	41	41	23	51.11
Alaska	0	0	15	33.33
New York	0	0	7	15.56
Median				
No median	38	55.88	30	66.67
Median (no barrier)	7	10.29	2	4.44
Median (barrier)	23	33.82	13	28.89
Horizontal Curve				

Variable Description	3-course HMA overlay with or without surface milling		3-course HMA with crack and seat of PCC PVM	
	Frequency	Percent	Frequency	Percent
Presence of horizontal curve	63	92.65	44	97.78
No horizontal curve present	5	7.35	1	2.22
Vertical Curve				
Presence of vertical curve	61	89.71	40	88.89
No vertical curve present	7	10.29	5	11.11

Table 4.2.3 Descriptive statistics of the indicator variables for the Design-Build with 3R & 4R overlay treatments and 3R/4R PVM replacement treatments

	3R & 4R overlay treatments		3R/4R PVM replacement treatments	
Variable Description	Frequency	Percent	Frequency	Percent
System Type				
Interstate	3	23.08	9	42.86
Non-Interstate (NHS)	5	38.46	5	23.81
Non-Interstate (Non-NHS)	5	38.46	7	33.33
Function Class				
Rural	4	30.77	12	57.14
Urban	9	69.23	9	42.86
Drainage Efficiency				
Excessively drained	0	0.00	0	0.00
Somewhat excessively drained	1	7.69	0	0.00
Well drained	5	38.46	4	19.05
Moderately well drained	3	23.08	8	38.10
Somewhat poorly drained	2	15.38	6	28.57
Poorly drained	0	0.00	3	14.29
Very poorly drained	2	15.38	0	0.00
Work Description Type				
Functional	0	0.00	0	0.00
Structural	13	100.00	21	100.00
State				
Florida	0	0.00	0	0.00
Minnesota	0	0.00	0	0.00
Texas	0	0.00	7	33.33
Virginia	0	0.00	0	0.00
Indiana	0	0.00	14	66.67
Alaska	0	0.00	0	0.00
New York	13	100.00	0	0.00
Median				
No median	6	46.15	14	66.67
Median (no barrier)	0	0.00	1	4.76
Median (barrier)	7	53.85	6	28.57
Horizontal Curve				
Presence of horizontal curve	12	92.31	20	4.76

Variable Description	3R & 4R overlay treatments		3R/4R PVM replacement treatments	
	Frequency	Percent	Frequency	Percent
No horizontal curve present	1	7.69	1	95.24
Vertical Curve				
Presence of vertical curve	13	100.00	21	100.00
No vertical curve present	0	0.00	0	0.00

Table 4.2.4 Descriptive statistics of the continuous variables for the Design-Build with 2-course HMA and Concrete PVM restoration

	2-course HMA				Concrete PVM restoration			
Variable Description	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
Average AADT (in 1,000 vehicles)	15.986	527.536	0.27	57.86	11.209	23.132	0.36	138.00
Commercial truck percentage	0.202	0.155	0.00	0.50	0.167	0.144	0.03	0.52
Contract final cost (in millions of dollars)	1.630	1.661	0.17	9.96	3.934	7.965	0.06	37.70
Temperature between October and March year t (°F)								
Average of the high temperature	49.249	1.962	45.60	52.85	49.261	3.212	41.23	56.92
Average of the lowest temperature	31.454	1.243	28.99	34.17	31.594	2.190	25.43	36.89
Average temperature	41.411	1.796	37.76	45.71	42.143	3.461	37.38	52.86
Temperature between October and March year t-1 (°F)								
Average of the High temperature	47.443	2.239	43.64	52.42	47.417	3.518	38.38	55.54
Average of the lowest temperature	32.765	1.470	30.17	37.37	33.361	3.117	27.67	42.91
Average temperature	38.886	2.052	35.10	43.24	39.881	4.095	33.81	52.32
Rain coefficient between October and March year t (inches)								
Average amount of rain	3.058	0.492	2.07	4.24	3.073	0.559	1.32	4.19
Average of the min amount of rain	1.353	0.564	0.21	3.71	1.407	0.671	0.32	3.89
Average of the max amount of rain	9.245	1.428	3.49	11.12	9.357	1.173	6.77	13.05
Rain coefficient between October and March year t-1 (inches)								
Average amount of rain	3.598	0.670	2.25	4.94	3.651	0.717	2.17	5.41
Average of the min amount of rain	1.580	0.447	0.69	3.23	1.600	0.544	0.45	3.36
Average of the max amount of rain	8.375	1.533	2.95	10.14	8.514	0.988	5.71	10.14

Variable Description	2-course HMA Mean	Std. Dev.	Min	Max	Concrete PVM restoration Mean	Std. Dev.	Min	Max
IRI (inches/miles)								
IRI year t	128.485	56.316	45.00	335.00	115.301	56.736	43.00	309.00
IRI year t-1	113.182	49.438	39.00	254.00	104.718	52.272	33.00	307.00
Base IRI	93.758	50.323	33.00	225.00	90.769	52.668	25.00	278.00
PCR (0 to 100 rating)								
PCR year t	80.394	8.807	59.00	98.00	81.590	6.870	69.00	96.00
PCR year t-1	85.788	8.670	67.00	100.00	87.795	6.574	74.00	99.00
Base PCR	92.515	6.231	79.00	100.00	95.205	5.745	76.00	100.00
RUT (inches)								
RUT year t	0.245	0.310	0.05	1.83	0.166	0.074	0.03	0.32
RUT year t-1	0.164	0.100	0.02	0.50	0.140	0.068	0.02	0.25
Base RUT	0.136	0.099	0.01	0.49	0.120	0.070	0.02	0.24
Number of miles in contract	97.121	215.144	2.00	802.00	54.359	100.445	2.00	494.00
Number of years	3.333	1.137	2.00	5.00	3.641	1.203	2.00	7.00
Cost of savings (%)	0.002	0.060	-0.28	0.18	0.007	0.024	-0.08	0.10
Number of bids	2.879	0.485	1.00	3.00	2.846	0.587	1.00	4.00
Cost of overrun (%)	0.151	0.218	-0.16	0.73	0.096	0.176	-0.03	0.43
Time delay	0.487	0.057	0.31	0.62	0.486	0.053	0.25	0.56
Change of orders	6.091	1.877	2.00	10.00	3.102	1.903	0.00	9.00
Number of lanes	2.152	0.508	1.00	3.00	2.231	0.427	2.00	3.00
Median width (inches)	22.576	39.375	0.00	113.00	58.667	55.542	0.00	142.00
Shoulder width (inches)								
Interior width	7.439	4.292	0.00	13.90	6.672	4.608	0.00	14.40
Outside width	9.985	4.648	0.00	16.60	7.879	4.631	0.00	16.80

Table 4.2.5 Descriptive statistics of the continuous variables for the Design-Build with 3-course HMA overlay with or without surface milling and 3-course HMA with crack and seat of PCC PVM

	3-course HMA overlay with or without surface milling				3-course HMA with crack and seat of PCC PVM			
Variable Description	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
Average AADT (in 1,000 vehicles)	8.083	16.181	0.24	131.42	20.486	30.032	0.23	152.03
Commercial truck percentage	0.131	0.086	0	0.427	0.157	0.122	0	0.522
Contract final cost (in millions of dollars)	1.615	4.711	0.10	39.50	5.518	11.749	0.07	66.15
Temperature between October and March year t (°F)								
Average of the high temperature	49.42	2.446	41.23	53.79	48.975	3.365	41.23	58.89
Average of the lowest temperature	31.478	1.987	27.8	36.89	30.787	1.782	25.43	37.82
Average temperature	41.861	3.037	29.8	52.86	42.387	4.347	37.88	60.4
Temperature between October and March year t-1 (°F)								
Average of the High temperature	47.651	2.738	38.23	52.29	47.033	3.739	38.3	57.59
Average of the lowest temperature	32.623	1.843	29.62	37.21	32.655	2.766	29.62	42.91
Average temperature	36.607	3.63	26.04	52.32	39.799	5.263	33.81	61.01
Rain coefficient between October and March year t (inches)								
Average amount of rain	3.196	0.549	2.28	4.45	2.934	0.56	1.36	4.5
Average of the min amount of rain	1.289	0.244	0.7	1.82	1.483	0.725	0.55	3.66
Average of the max amount of rain	9.435	1.387	7.23	13.05	9.132	1.009	6.77	12.29
Rain coefficient between October and March year t-1 (inches)								
Average amount of rain	3.788	0.673	2.84	4.96	3.451	0.626	2.16	4.92
Average of the min amount of rain	1.52	0.288	1.07	2.35	1.603	0.542	1.07	3.2
Average of the max amount of rain	8.597	0.897	6.67	10.9	8.293	1.287	3.54	10.11

Variable Description	3-course HMA overlay with or without surface milling				3-course HMA with crack and seat of PCC PVM			
	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
IRI (inches/miles)								
IRI year t	115.206	39.112	57	243	125.289	45.307	47	275
IRI year t-1	106.412	36.516	52	203	114.6	43.186	44	257
Base IRI	95.353	37.814	28	202	98.556	44.872	20	248
PCR (0 to 100 rating)								
PCR year t	84.103	8.728	60	100	82.756	7.333	69	98
PCR year t-1	89.574	8.125	70	100	88.711	7.159	73	100
Base PCR	94.927	6.295	74	100	94.511	6.093	74	100
RUT (inches)								
RUT year t	0.145	0.071	0.03	0.31	0.181	0.121	0.04	0.6
RUT year t-1	0.121	0.062	0.02	0.27	0.157	0.113	0.02	0.6
Base RUT	0.108	0.06	0.02	0.27	0.123	0.108	0.01	0.59
Number of miles in contract	58.721	107.659	2	585	53.578	83.879	2	342
Number of years	3.412	1.2	2	7	3.178	0.984	2	6
Cost of savings (%)	0.005	0.028	-0.17	0.125	0.005	0.101	-0.487	0.185
Number of bids	2.544	0.854	1	4	2.956	0.475	2	4
Cost of overrun (%)	0.101	0.189	-0.338	0.922	0.157	0.285	-0.299	0.129
Time delay	0.495	0.032	0.403	0.63	0.494	0.069	0.304	0.7
Change of orders	3.382	2.045	0	10	4.244	2.268	0	10
Number of lanes	2.191	0.0465	1	3	2.244	0.712	1	5
Median width (inches)	27.162	40.46	0	130	20.889	41.122	0	142

Variable Description	3-course HMA overlay with or without surface milling				3-course HMA with crack and seat of PCC PVM			
	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
Shoulder width (inches)								
Interior width	6.6	5.03	0	14.9	7.242	4.844	0	14.9
Outside width	9.457	5.191	0	16.8	10.462	4.91	0	16.8

Table 4.2.6 Descriptive statistics of the continuous variables for the Design-Build with 3R & 4R overlay treatments and 3R/4R PVM replacement treatments

	3R & 4R overlay treatments				3R/4R PVM replacement treatments			
Variable Description	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
Average AADT (in 1,000 vehicles)	10.369	9.441	0.80	28.88	24.996	18.386	3.08	58.50
Commercial truck percentage	0.226	0.156	0.04	0.46	0.219	0.126	0.03	0.44
Contract final cost (in millions of dollars)	2.396	3.113	0.38	11.52	5.762	5.428	0.62	18.96
Temperature between October and March year t (°F)								
Average of the high temperature	51.074	4.683	41.23	58.89	48.707	2.359	45.20	53.06
Average of the lowest temperature	31.487	2.684	27.80	37.82	31.288	1.759	26.82	34.46
Average temperature	44.845	6.509	37.88	60.40	41.572	2.059	37.94	44.93
Temperature between October and March year t-1 (°F)								
Average of the High temperature	49.000	5.082	38.34	57.36	46.965	2.731	43.19	51.81
Average of the lowest temperature	34.087	3.839	29.62	42.91	32.930	1.664	30.17	36.44
Average temperature	42.454	7.593	33.81	60.70	39.405	2.596	35.31	43.48
Rain coefficient between October and March year t (inches)								
Average amount of rain	3.096	0.522	2.47	4.20	3.189	0.048	2.60	4.51
Average of the min amount of rain	1.589	0.775	0.91	3.68	1.576	0.704	0.32	3.08
Average of the max amount of rain	9.402	0.938	7.95	10.59	9.041	1.167	5.65	10.49
Rain coefficient between October and March year t-1 (inches)								
Average amount of rain	3.728	0.638	2.77	4.60	3.798	0.639	3.04	5.45
Average of the min amount of rain	1.712	0.597	1.16	3.22	1.600	0.527	0.78	2.79
Average of the max amount of rain	8.547	0.675	7.68	9.97	8.520	1.069	5.62	10.24
IRI (inches/miles)								

Variable Description	3R & 4R overlay treatments Mean	Std. Dev.	Min	Max	3R/4R PVM replacement treatments Mean	Std. Dev.	Min	Max
IRI year t	103.923	34.165	62.00	187.00	98.429	42.036	52.00	215.00
IRI year t-1	94.923	33.688	58.00	167.00	89.286	41.901	50.00	209.00
Base IRI	80.308	39.746	40.00	165.00	73.000	40.954	22.00	192.00
PCR (0 to 100 rating)								
PCR year t	80.923	6.664	69.00	92.00	81.905	9.502	60.00	94.00
PCR year t-1	86.692	7.307	79.00	96.00	87.429	7.487	74.00	97.00
Base PCR	94.385	6.239	82.00	100.00	96.238	4.742	81.00	100.00
RUT (inches)								
RUT year t	0.182	0.125	0.05	0.53	0.136	0.074	0.03	0.34
RUT year t-1	0.142	0.095	0.05	0.40	0.116	0.070	0.02	0.32
Base RUT	0.120	0.092	0.02	0.34	0.098	0.068	0.01	0.30
Number of miles in contract	59.692	102.200	2.00	389.00	35.857	81.045	2.00	379.00
Number of years	4.000	1.225	2.00	6.00	3.810	1.365	2.00	7.00
Cost of savings (%)	0.073	0.090	0.00	0.18	0.061	0.082	0.00	0.18
Number of bids	3.077	0.277	3.00	4.00	3.095	0.539	2.00	5.00
Cost of overrun (%)	0.050	0.185	-0.35	0.38	0.105	0.163	-0.19	0.41
Time delay	0.407	0.105	0.25	0.54	0.429	0.129	0.07	0.59
Change of orders	4.923	1.754	2.00	7.00	5.190	2.015	2.00	9.00
Number of lanes	2.154	0.376	2.00	3.00	2.095	0.539	1.00	3.00
Median width (inches)	42.538	57.717	0.00	142.00	17.905	32.159	0.00	97.00
Shoulder width (inches)								
Interior width	6.485	4.298	0.00	13.10	9.143	4.736	1.30	14.90
Outside width	9.408	4.816	0.00	15.70	10.095	4.516	0.00	16.30

Table 4.3.1 Descriptive statistics of the indicator variables for the Incentives/Disincentives with 2-course HMA and Concrete PVM restoration

	2-course HMA		Concrete PVM restoration	
Variable Description	Frequency	Percent	Frequency	Percent
System Type				
Interstate	3	18.75	3	25.00
Non-Interstate (NHS)	4	25.00	1	8.33
Non-Interstate (Non-NHS)	9	56.25	8	66.67
Function Class				
Rural	12	75.00	9	75.00
Urban	4	25.00	3	25.00
Drainage Efficiency				
Excessively drained	2	12.50	0	0.00
Somewhat excessively drained	2	12.50	2	16.67
Well drained	3	18.75	0	0.00
Moderately well drained	3	18.75	3	25.00
Somewhat poorly drained	4	25.00	5	41.67
Poorly drained	1	6.25	2	16.67
Very poorly drained	1	6.25	0	0.00
Work Description Type				
Functional	16	100.00	12	100.00
Structural	0	0.00	0	0.00
State				
Florida	0	0.00	0	0.00
Minnesota	16	100.00	3	25.00
Texas	0	0.00	8	66.67
Virginia	0	0.00	1	8.33
Indiana	0	0.00	0	0.00
Alaska	0	0.00	0	0.00
New York	0	0.00	0	0.00
Median				
No median	6	37.50	9	75.00
Median (no barrier)	2	12.50	0	0.00
Median (barrier)	8	50.00	3	25.00
Horizontal Curve				
Presence of horizontal curve	16	100.00	11	91.67
No horizontal curve present	0	0.00	1	8.33
Vertical Curve				
Presence of vertical curve	14	87.50	10	83.33
No vertical curve present	2	12.50	2	16.67

Table 4.3.2 Descriptive statistics of the indicator variables for the Incentives/Disincentives with 3-course HMA overlay with or without surface milling and 3-course HMA with crack and seat of PCC PVM

	3-course HMA overlay with or without surface milling		3-course HMA with crack and seat of PCC PVM	
Variable Description	Frequency	Percent	Frequency	Percent
System Type				
Interstate	2	16.67	2	12.5
Non-Interstate (NHS)	4	33.33	6	37.5
Non-Interstate (Non-NHS)	6	50	8	50
Function Class				
Rural	2	83.33	9	56.25
Urban	10	16.67	7	43.75
Drainage Efficiency				
Excessively drained	0	0	1	6.25
Somewhat excessively drained	0	0	1	6.25
Well drained	1	8.33	4	25
Moderately well drained	5	41.67	5	31.25
Somewhat poorly drained	3	25	2	12.5
Poorly drained	2	16.67	2	12.5
Very poorly drained	1	8.33	1	6.25
Work Description Type				
Functional	0	0	0	0
Structural	12	100	16	100
State				
Florida	0	0	0	0
Minnesota	0	0	0	0
Texas	0	0	0	0
Virginia	6	50	0	0
Indiana	6	50	9	56.25
Alaska	0	0	6	37.5
New York	0	0	1	6.25
Median				
No median	7	58.33	8	50
Median (no barrier)	1	8.33	0	0

Variable Description	3-course HMA overlay with or without surface milling		3-course HMA with crack and seat of PCC PVM	
	Frequency	Percent	Frequency	Percent
Median (barrier)	4	33.33	8	50
Horizontal Curve				
Presence of horizontal curve	11	91.67	16	100
No horizontal curve present	1	8.33	0	0
Vertical Curve				
Presence of vertical curve	7	58.33	16	100
No vertical curve present	5	41.67	0	0

Table 4.3.3 Descriptive statistics of the indicator variables for the Incentives/Disincentives with 3R & 4R overlay treatments and 3R/4R PVM replacement treatments

	3R & 4R overlay treatments		3R/4R PVM replacement treatments	
Variable Description	Frequency	Percent	Frequency	Percent
System Type				
Interstate	0	0.00	4	40.00
Non-Interstate (NHS)	0	0.00	3	30.00
Non-Interstate (Non-NHS)	2	100.00	3	30.00
Function Class				
Rural	2	100.00	4	40.00
Urban	0	0.00	6	60.00
Drainage Efficiency				
Excessively drained	0	0.00	1	10.00
Somewhat excessively drained	0	0.00	0	0.00
Well drained	0	0.00	2	20.00
Moderately well drained	1	50.00	2	20.00
Somewhat poorly drained	0	0.00	4	40.00
Poorly drained	0	0.00	1	10.00
Very poorly drained	1	50.00	0	0.00
Work Description Type				
Functional	0	0.00	0	0.00
Structural	2	100.00	10	100.00
State				
Florida	0	0.00	0	0.00
Minnesota	0	0.00	0	0.00
Texas	0	0.00	2	20.00
Virginia	0	0.00	0	0.00
Indiana	0	0.00	8	80.00
Alaska	0	0.00	0	0.00
New York	2	100.00	0	0.00
Median				
No median	1	50.00	7	70.00
Median (no barrier)	0	0.00	1	10.00
Median (barrier)	1	50.00	2	20.00
Horizontal Curve				
Presence of horizontal curve	1	50.00	10	100.00
No horizontal curve present	1	50.00	0	0.00

Variable Description	3R & 4R overlay treatments		3R/4R PVM replacement treatments	
	Frequency	Percent	Frequency	Percent
Vertical Curve				
Presence of vertical curve	2	100.00	10	100.00
No vertical curve present	0	0.00	0	0.00

Table 4.3.4 Descriptive statistics of the continous variables for the Incentives/Disincentives with 2-course HMA and Concrete PVM restoration

	2-course HMA				Concrete PVM restoration			
Variable Description	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
Average AADT (in 1,000 vehicles)	16.701	16.840	0.31	55.38	16.606	28.773	0.27	97.55
Commercial truck percentage	0.138	0.114	0.00	0.44	0.172	0.084	0.05	0.31
Contract final cost (in millions of dollars)	1.551	0.767	0.16	3.08	1.550	1.295	0.19	4.42
Temperature between October and March year t (°F)								
Average of the high temperature	50.376	2.686	45.77	5692.00	49.371	1.847	46.97	52.41
Average of the lowest temperature	31.404	2.516	25.43	37.82	31.527	1.378	30.00	34.38
Average temperature	42.708	2.907	38.97	50.65	41.399	1.976	38.57	44.76
Temperature between October and March year t-1 (°F)								
Average of the High temperature	48.745	3.065	42.40	55.54	47.796	2.080	44.60	50.88
Average of the lowest temperature	33.779	3.171	30.40	42.91	32.983	1.498	31.28	36.44
Average temperature	40.523	3.480	34.43	49.80	38.953	2.379	36.02	43.07
Rain coefficient between October and March year t (inches)								
Average amount of rain	3.203	0.702	1.35	4.43	3.051	0.374	2.45	3.65
Average of the min amount of rain	1.713	0.751	0.99	3.76	1.475	0.745	0.32	3.57
Average of the max amount of rain	9.276	0.955	6.77	10.42	9.159	1.204	7.47	11.18
Rain coefficient between October and March year t-1 (inches)								
Average amount of rain	3.778	0.742	2.21	4.85	3.789	0.730	2.89	5.37
Average of the min amount of rain	1.809	0.574	1.06	3.27	1.599	0.599	0.78	3.13
Average of the max amount of rain	8.368	0.937	5.71	10.14	8.651	1.050	7.43	10.14

Variable Description	2-course HMA Mean	Std. Dev.	Min	Max	Concrete PVM restoration Mean	Std. Dev.	Min	Max
IRI (inches/miles)								
IRI year t	136.875	47.534	73.00	228.00	98.250	30.931	55.00	151.00
IRI year t-1	119.938	50.498	44.00	213.00	90.833	30.325	42.00	137.00
Base IRI	92.500	53.671	39.00	188.00	79.000	26.188	38.00	133.00
PCR (0 to 100 rating)								
PCR year t	81.188	10.803	58.00	93.00	85.250	9.753	69.00	100.00
PCR year t-1	88.063	9.560	64.00	100.00	91.917	6.708	83.00	100.00
Base PCR	92.063	8.193	74.00	100.00	95.167	5.766	85.00	100.00
RUT (inches)								
RUT year t	0.183	0.091	0.09	0.44	0.170	0.087	0.07	0.35
RUT year t-1	0.165	0.087	0.09	0.42	0.148	0.083	0.05	0.33
Base RUT	0.127	0.102	0.04	0.40	0.118	0.096	0.02	0.32
Number of miles in contract	269.500	332.272	2.00	827.00	55.083	36.766	9.00	134.00
Number of years	3.063	1.063	2.00	5.00	3.333	1.303	2.00	5.00
Cost of savings (%)	0.138	0.070	-0.06	0.25	0.121	0.059	-0.04	0.23
Number of bids	3.375	0.719	2.00	5.00	2.750	0.452	2.00	3.00
Cost of overrun (%)	0.005	0.197	-0.26	0.56	0.002	0.214	-0.42	0.40
Time delay	-0.021	0.185	-0.51	0.13	-0.206	0.255	-0.63	0.28
Change of orders	1.813	2.315	0.00	7.00	2.167	2.167	0.00	6.00
Number of lanes	2.000	0.516	1.00	3.00	1.917	0.289	1.00	2.00
Median width (inches)	31.875	33.677	0.00	88.00	9.917	21.407	0.00	64.00
Shoulder width (inches)								
Interior width	6.488	4.127	0.00	13.50	6.717	5.483	0.00	14.90
Outside width	10.119	5.472	0.00	16.80	9.158	4.329	0.00	15.30

Table 4.3.5 Descriptive statistics of the indicator variables for the Incentives/Disincentives with 3-course HMA overlay with or without surface milling and 3-course HMA with crack and seat of PCC PVM

	3-course HMA overlay with or without surface milling				3-course HMA with crack and seat of PCC PVM			
Variable Description	Mean	Std. Deviation	Min	Max	Mean	Std. Deviation	Min	Max
Average AADT (in 1,000 vehicles)	11.912	12.301	0.92	38.61	9.255	19.041	0.61	73.93
Commercial truck percentage	0.143	0.091	0.05	0.35	0.114	0.067	0.02	0.23
Contract final cost (in millions of dollars)	0.829	0.792	0.11	2.61	3.905	8.853	0.13	36.75
Temperature between October and March year t (°F)								
Average of the high temperature	49.426	1.572	48.13	53.79	50.482	3.480	41.23	54.72
Average of the lowest temperature	30.948	2.191	28.86	36.89	32.138	2.799	26.82	37.82
Average temperature	41.569	1.663	39.10	45.77	43.626	3.424	37.88	52.86
Temperature between October and March year t-1 (°F)								
Average of the High temperature	48.072	1.729	45.97	52.29	48.603	3.868	38.38	52.94
Average of the lowest temperature	32.447	1.646	31.03	37.21	33.418	2.744	27.67	39.54
Average temperature	39.373	2.229	36.58	45.22	41.652	4.042	33.81	52.17
Rain coefficient between October and March year t (inches)								
Average amount of rain	3.288	0.549	2.54	4.25	3.344	0.536	2.64	4.27
Average of the min amount of rain	1.438	0.253	0.91	1.70	1.555	0.814	0.42	3.27
Average of the max amount of rain	9.747	1.459	8.04	13.05	9.760	1.522	5.65	13.05

Variable Description	3-course HMA overlay with or without surface milling				3-course HMA with crack and seat of PCC PVM			
	Mean	Std. Deviation	Min	Max	Mean	Std. Deviation	Min	Max
Rain coefficient between October and March year t-1 (inches)								
Average amount of rain	4.022	0.648	3.06	5.14	3.915	0.606	3.00	4.73
Average of the min amount of rain	1.673	0.294	1.22	2.17	1.596	0.615	0.45	2.91
Average of the max amount of rain	8.766	0.901	7.68	10.14	8.838	1.122	5.62	10.14
IRI (inches/miles)								
IRI year t	104.083	24.530	66.00	137.00	131.000	44.026	82.00	229.00
IRI year t-1	98.833	25.316	60.00	132.00	119.188	40.907	64.00	210.00
Base IRI	86.833	26.471	46.00	123.00	106.813	45.511	41.00	208.00
PCR (0 to 100 rating)								
PCR year t	86.417	9.624	71.00	99.00	81.500	10.913	60.00	97.00
PCR year t-1	91.167	7.578	80.00	100.00	88.688	8.122	72.00	100.00
Base PCR	94.167	6.726	83.00	100.00	95.313	6.129	81.00	100.00
RUT (inches)								
RUT year t	0.105	0.059	0.03	0.21	0.172	0.100	0.05	0.46
RUT year t-1	0.091	0.052	0.03	0.19	0.153	0.102	0.02	0.46
Base RUT	0.077	0.046	0.02	0.17	0.144	0.103	0.02	0.45
Number of miles in contract	54.333	89.224	2.00	252.00	28.188	30.590	2.00	120.00
Number of years	3.417	1.164	2.00	6.00	3.375	1.088	2.00	5.00
Cost of savings (%)	0.150	0.094	0.00	0.33	0.154	0.046	0.99	0.26
Number of bids	3.750	1.603	2.00	7.00	3.500	1.211	2.00	6.00
Cost of overrun (%)	-0.054	0.265	-0.83	0.15	0.005	0.173	-0.40	0.36

Variable Description	3-course HMA overlay with or without surface milling				3-course HMA with crack and seat of PCC PVM			
	Mean	Std. Deviation	Min	Max	Mean	Std. Deviation	Min	Max
Time delay	-0.128	0.219	-0.46	0.24	-0.223	0.202	-0.48	0.22
Change of orders	2.083	1.929	0.00	4.00	1.375	1.500	0.00	4.00
Number of lanes	1.750	0.622	1.00	3.00	2.375	0.500	2.00	3.00
Median width (inches)	21.083	31.064	0.00	80.00	19.938	29.048	0.00	104.00
Shoulder width (inches)								
Interior width	6.942	4.949	0.00	14.40	5.500	2.973	0.00	9.80
Outside width	7.650	5.908	0.00	16.80	8.275	4.156	0.00	15.30

Table 4.3.6 Descriptive statistics of the indicator variables for the Incentives/Disincentives with 3R & 4R overlay treatments and 3R/4R PVM replacement treatments

	3R & 4R overlay treatments				3R/4R PVM replacement treatments			
Variable Description	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
Average AADT (in 1,000 vehicles)	1.118	0.793	0.56	1.68	14.909	12.974	0.74	40.28
Commercial truck percentage	0.073	0.013	0.06	0.08	0.240	0.141	0.03	0.44
Contract final cost (in millions of dollars)	2.211	2.101	0.73	3.70	5.392	5.015	0.38	16.35
Temperature between October and March year t (°F)								
Average of the high temperature	44.160	4.144	41.23	47.09	50.975	2.727	47.08	56.92
Average of the lowest temperature	31.580	2.022	30.15	33.01	31.350	1.687	28.98	33.77
Average temperature	46.325	9.242	39.79	52.86	43.060	2.984	39.64	50.65
Temperature between October and March year t-1 (°F)								
Average of the High temperature	41.795	4.985	38.27	45.32	48.931	3.063	44.54	55.54
Average of the lowest temperature	32.865	2.242	31.28	34.45	33.883	3.392	30.72	42.91
Average temperature	44.825	10.458	37.43	52.22	40.622	3.722	36.07	49.71
Rain coefficient between October and March year t (inches)								
Average amount of rain	3.085	0.035	3.06	3.11	3.362	0.494	2.44	4.01
Average of the min amount of rain	1.230	0.170	1.11	1.35	1.666	0.821	1.02	3.89
Average of the max amount of rain	9.530	1.259	8.64	10.42	9.793	0.750	8.59	10.64
Rain coefficient between October and March year t-1 (inches)								
Average amount of rain	3.420	0.170	3.30	3.54	4.018	0.631	2.85	4.77
Average of the min amount of rain	1.255	0.177	1.13	1.38	1.918	0.585	1.43	3.36
Average of the max amount of rain	9.110	1.216	8.25	9.97	8.604	0.350	8.16	9.25

Variable Description	3R & 4R overlay treatments				3R/4R PVM replacement treatments			
	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
IRI (inches/miles)								
IRI year t	174.000	15.556	163.00	185.00	103.600	29.915	60.00	157.00
IRI year t-1	171.500	19.092	158.00	185.00	95.100	27.205	60.00	146.00
Base IRI	156.500	17.678	144.00	169.00	83.800	25.125	37.00	133.00
PCR (0 to 100 rating)								
PCR year t	66.000	12.728	57.00	75.00	86.700	7.903	76.00	97.00
PCR year t-1	75.000	5.657	71.00	79.00	93.100	6.226	81.00	100.00
Base PCR	86.500	4.950	83.00	90.00	96.300	5.478	83.00	100.00
RUT (inches)								
RUT year t	0.230	0.141	0.13	0.33	0.135	0.060	0.02	0.21
RUT year t-1	0.220	0.127	0.13	0.31	0.120	0.057	0.02	0.20
Base RUT	0.180	0.127	0.09	0.27	0.109	0.053	0.02	0.19
Number of miles in contract	13.000	2.828	11.00	15.00	17.600	12.563	7.00	47.00
Number of years	3.500	0.707	3.00	4.00	3.000	1.155	2.00	5.00
Cost of savings (%)	0.220	0.125	0.13	0.31	0.195	0.097	0.08	0.31
Number of bids	3.000	0.000	3.00	3.00	3.100	0.876	1.00	4.00
Cost of overrun (%)	0.042	0.040	-0.07	-0.01	-0.166	0.299	-0.73	0.13
Time delay	-0.264	0.255	-0.45	-0.08	-0.300	0.173	-0.66	-0.11
Change of orders	3.500	2.121	2.00	5.00	5.300	3.466	2.00	10.00
Number of lanes	2.000	0.000	2.00	2.00	2.100	0.568	1.00	3.00
Median width (inches)	6.500	9.192	0.00	13.00	20.400	42.854	0.00	133.00
Shoulder width (inches)								
Interior width	6.450	2.475	4.70	8.20	9.610	3.842	2.40	14.90
Outside width	5.700	1.697	4.50	6.90	8.440	2.600	4.70	11.60

Table 4.4.1 Descriptive statistics of the indicator variables for the Lane Rental with 2-course HMA and Concrete PVM restoration

	2-course HMA		Concrete PVM restoration	
Variable Description	Frequency	Percent	Frequency	Percent
System Type				
Interstate	2	9.52	1	50.00
Non-Interstate (NHS)	7	33.33	0	0.00
Non-Interstate (Non-NHS)	12	57.14	1	50.00
Function Class				
Rural	7	33.33	0	0.00
Urban	14	66.67	2	100.00
Drainage Efficiency				
Excessively drained	0	0.00	0	0.00
Somewhat excessively drained	2	9.52	0	0.00
Well drained	5	23.81	1	50.00
Moderately well drained	7	33.33	1	50.00
Somewhat poorly drained	4	19.05	0	0.00
Poorly drained	3	14.29	0	0.00
Very poorly drained	0	0.00	0	0.00
Work Description Type				
Functional	21	100.00	2	100.00
Structural	0	0.00	0	0.00
State				
Florida	8	38.10	0	0.00
Minnesota	13	61.90	1	50.00
Texas	0	0.00	1	50.00
Virginia	0	0.00	0	0.00
Indiana	0	0.00	0	0.00
Alaska	0	0.00	0	0.00
New York	0	0.00	0	0.00
Median				
No median	14	66.67	1	50.00
Median (no barrier)	1	4.76	0	0.00
Median (barrier)	6	28.57	1	50.00
Horizontal Curve				
Presence of horizontal curve	19	90.48	2	100.00
No horizontal curve present	2	9.52	0	0.00
Vertical Curve				
Presence of vertical curve	17	80.95	2	100.00
No vertical curve present	4	19.05	0	0.00

Table 4.4.2 Descriptive statistics of the indicator variables for the Lane Rental with 3-course HMA overlay with or without surface milling and 3-course HMA with crack and seat of PCC PVM

	3-course HMA overlay with or without surface milling		3-course HMA with crack and seat of PCC PVM	
Variable Description	Frequency	Percent	Frequency	Percent
System Type				
Interstate	1	6.67	2	22.22
Non-Interstate (NHS)	2	13.33	0	0
Non-Interstate (Non-NHS)	12	80	7	77.78
Function Class				
Rural	4	26.67	6	66.67
Urban	11	73.33	3	33.33
Drainage Efficiency				
Excessively drained	0	0	1	11.11
Somewhat excessively drained	0	0	1	11.11
Well drained	3	20	2	22.22
Moderately well drained	4	26.67	1	11.11
Somewhat poorly drained	4	27.67	3	33.33
Poorly drained	3	29	1	11.11
Very poorly drained	1	6.67	0	0
Work Description Type				
Functional	0	0	0	0
Structural	15	100	9	100
State				
Florida	0	0	0	0
Minnesota	0	0	0	0
Texas	0	0	0	0
Virginia	0	0	0	0
Indiana	15	100	4	44.44
Alaska	0	0	1	11.11
New York	0	0	4	44.44
Median				
No median	7	46.67	6	66.67
Median (no barrier)	2	13.33	0	0

Median (barrier)	6	40	3	33.33
Horizontal Curve				
Presence of horizontal curve	15	100	9	100
No horizontal curve present	0	0	0	0
Vertical Curve				
Presence of vertical curve	15	100	8	88.89
No vertical curve present	0	0	1	11.11

Table 4.4.3 Descriptive statistics of the indicator variables for the Lane Rentals with 3R & 4R overlay treatments and 3R/4R PVM replacement treatments

	3R & 4R overlay treatments		3R/4R PVM replacement treatments	
Variable Description	Frequency	Percent	Frequency	Percent
System Type				
Interstate	6	33.33	4	33.33
Non-Interstate (NHS)	5	27.78	2	16.67
Non-Interstate (Non-NHS)	7	38.89	6	50
Function Class				
Rural	7	38.89	4	33.33
Urban	11	61.11	8	66.67
Drainage Efficiency				
Excessively drained	0	0	0	0
Somewhat excessively drained	1	5.56	1	8.33
Well drained	6	33.33	3	25
Moderately well drained	5	27.78	3	25
Somewhat poorly drained	1	5.56	4	33.33
Poorly drained	1	5.56	1	8.33
Very poorly drained	4	22.22	0	0
Work Description Type				
Functional	0	0	0	0
Structural	18	100	12	100
State				
Florida	0	0	0	0
Minnesota	0	0	0	0
Texas	0	0	4	33.33
Virginia	0	0	0	0
Indiana	0	0	8	66.67
Alaska	0	0	0	0
New York	18	100	0	0
Median				
No median	6	33.33	8	66.67
Median (no barrier)	2	11.11	2	16.67
Median (barrier)	10	55.56	2	16.67
Horizontal Curve				
Presence of horizontal curve	18	100	12	100

No horizontal curve present	0	0	0	0
Vertical Curve				
Presence of vertical curve	18	100	10	83.33
No vertical curve present	0	0	2	16.67

Table 4.4.4 Descriptive statistics of the continuous variables for the Lane Rentals with 2-course HMA and Concrete PVM restoration

Variable Description	2-course HMA Mean	Std. Deviation	Min	Max	Concrete PVM restoration Mean	Std. Deviation	Min	Max
Average AADT (in 1,000 vehicles)	9.641	7.677	0.94	34.52	12.440	24.880	3.33	21.55
Commercial truck percentage	0.148	0.098	0.05	0.47	0.198	0.192	0.06	0.33
Contract final cost (in millions of dollars)	2.257	3.285	0.45	16.17	1.603	0.005	1.60	1.61
Temperature between October and March year t (°F)								
Average of the high temperature	49.749	2.912	45.41	58.89	48.350	4.921	44.87	51.83
Average of the lowest temperature	31.360	1.343	28.54	33.61	30.035	3.161	27.80	32.27
Average temperature	42.460	5.298	29.80	60.40	40.435	3.613	37.88	42.99
Temperature between October and March year t-1 (°F)								
Average of the High temperature	48.296	3.159	43.41	57.48	46.585	5.768	42.57	50.60
Average of the lowest temperature	32.644	1.459	29.80	35.23	31.310	2.390	29.62	33.00
Average temperature	40.494	6.020	26.04	60.77	36.850	4.299	33.81	39.89
Rain coefficient between October and March year t (inches)								
Average amount of rain	3.240	0.434	2.42	4.11	3.240	0.693	2.75	3.75
Average of the min amount of rain	1.409	0.515	0.21	2.62	1.200	0.184	1.07	1.33
Average of the max amount of rain	9.429	1.827	3.49	12.29	9.680	1.471	8.64	10.72
Rain coefficient between October and March year t-1 (inches)								
Average amount of rain	3.818	0.637	2.28	4.66	3.510	0.537	3.13	3.89
Average of the min amount of rain	1.574	0.380	0.69	2.45	1.235	0.205	1.09	1.38

Variable Description	2-course HMA Mean	Std. Deviation	Min	Max	Concrete PVM restoration Mean	Std. Deviation	Min	Max
Average of the max amount of rain	8.380	1.408	2.95	9.77	9.085	1.393	8.10	10.07
IRI (inches/miles)								
IRI year t	118.143	48.010	61.00	231.00	70.000	16.971	58.00	82.00
IRI year t-1	101.619	48.262	41.00	202.00	67.500	14.849	57.00	78.00
Base IRI	83.667	51.505	36.00	198.00	58.000	4.243	55.00	61.00
PCR (0 to 100 rating)								
PCR year t	81.333	6.792	71.00	99.00	81.500	7.778	76.00	87.00
PCR year t-1	87.857	7.090	75.00	100.00	89.000	2.828	87.00	91.00
Base PCR	94.667	4.933	85.00	100.00	94.000	8.485	88.00	100.00
RUT (inches)								
RUT year t	0.174	0.129	0.06	0.58	0.090	0.014	0.08	0.10
RUT year t-1	0.139	0.112	0.02	0.45	0.085	0.007	0.08	0.09
Base RUT	0.115	0.116	0.01	0.44	0.070	0.014	0.06	0.08
Number of miles in contract	190.667	271.101	2.00	672.00	267.000	325.269	37.00	497.00
Number of years	3.762	1.513	2.00	7.00	3.500	2.120	2.00	5.00
Cost of savings (%)	0.084	0.680	-0.18	0.20	0.086	0.000	0.09	0.09
Number of bids	4.810	1.569	1.00	8.00	5.000	0.000	5.00	5.00
Cost of overrun (%)	0.140	0.178	-0.08	0.73	0.020	0.005	0.02	0.02
Time delay	0.243	0.100	0.53	0.53	0.249	0.021	0.23	0.26
Change of orders	3.762	1.868	0.00	8.00	1.500	2.121	0.00	3.00
Number of lanes	2.190	0.680	1.00	4.00	2.000	0.000	2.00	2.00
Median width (inches)	19.619	43.399	0.00	130.00	63.500	89.803	0.00	127.00
Shoulder width (inches)								
Interior width	6.514	4.817	0.00	13.70	8.250	0.636	7.80	8.70

Variable Description	2-course HMA				Concrete PVM restoration			
	Mean	Std. Deviation	Min	Max	Mean	Std. Deviation	Min	Max
Outside width	8.129	4.969	0.00	16.30	8.200	1.556	7.10	9.30

Table 4.4.5 Descriptive statistics of the continuous variables for the Lane Rental with 3-course HMA overlay with or without surface miling and 3-course HMA with crack and seat of PCC PVM

	3-course HMA overlay with or without surface miling				3-course HMA with crack and seat of PCC PVM			
Variable Description	Mean	Std. Deviation	Min	Max	Mean	Std. Deviation	Min	Max
Average AADT (in 1,000 vehicles)	14.285	33.148	0.56	132.22	30.076	49.173	0.67	148.11
Commercial truck percentage	0.120	0.085	0.03	0.29	0.222	0.151	0.04	0.44
Contract final cost (in millions of dollars)	1.632	2.258	0.61	9.64	0.737	16.688	0.08	51.51
Temperature between October and March year t (°F)								
Average of the high temperature	49.229	2.018	46.23	52.78	50.130	3.500	44.87	54.72
Average of the lowest temperature	30.421	1.716	26.82	33.71	31.434	2.970	27.80	37.82
Average temperature	41.611	1.741	39.26	44.46	40.404	4.940	29.80	47.72
Temperature between October and March year t-1 (°F)								
Average of the High temperature	47.643	2.306	44.32	51.49	48.438	3.880	42.57	52.94
Average of the lowest temperature	32.334	1.411	29.80	34.72	31.962	3.466	27.67	39.54
Average temperature	39.377	2.078	36.07	42.68	37.622	5.633	26.04	45.77
Rain coefficient between October and March year t (inches)								
Average amount of rain	3.159	0.500	2.57	4.25	3.181	0.676	2.47	4.27
Average of the min amount of rain	1.429	0.541	0.70	3.01	1.098	0.294	0.42	1.48
Average of the max amount of rain	9.477	1.485	5.65	12.03	9.631	1.157	8.03	11.12
Rain coefficient between October and March year t-1 (inches)								
Average amount of rain	3.807	0.659	3.04	5.34	3.651	0.802	2.89	4.94

Variable Description	3-course HMA overlay with or without surface miling				3-course HMA with crack and seat of PCC PVM			
	Mean	Std. Deviation	Min	Max	Mean	Std. Deviation	Min	Max
Average of the min amount of rain	1.489	0.301	0.83	1.89	1.303	0.361	0.45	1.64
Average of the max amount of rain	8.785	1.292	5.62	10.90	8.646	0.722	7.85	9.86
IRI (inches/miles)								
IRI year t	108.133	36.357	69.00	177.00	108.000	40.000	66.00	204.00
IRI year t-1	99.200	36.964	56.00	166.00	100.889	40.846	58.00	197.00
Base IRI	82.467	33.088	44.00	148.00	88.667	44.326	51.00	197.00
PCR (0 to 100 rating)								
PCR year t	81.867	5.502	71.00	89.00	81.778	9.189	67.00	94.00
PCR year t-1	89.200	6.614	72.00	99.00	87.889	8.085	74.00	99.00
Base PCR	94.400	5.422	85.00	100.00	94.111	5.231	86.00	100.00
RUT (inches)								
RUT year t	0.160	0.078	0.05	0.29	0.201	0.118	0.05	0.43
RUT year t-1	0.130	0.072	0.04	0.28	0.168	0.105	0.04	0.39
Base RUT	0.107	0.066	0.03	0.27	0.148	0.104	0.02	0.35
Number of miles in contract	75.267	140.630	2.00	482.00	35.000	51.181	4.00	169.00
Number of years	3.600	1.121	2.00	6.00	3.667	0.866	3.00	5.00
Cost of savings (%)	0.086	0.001	0.08	0.09	0.126	0.078	0.09	0.26
Number of bids	4.467	0.743	4.00	6.00	4.778	0.667	4.00	6.00
Cost of overrun (%)	0.121	0.163	-0.18	0.43	0.072	0.121	-0.11	0.27
Time delay	0.279	0.056	0.16	0.35	0.189	0.141	-0.10	0.33
Change of orders	3.733	1.870	0.00	5.00	4.444	3.206	0.00	12.00
Number of lanes	2.267	0.458	2.00	3.00	2.111	0.333	2.00	3.00
Median width (inches)	37.800	45.581	0.00	130.00	17.110	28.184	0.00	78.00
Shoulder width (inches)								

Variable Description	3-course HMA overlay with or without surface miling				3-course HMA with crack and seat of PCC PVM			
	Mean	Std. Deviation	Min	Max	Mean	Std. Deviation	Min	Max
Interior width	6.140	5.332	0.00	12.80	6.967	5.170	0.00	12.80
Outside width	8.873	4.959	0.00	16.80	10.600	3.250	6.10	15.30

Table 4.4.6 Descriptive statistics of the continuous variables for the Lane Rentals with 3R & 4R overlay treatments and 3R/4R PVM replacement treatments

	3R & 4R overlay treatments				3R/4R PVM replacement treatments			
Variable Description	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
Average AADT (in 1,000 vehicles)	9.316	10.673	0.77	38.74	12.543	13.108	0.45	41.80
Commercial truck percentage	0.218	0.146	0.04	0.50	0.204	0.131	0.05	0.43
Contract final cost (in millions of dollars)	4.802	7.270	0.11	29.48	4.018	4.340	0.82	15.05
Temperature between October and March year t (°F)								
Average of the high temperature	50.258	3.879	41.23	58.89	49.596	3.389	41.23	53.08
Average of the lowest temperature	31.227	3.319	26.82	37.82	31.594	1.250	29.68	33.71
Average temperature	44.381	5.424	39.11	60.40	42.995	3.712	39.02	52.86
Temperature between October and March year t-1 (°F)								
Average of the High temperature	48.621	4.258	38.19	57.48	47.803	3.913	38.27	51.79
Average of the lowest temperature	33.212	2.828	29.91	39.54	33.163	1.630	30.25	35.05
Average temperature	42.554	6.245	35.53	60.89	41.123	4.165	36.27	52.27
Rain coefficient between October and March year t (inches)								
Average amount of rain	3.397	0.676	2.13	4.49	3.327	0.505	2.75	4.00
Average of the min amount of rain	1.732	1.003	0.55	3.61	1.390	0.492	0.70	2.62
Average of the max amount of rain	9.501	1.592	5.65	13.05	9.827	1.001	7.47	11.27
Rain coefficient between October and March year t-1 (inches)								
Average amount of rain	4.030	0.797	2.33	5.12	3.753	0.560	3.01	4.68
Average of the min amount of rain	1.739	0.734	0.69	3.17	1.591	0.382	1.11	2.45
Average of the max amount of rain	8.525	1.671	3.54	10.03	8.980	0.830	7.43	10.24
IRI (inches/miles)								

Variable Description	3R & 4R overlay treatments Mean	Std. Dev.	Min	Max	3R/4R PVM replacement treatments Mean	Std. Dev.	Min	Max
IRI year t	96.444	33.229	51.00	167.00	97.833	39.096	59.00	185.00
IRI year t-1	87.944	35.234	41.00	165.00	88.250	33.891	53.00	166.00
Base IRI	73.222	31.323	20.00	131.00	72.917	37.379	27.00	152.00
PCR (0 to 100 rating)								
PCR year t	83.556	7.098	73.00	95.00	80.417	10.273	57.00	97.00
PCR year t-1	88.667	7.731	74.00	100.00	86.833	8.983	65.00	100.00
Base PCR	93.833	7.180	77.00	100.00	95.167	5.797	87.00	100.00
RUT (inches)								
RUT year t	0.158	0.104	0.05	0.37	0.153	0.081	0.08	0.38
RUT year t-1	0.127	0.097	0.04	0.34	0.125	0.066	0.06	0.31
Base RUT	0.110	0.099	0.02	0.33	0.092	0.034	0.04	0.15
Number of miles in contract	26.110	11.178	7.00	45.00	63.833	96.023	3.00	344.00
Number of years	3.611	1.145	2.00	6.00	3.917	1.564	2.00	7.00
Cost of savings (%)	0.195	0.089	0.09	0.27	0.136	0.080	0.09	0.27
Number of bids	4.722	0.461	4.00	5.00	4.083	1.084	1.00	5.00
Cost of overrun (%)	0.014	0.102	-0.20	0.20	0.076	0.154	-0.14	0.38
Time delay	0.024	0.259	-0.46	0.36	0.247	0.141	-0.05	0.44
Change of orders	4.889	1.676	3.00	8.00	5.750	2.527	3.00	12.00
Number of lanes	2.278	0.669	1.00	4.00	2.083	0.289	2.00	3.00
Median width (inches)	39.779	42.277	0.00	113.00	24.583	37.198	0.00	92.00
Shoulder width (inches)								
Interior width	7.750	4.052	0.00	13.30	5.158	4.755	0.00	13.50
Outside width	6.900	4.367	0.00	15.10	10.575	3.795	5.70	15.90

Table 4.5.1 Descriptive statistics of the indicator variables for the Performance-Based contracting with 2-course HMA and Concrete PVM restoration

	2-course HMA		Concrete PVM restoration	
Variable Description	Frequency	Percent	Frequency	Percent
System Type				
Interstate	5	25.00	7	29.17
Non-Interstate (NHS)	4	20.00	4	16.67
Non-Interstate (Non-NHS)	11	55.00	13	54.17
Function Class				
Rural	7	35.00	15	62.50
Urban	13	65.00	9	37.50
Drainage Efficiency				
Excessively drained	0	0.00	0	0.00
Somewhat excessively drained	1	5.00	2	8.33
Well drained	4	20.00	5	20.83
Moderately well drained	4	20.00	9	37.50
Somewhat poorly drained	5	25.00	6	25.00
Poorly drained	3	15.00	1	4.17
Very poorly drained	3	15.00	1	4.17
Work Description Type				
Functional	20	100.00	24	100.00
Structural	0	0.00	0	0.00
State				
Florida	17	85.00	0	0.00
Minnesota	3	15.00	1	4.17
Texas	0	0.00	23	95.83
Virginia	0	0.00	0	0.00
Indiana	0	0.00	0	0.00
Alaska	0	0.00	0	0.00
New York	0	0.00	0	0.00
Median				
No median	8	40.00	15	62.50
Median (no barrier)	1	5.00	0	0.00
Median (barrier)	11	55.00	9	37.50
Horizontal Curve				
Presence of horizontal curve	20	100.00	24	100.00
No horizontal curve present	0	0.00	0	0.00
Vertical Curve				
Presence of vertical curve	20	100.00	24	100.00
No vertical curve present	0	0.00	0	0.00

Table 4.5.2 Descriptive statistics of the indicator variables for the Performance-Based contracting with 3-course HMA overlay with or without surface miling and 3-course HMA with crack and seat of PCC PVM

	3-course HMA overlay with or without surface miling		3-course HMA with crack and seat of PCC PVM	
Variable Description	Frequency	Percent	Frequency	Percent
System Type				
Interstate	1	3.13	2	16.67
Non-Interstate (NHS)	9	28.13	6	50
Non-Interstate (Non-NHS)	22	68.75	4	33.33
Function Class				
Rural	7	21.88	4	33.33
Urban	25	78.13	8	66.67
Drainage Effectiency				
Excessively drained	0	0	1	8.33
Somewhat excessively drained	1	3.13	0	0
Well drained	5	15.63	2	16.67
Moderately well drained	5	15.63	0	0
Somewhat poorly drained	12	37.5	7	58.33
Poorly drained	6	18.75	1	8.33
Very poorly drained	3	9.38	1	8.33
Work Description Type				
Functional	0	0	0	0
Structural	32	100	12	100
State				
Florida	0	0	0	0
Minnesota	0	0	0	0
Texas	0	0	0	0
Virginia	32	100	0	0
Indiana	0	0	0	0
Alaska	0	0	9	75

Variable Description	3-course HMA overlay with or without surface miling		3-course HMA with crack and seat of PCC PVM	
	Frequency	Percent	Frequency	Percent
New York	0	0	3	25
Median				
No median	20	62.5	8	66.67
Median (no barrier)	5	15.63	1	8.33
Median (barrier)	7	21.88	3	25
Horizontal Curve				
Presence of horizontal curve	29	90.63	11	91.67
No horizontal curve present	3	9.38	1	8.33
Vertical Curve				
Presence of vertical curve	29	90.63	12	100
No vertical curve present	3	9.38	0	0

Table 4.5.3 Descriptive statistics of the indicator variables for the Performance-Based contracting with 3R & 4R overlay treatments and 3-course HMA overlay with or without surface milling

	3R & 4R overlay treatments		3-course HMA overlay with or without surface milling	
Variable Description	Frequency	Percent	Frequency	Percent
System Type				
Interstate	8	32.00	12	38.71
Non-Interstate (NHS)	9	36.00	4	12.90
Non-Interstate (Non-NHS)	8	32.00	15	48.39
Function Class				
Rural	11	44.00	9	29.03
Urban	14	56.00	22	70.97
Drainage Efficiency				
Excessively drained	0	0.00	0	0.00
Somewhat excessively drained	2	8.00	2	6.45
Well drained	9	36.00	10	32.26
Moderately well drained	8	32.00	6	19.35
Somewhat poorly drained	3	12.00	8	25.81
Poorly drained	1	4.00	2	6.45
Very poorly drained	2	8.00	3	9.68
Work Description Type				
Functional	0	0.00	0	0.00
Structural	25	100.00	31	100.00
State				
Florida	0	0.00	0	0.00
Minnesota	0	0.00	0	0.00
Texas	0	0.00	5	16.13
Virginia	0	0.00	0	0.00
Indiana	0	0.00	26	83.87
Alaska	0	0.00	0	0.00
New York	25	100.00	0	0.00
Median				
No median	13	52.00	16	51.61
Median (no barrier)	4	16.00	0	0.00
Median (barrier)	8	32.00	15	48.39
Horizontal Curve				

Variable Description	3R & 4R overlay treatments		3-course HMA overlay with or without surface milling	
	Frequency	Percent	Frequency	Percent
Presence of horizontal curve	25	100.00	31	100.00
No horizontal curve present	0	0.00	0	0.00
Vertical Curve				
Presence of vertical curve	25	100.00	31	100.00
No vertical curve present	0	0.00	0	0.00

Table 4.5.4 Descriptive statistics of the continuous variables for the Performance-Based contracting with 2-course HMA and Concrete PVM restoration

	2-course HMA				Concrete PVM restoration			
Variable Description	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
Average AADT (in 1,000 vehicles)	14.498	15.356	0.99	48.01	8.984	11.926	0.65	47.36
Commercial truck percentage	0.190	0.143	0.04	0.45	0.168	0.130	0.04	0.50
Contract final cost (in millions of dollars)	1.748	0.971	0.32	3.99	3.301	5.403	0.37	18.29
Temperature between October and March year t (°F)								
Average of the high temperature	49.792	2.222	44.94	53.45	49.444	2.019	46.23	52.77
Average of the lowest temperature	31.111	1.633	27.45	33.71	31.110	1.615	29.01	34.46
Average temperature	42.634	3.140	37.15	50.63	41.564	1.897	39.02	45.05
Temperature between October and March year t-1 (°F)								
Average of the High temperature	48.080	2.509	42.82	52.10	48.038	2.302	44.50	51.81
Average of the lowest temperature	32.695	1.310	29.97	34.37	32.322	1.699	29.80	36.44
Average temperature	40.375	3.749	34.37	49.83	39.565	2.084	37.22	43.49
Rain coefficient between October and March year t (inches)								
Average amount of rain	3.320	0.465	2.46	4.12	3.267	0.542	2.45	4.46
Average of the min amount of rain	1.672	0.835	0.70	3.98	1.611	0.856	0.32	3.76
Average of the max amount of rain	9.620	0.082	7.68	10.59	9.811	0.918	7.86	11.26
Rain coefficient between October and March year t-1 (inches)								
Average amount of rain	3.949	0.630	2.96	5.18	3.958	0.670	2.96	5.48
Average of the min amount of rain	1.778	0.631	1.06	3.43	1.627	0.668	0.51	3.27
Average of the max amount of rain	8.842	0.639	7.23	9.77	9.015	0.812	7.38	10.07

Variable Description	2-course HMA Mean	Std. Dev.	Min	Max	Concrete PVM restoration Mean	Std. Dev.	Min	Max
IRI (inches/miles)								
IRI year t	127.000	38.395	80.00	202.00	110.625	32.770	43.00	159.00
IRI year t-1	115.450	38.897	58.00	197.00	99.458	30.300	40.00	146.00
Base IRI	97.550	47.036	35.00	196.00	86.917	29.923	21.00	139.00
PCR (0 to 100 rating)								
PCR year t	82.550	7.522	68.00	93.00	83.792	10.147	63.00	99.00
PCR year t-1	90.100	4.633	81.00	99.00	88.875	8.363	68.00	100.00
Base PCR	94.950	4.926	82.00	100.00	94.083	6.480	79.00	100.00
RUT (inches)								
RUT year t	0.195	0.086	0.02	0.34	0.174	0.097	0.04	0.39
RUT year t-1	0.169	0.091	0.02	0.34	0.160	0.093	0.04	0.38
Base RUT	0.150	0.098	0.02	0.33	0.138	0.090	0.04	0.35
Number of miles in contract	116.050	214.724	2.00	762.00	48.417	78.130	2.00	378.00
Number of years	3.400	1.095	2.00	5.00	3.708	0.999	2.00	5.00
Cost of savings (%)	0.081	0.098	-0.15	0.30	0.061	0.065	-0.11	0.22
Number of bids	3.050	0.826	1.00	5.00	3.167	1.274	1.00	7.00
Cost of overrun (%)	-0.039	0.152	-0.28	0.23	-0.028	0.169	-0.26	0.29
Time delay	-0.294	0.303	-0.62	0.43	-0.183	0.343	-0.66	0.42
Change of orders	7.050	2.781	1.00	12.00	5.042	4.165	0.00	12.00
Number of lanes	2.250	0.444	2.00	3.00	2.125	0.448	1.00	3.00
Median width (inches)	49.600	54.027	0.00	142.00	11.500	28.589	0.00	121.00
Shoulder width (inches)								
Interior width	5.740	4.008	0.00	11.90	7.113	4.225	0.00	14.20
Outside width	9.095	4.694	0.00	15.50	8.617	4.734	0.00	15.70

Table 4.5.5 Descriptive statistics of the continuous variables for the Performance-Based contracting with 3-course HMA overlay with or without surface miling and 3-course HMA with crack and seat of PCC PVM

	3-course HMA overlay with or without surface miling				3-course HMA with crack and seat of PCC PVM			
Variable Description	Mean	Std. Deviation	Min	Max	Mean	Std. Deviation	Min	Max
Average AADT (in 1,000 vehicles)	9.927	20.871	0.78	112.47	16.550	24.990	1.19	90.31
Commercial truck percentage	0.094	0.069	0.02	0.29	0.146	0.091	0.06	0.32
Contract final cost (in millions of dollars)	1.500	1.428	0.19	0.53	2.887	3.581	0.34	12.89
Temperature between October and March year t (°F)								
Average of the high temperature	50.326	2.766	46.72	58.89	48.907	2.290	45.94	52.09
Average of the lowest temperature	30.989	1.293	28.96	34.92	31.333	1.744	27.84	34.15
Average temperature	42.726	4.919	36.91	60.40	41.849	2.118	39.79	47.13
Temperature between October and March year t-1 (°F)								
Average of the High temperature	48.791	2.971	44.93	57.48	47.044	2.274	43.99	50.71
Average of the lowest temperature	32.542	1.028	31.05	36.03	32.013	1.821	27.67	35.05
Average temperature	40.591	5.688	34.16	61.01	39.719	2.342	37.43	45.71
Rain coefficient between October and March year t (inches)								
Average amount of rain	3.402	0.492	2.39	4.12	3.022	0.360	2.58	3.92
Average of the min amount of rain	1.465	0.382	0.86	3.04	1.378	0.860	0.21	3.28
Average of the max amount of rain	9.855	1.122	7.17	12.29	8.915	2.196	3.49	12.03

Variable Description	3-course HMA overlay with or without surface miling				3-course HMA with crack and seat of PCC PVM			
	Mean	Std. Deviation	Min	Max	Mean	Std. Deviation	Min	Max
Rain coefficient between October and March year t-1 (inches)								
Average amount of rain	4.037	0.580	3.08	5.08	3.321	0.527	2.18	4.19
Average of the min amount of rain	1.676	0.375	1.06	2.76	1.527	0.647	0.45	2.93
Average of the max amount of rain	9.029	0.813	7.11	10.24	8.312	2.040	2.95	10.90
IRI (inches/miles)								
IRI year t	116.781	46.405	55.00	261.00	130.083	56.150	53.00	247.00
IRI year t-1	108.375	43.337	55.00	253.00	116.250	50.326	48.00	244.00
Base IRI	97.563	42.288	46.00	242.00	105.833	49.901	45.00	241.00
PCR (0 to 100 rating)								
PCR year t	82.938	8.136	65.00	97.00	79.667	8.195	68.00	94.00
PCR year t-1	89.281	8.176	70.00	100.00	87.417	7.513	78.00	100.00
Base PCR	95.125	6.661	79.00	100.00	93.330	6.597	81.00	100.00
RUT (inches)								
RUT year t	0.163	0.129	0.04	0.58	0.161	0.095	0.03	0.34
RUT year t-1	0.143	0.129	0.02	0.56	0.139	0.086	0.03	0.30
Base RUT	0.129	0.125	0.01	0.56	0.129	0.084	0.03	0.29
Number of miles in contract	35.844	56.681	2.00	275.00	16.083	10.095	2.00	34.00
Number of years	3.406	1.132	2.00	5.00	2.917	0.996	2.00	5.00
Cost of savings (%)	0.066	0.093	-0.18	0.22	0.140	0.070	0.00	0.23
Number of bids	1.875	1.070	1.00	4.00	2.167	1.193	1.00	5.00
Cost of overrun (%)	-0.038	0.164	-0.36	0.40	-0.001	0.197	-0.40	0.36

Variable Description	3-course HMA overlay with or without surface miling				3-course HMA with crack and seat of PCC PVM			
	Mean	Std. Deviation	Min	Max	Mean	Std. Deviation	Min	Max
Time delay	-0.183	0.265	-0.55	0.56	0.079	0.240	-0.24	0.55
Change of orders	3.406	2.525	0.00	9.00	3.167	3.157	0.00	8.00
Number of lanes	2.281	0.457	2.00	3.00	2.333	0.651	2.00	4.00
Median width (inches)	22.219	41.603	0.00	133.00	13.167	29.251	0.00	99.00
Shoulder width (inches)								
Interior width	5.709	4.363	0.00	13.30	6.600	5.085	0.00	14.20
Outside width	9.350	4.043	0.00	16.30	10.883	3.580	2.90	15.90

Table 4.5.6 Descriptive statistics of the continuous variables for the Performance-Based contracting with 3R & 4R overlay treatments and 3R/4R PVM replacement treatments

	3R & 4R overlay treatments				3R/4R PVM replacement treatments			
Variable Description	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
Average AADT (in 1,000 vehicles)	12.789	12.523	0.85	42.40	16.608	514.842	0.76	40.66
Commercial truck percentage	0.222	0.137	0.02	0.46	0.236	0.151	0.02	0.51
Contract final cost (in millions of dollars)	2.766	4.074	0.17	20.39	4.053	3.841	0.40	14.59
Temperature between October and March year t (°F)								
Average of the high temperature	50.082	3.125	44.87	58.89	49.123	2.589	41.23	53.25
Average of the lowest temperature	31.517	2.421	27.80	36.89	30.587	1.405	27.80	34.12
Average temperature	43.052	4.935	37.88	60.44	32.044	1.547	27.67	36.22
Temperature between October and March year t-1 (°F)								
Average of the High temperature	48.448	3.346	42.57	57.53	47.515	2.930	38.34	52.02
Average of the lowest temperature	33.217	3.004	29.62	42.91	32.044	1.547	27.67	36.22
Average temperature	41.142	5.732	33.81	60.70	41.837	2.867	36.64	52.86
Rain coefficient between October and March year t (inches)								
Average amount of rain	3.318	0.509	2.62	4.22	39.756	3.344	33.81	52.32
Average of the min amount of rain	1.736	0.969	0.21	3.63	3.850	0.585	3.05	4.98
Average of the max amount of rain	9.737	1.804	3.49	13.05	1.603	0.610	0.45	3.05
Rain coefficient between October and March year t-1 (inches)								
Average amount of rain	3.885	0.754	2.38	5.28	3.211	0.445	2.44	3.95
Average of the min amount of rain	1.846	0.673	0.78	3.18	1.600	0.763	0.42	3.44
Average of the max amount of rain	8.718	1.418	2.95	10.24	9.432	1.084	7.23	11.12
IRI (inches/miles)								

Variable Description	3R & 4R overlay treatments				3R/4R PVM replacement treatments			
	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
IRI year t	131.520	48.052	65.00	258.00	8.804	1.021	6.67	10.24
IRI year t-1	120.040	42.980	55.00	227.00	99.161	41.759	43.00	221.00
Base IRI	104.040	46.504	50.00	215.00	76.581	37.000	28.00	152.00
PCR (0 to 100 rating)								
PCR year t	78.880	8.338	65.00	98.00	90.097	36.169	42.00	161.00
PCR year t-1	86.440	7.616	73.00	99.00	83.516	9.391	59.00	99.00
Base PCR	95.280	5.481	82.00	100.00	94.871	6.597	78.00	100.00
RUT (inches)								
RUT year t	0.181	0.105	0.05	0.46	0.148	0.097	0.02	0.35
RUT year t-1	0.163	0.100	0.05	0.40	0.122	0.071	0.01	0.28
Base RUT	0.132	0.090	0.03	0.39	0.102	0.066	0.01	0.24
Number of miles in contract	47.120	85.336	2.00	430.00	38.806	78.239	2.00	444.00
Number of years	3.640	1.319	2.00	6.00	3.452	1.261	2.00	7.00
Cost of savings (%)	0.121	0.096	-0.10	0.30	0.087	0.083	-0.08	0.25
Number of bids	2.080	1.115	1.00	5.00	1.774	1.023	1.00	4.00
Cost of overrun (%)	-0.006	0.168	-0.41	0.21	-0.033	0.158	-0.38	0.25
Time delay	-0.225	0.407	-0.75	0.51	0.012	0.324	-0.61	0.48
Change of orders	6.040	3.942	0.00	14.00	4.161	2.782	0.00	14.00
Number of lanes	2.200	0.408	2.00	3.00	2.387	1.283	2.00	9.00
Median width (inches)	27.880	40.679	0.00	139.00	31.226	41.031	0.00	113.00
Shoulder width (inches)								
Interior width	7.736	4.655	0.00	14.90	6.416	4.919	0.00	14.90
Outside width	8.736	4.067	2.00	16.60	8.271	5.583	0.00	16.30

Table 4.6.1 Descriptive statistics of the indicator variables for the Warranty with 2-course HMA and Concrete PVM restoration

	2-course HMA		Concrete PVM restoration	
Variable Description	Frequency	Percent	Frequency	Percent
System Type				
Interstate	2	15.38	3	25.00
Non-Interstate (NHS)	2	15.38	3	25.00
Non-Interstate (Non-NHS)	9	69.23	6	50.00
Function Class				
Rural	5	38.46	6	50.00
Urban	8	61.54	6	50.00
Drainage Efficiency				
Excessively drained	0	0.00	0	0.00
Somewhat excessively drained	1	7.69	1	8.33
Well drained	4	30.77	0	0.00
Moderately well drained	5	38.46	4	33.33
Somewhat poorly drained	0	0.00	6	50.00
Poorly drained	2	15.38	1	8.33
Very poorly drained	1	7.69	0	0.00
Work Description Type				
Functional	13	100.00	12	100.00
Structural	0	0.00	0	0.00
State				
Florida	0	0.00	0	0.00
Minnesota	13	100.00	11	91.67
Texas	0	0.00	0	0.00
Virginia	0	0.00	1	8.33
Indiana	0	0.00	0	0.00
Alaska	0	0.00	0	0.00
New York	0	0.00	0	0.00
Median				
No median	5	38.46	8	66.67
Median (no barrier)	0	0.00	1	8.33
Median (barrier)	8	61.54	3	25.00
Horizontal Curve				
Presence of horizontal curve	13	100.00	11	91.67
No horizontal curve present	0	0.00	1	8.33
Vertical Curve				
Presence of vertical curve	13	100.00	10	83.33
No vertical curve present	0	0.00	2	16.67

Table 4.6.2 Descriptive statistics of the indicator variables for the Warranty with 3-course HMA overlay with or without surface miling and 3-course HMA with crack and seat of PCC PVM

	3-course HMA overlay with or without surface miling		3-course HMA with crack and seat of PCC PVM	
Variable Description	Frequency	Percent	Frequency	Percent
System Type				
Interstate	13	17.11	1	5.56
Non-Interstate (NHS)	15	19.74	5	27.78
Non-Interstate (Non-NHS)	48	63.16	12	66.67
Function Class				
Rural	22	28.95	6	33.33
Urban	54	71.05	12	66.67
Drainage Effectiency				
Excessively drained	3	3.95	0	0
Somewhat excessively drained	2	2.63	0	0
Well drained	17	22.37	4	22.22
Moderately well drained	19	25	6	33.33
Somewhat poorly drained	19	25	4	22.22
Poorly drained	10	13.16	3	16.67
Very poorly drained	6	7.89	1	5.56
Work Description Type				
Functional	76	100	0	0
Structural	0	0	18	100
State				
Florida	0	0	0	0
Minnesota	0	0	0	0
Texas	0	0	0	0
Virginia	37	48.68	0	0
Indiana	39	51.32	11	61.11
Alaska	0	0	7	38.89
New York	0	0	0	0
Median				

Variable Description	3-course HMA overlay with or without surface miling		3-course HMA with crack and seat of PCC PVM	
	Frequency	Percent	Frequency	Percent
No median	62	81.58	10	55.56
Median (no barrier)	7	9.21	3	16.67
Median (barrier)	7	9.21	5	27.78
Horizontal Curve				
Presence of horizontal curve	64	84.21	17	94.44
No horizontal curve present	12	15.79	1	5.56
Vertical Curve				
Presence of vertical curve	52	68.42	16	88.89
No vertical curve present	24	31.58	2	11.11

Table 4.6.3 Descriptive statistics of the indicator variables for the Warranty with 3R & 4R overlay treatments and 3R/4R PVM replacement treatments

	3R & 4R overlay treatments		3R/4R PVM replacement treatments	
Variable Description	Frequency	Percent	Frequency	Percent
System Type				
Interstate	4	22.2`2	12	38.71
Non-Interstate (NHS)	7	38.89	9	29.03
Non-Interstate (Non-NHS)	7	38.89	10	32.26
Function Class				
Rural	5	27.78	11	35.48
Urban	13	72.22	20	64.52
Drainage Effectiency				
Excessively drained	0	0	0	0
Somewhat excessively drained	0	0	1	3.23
Well drained	3	16.67	7	22.58
Moderately well drained	6	33.33	7	22.58
Somewhat poorly drained	3	16.67	10	32.26
Poorly drained	5	27.78	5	16.13
Very poorly drained	1	5.56	1	3.23
Work Description Type				
Functional	0	0	0	0
Structural	18	100	31	100
State				
Florida	0	0	0	0
Minnesota	0	0	0	0
Texas	0	0	7	22.58
Virginia	0	0	0	0
Indiana	0	0	24	77.42
Alaska	0	0	0	0
New York	18	100	0	0
Median				
No median	10	55.56	18	58.06
Median (no barrier)	1	5.56	1	3.23
Median (barrier)	7	38.89	12	38.71
Horizontal Curve				
Presence of horizontal curve	17	94.44	31	100

Variable Description	3R & 4R overlay treatments		3R/4R PVM replacement treatments	
	Frequency	Percent	Frequency	Percent
No horizontal curve present	1	5.56	0	0
Vertical Curve				
Presence of vertical curve	17	94.44	31	100
No vertical curve present	1	5.56	0	0

Table 4.6.4 Descriptive statistics of the continuous variables for the Warranty with 2-course HMA and Concrete PVM restoration

Variable Description	2-course HMA Mean	Std. Dev.	Min	Max	Concrete PVM restoration Mean	Std. Dev.	Min	Max
Average AADT (in 1,000 vehicles)	9.334	9.374	1.32	36.44	16.865	33.233	0.09	116.01
Commercial truck percentage	0.162	0.127	0.03	0.44	0.179	0.189	0.06	0.67
Contract final cost (in millions of dollars)	1.503	0.897	0.25	3.04	1.268	1.317	0.10	4.73
Temperature between October and March year t (°F)								
Average of the high temperature	50.709	3.195	56.92	46.60	51.842	3.658	46.61	58.89
Average of the lowest temperature	30.911	1.078	29.15	32.25	31.850	1.580	29.56	34.15
Average temperature	43.079	3.772	38.42	50.65	43.145	7.398	29.80	60.40
Temperature between October and March year t-1 (°F)								
Average of the High temperature	49.334	3.485	44.51	55.75	50.708	3.687	44.93	57.53
Average of the lowest temperature	33.927	4.138	30.25	42.91	33.847	3.429	29.80	42.91
Average temperature	41.218	4.349	35.96	49.90	41.330	8.376	26.17	60.89
Rain coefficient between October and March year t (inches)								
Average amount of rain	3.281	0.455	2.63	3.99	3.318	0.628	2.04	4.31
Average of the min amount of rain	2.037	0.974	1.06	3.63	1.761	1.137	0.55	3.81
Average of the max amount of rain	9.303	0.606	8.34	10.31	9.368	1.341	7.23	11.12
Rain coefficient between October and March year t-1 (inches)								
Average amount of rain	3.855	0.688	2.95	5.01	4.072	0.821	2.22	4.87
Average of the min amount of rain	1.999	0.754	1.06	3.19	1.858	0.820	0.69	3.32
Average of the max amount of rain	8.644	0.540	7.73	9.55	8.377	1.848	3.54	10.14
IRI (inches/miles)								

Variable Description	2-course HMA Mean	2-course HMA Std. Dev.	2-course HMA Min	2-course HMA Max	Concrete PVM restoration Mean	Concrete PVM restoration Std. Dev.	Concrete PVM restoration Min	Concrete PVM restoration Max
IRI year t	122.615	32.694	74.00	200.00	145.750	104.153	54.00	429.00
IRI year t-1	102.769	41.885	41.00	182.00	135.833	102.797	48.00	419.00
Base IRI	93.538	44.476	41.00	181.00	125.833	101.680	32.00	404.00
PCR (0 to 100 rating)								
PCR year t	83.308	6.033	73.00	92.00	97.833	8.055	75.00	98.00
PCR year t-1	90.385	4.482	84.00	98.00	92.833	5.114	84.00	100.00
Base PCR	95.154	5.800	84.00	100.00	95.833	4.282	86.00	100.00
RUT (inches)								
RUT year t	0.226	0.130	0.07	0.52	0.125	0.070	0.04	0.26
RUT year t-1	0.183	0.104	0.04	0.38	0.113	0.067	0.04	0.26
Base RUT	0.158	0.094	0.04	0.35	0.100	0.067	0.40	0.25
Number of miles in contract	160.539	262.342	2.00	665.00	12.167	10.903	2.00	34.00
Number of years	3.308	1.316	2.00	6.00	3.333	1.073	2.00	5.00
Cost of savings (%)	-0.059	0.098	-0.16	0.15	-0.063	0.079	-0.12	0.06
Number of bids	3.462	1.050	2.00	6.00	2.917	0.289	2.00	3.00
Cost of overrun (%)	0.314	0.240	0.00	0.82	0.197	0.212	0.01	0.71
Time delay	0.404	0.166	0.06	0.58	0.490	5.875	0.23	0.67
Change of orders	3.923	1.382	2.00	6.00	4.500	2.236	1.00	8.00
Number of lanes	2.385	0.650	2.00	4.00	2.333	0.651	1.00	3.00
Median width (inches)	39.154	41.687	0.00	130.00	36.750	55.234	0.00	130.00
Shoulder width (inches)								
Interior width	7.154	4.887	0.00	13.70	7.008	4.708	0.00	12.50
Outside width	7.846	3.456	3.30	14.90	9.358	3.514	2.50	16.30

Table 4.6.5 Descriptive statistics of the continuous variables for the Warranty with 3-course HMA overlay with or without surface miling and 3-course HMA with crack and seat of PCC PVM

	3-course HMA overlay with or without surface miling				3-course HMA with crack and seat of PCC PVM			
Variable Description	Mean	Std. Deviation	Min	Max	Mean	Std. Deviation	Min	Max
Average AADT (in 1,000 vehicles)	16.234	32.108	0.54	140.41	8.233	11.143	0.64	47.49
Commercial truck percentage	0.122	0.089	0.02	0.50	0.109	0.069	0.03	0.30
Contract final cost (in millions of dollars)	2.070	4.714	0.11	38.93	2.015	2.623	0.12	11.40
Temperature between October and March year t (°F)								
Average of the high temperature	48.913	2.481	41.23	56.92	49.666	3.351	45.77	58.89
Average of the lowest temperature	30.978	1.635	26.82	36.89	31.439	2.718	25.43	36.89
Average temperature	42.006	3.084	37.15	52.86	43.400	5.060	38.97	60.40
Temperature between October and March year t-1 (°F)								
Average of the High temperature	47.217	2.798	38.30	55.65	48.118	3.617	42.40	57.30
Average of the lowest temperature	32.411	2.048	27.67	42.91	32.376	2.161	27.67	37.21
Average temperature	39.968	3.550	33.81	52.27	41.578	5.939	34.43	61.01
Rain coefficient between October and March year t (inches)								
Average amount of rain	3.127	0.557	2.01	4.43	2.949	0.692	1.39	4.23
Average of the min amount of rain	1.438	0.535	0.21	3.33	1.481	0.798	0.42	3.27
Average of the max amount of rain	9.425	1.376	3.49	13.05	9.447	1.639	6.77	13.05

Variable Description	3-course HMA overlay with or without surface miling Mean	Std. Deviation	Min	Max	3-course HMA with crack and seat of PCC PVM Mean	Std. Deviation	Min	Max
Rain coefficient between October and March year t-1 (inches)								
Average amount of rain	3.672	0.687	2.19	4.92	3.542	0.772	2.27	4.93
Average of the min amount of rain	1.598	0.405	0.45	2.91	1.592	0.640	0.45	2.92
Average of the max amount of rain	8.609	1.580	2.95	10.60	8.672	1.332	5.71	10.90
IRI (inches/miles)								
IRI year t	113.487	36.467	53.00	245.00	127.111	47.653	48.00	258.00
IRI year t-1	102.974	34.920	53.00	238.00	114.222	43.228	46.00	226.00
Base IRI	91.961	36.218	46.00	229.00	101.056	42.283	40.00	208.00
PCR (0 to 100 rating)								
PCR year t	82.368	9.945	56.00	98.00	79.611	9.865	61.00	94.00
PCR year t-1	89.092	8.324	66.00	100.00	85.056	10.003	63.00	100.00
Base PCR	95.092	5.704	76.00	100.00	90.778	9.315	68.00	100.00
RUT (inches)								
RUT year t	0.154	0.088	0.03	0.49	0.214	0.138	0.06	0.60
RUT year t-1	0.126	0.078	0.02	0.48	0.172	0.107	0.02	0.42
Base RUT	0.108	0.070	0.01	0.47	0.150	0.102	0.02	0.41
Number of miles in contract	67.039	116.583	2.00	555.00	21.667	17.977	2.00	81.00
Number of years	3.421	0.913	2.00	5.00	3.389	1.335	2.00	7.00
Cost of savings (%)	-0.006	0.123	-0.67	0.29	-0.051	0.129	-0.24	0.18
Number of bids	2.461	1.437	1.00	7.00	3.111	0.758	2.00	4.00
Cost of overrun (%)	0.290	0.231	0.00	0.95	0.388	0.310	0.03	1.10

Variable Description	3-course HMA overlay with or without surface miling				3-course HMA with crack and seat of PCC PVM			
	Mean	Std. Deviation	Min	Max	Mean	Std. Deviation	Min	Max
Time delay	0.443	0.184	-0.67	0.75	0.489	0.127	0.19	0.62
Change of orders	5.250	2.603	0.00	12.00	5.556	2.595	1.00	11.00
Number of lanes	1.974	0.516	1.00	3.00	2.111	0.323	2.00	3.00
Median width (inches)	14.092	32.798	0.00	127.00	32.000	44.609	0.00	139.00
Shoulder width (inches)								
Interior width	6.600	4.334	0.00	14.90	4.961	4.360	0.00	13.30
Outside width	10.057	4.139	0.00	16.60	7.111	4.767	0.00	15.10

Table 4.6.6 Descriptive statistics of the continuous variables for the Warranty with 3R & 4R overlay treatments and 3R/4R PVM replacement treatments

	3R & 4R overlay treatments				3R/4R PVM replacement treatments			
Variable Description	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
Average AADT (in 1,000 vehicles)	11.365	9.452	1.25	33.70	16.642	18.474	0.57	94.80
Commercial truck percentage	0.166	0.126	0.02	0.41	0.217	0.128	0.01	0.48
Contract final cost (in millions of dollars)	2.747	3.692	0.27	12.82	5.197	6.431	0.06	5.43
Temperature between October and March year t (°F)								
Average of the high temperature	49.497	2.619	46.57	56.92	48.721	1.890	45.78	53.79
Average of the lowest temperature	31.781	1.395	29.48	34.17	30.977	1.752	28.15	36.89
Average temperature	41.150	3.126	39.02	50.65	41.178	2.102	38.97	46.66
Temperature between October and March year t-1 (°F)								
Average of the High temperature	47.511	2.615	44.51	55.48	47.012	2.226	43.79	52.29
Average of the lowest temperature	33.692	2.864	30.25	42.91	32.197	1.753	29.80	37.21
Average temperature	39.912	3.456	36.36	49.71	39.008	2.419	36.07	45.22
Rain coefficient between October and March year t (inches)								
Average amount of rain	3.169	0.509	2.18	3.99	3.115	0.534	1.98	4.05
Average of the min amount of rain	1.754	0.887	0.70	3.81	1.304	0.426	0.21	2.95
Average of the max amount of rain	9.458	1.307	7.47	12.29	9.365	1.491	3.49	13.05
Rain coefficient between October and March year t-1 (inches)								
Average amount of rain	3.669	0.653	2.75	4.72	3.582	0.677	2.16	4.96
Average of the min amount of rain	1.824	0.651	1.06	3.32	1.519	0.314	1.13	2.70
Average of the max amount of rain	8.673	0.840	7.43	10.11	8.472	1.541	2.95	10.14

Variable Description	3R & 4R overlay treatments Mean	Std. Dev.	Min	Max	3R/4R PVM replacement treatments Mean	Std. Dev.	Min	Max
IRI (inches/miles)								
IRI year t	114.722	52.117	57.00	297.00	111.323	48.719	58.00	283.00
IRI year t-1	106.389	52.292	54.00	294.00	99.548	46.996	54.00	279.00
Base IRI	93.778	48.587	45.00	260.00	85.032	46.747	44.00	265.00
PCR (0 to 100 rating)								
PCR year t	78.889	8.152	68.00	99.00	81.581	6.617	65.00	95.00
PCR year t-1	87.056	6.629	75.00	100.00	88.355	8.023	68.00	99.00
Base PCR	94.333	5.087	84.00	100.00	95.032	6.172	79.00	100.00
RUT (inches)								
RUT year t	0.161	0.083	0.03	0.31	0.165	0.096	0.05	0.44
RUT year t-1	0.133	0.079	0.02	0.31	0.142	0.092	0.04	0.38
Base RUT	0.116	0.008	0.02	0.30	0.113	0.079	0.02	0.31
Number of miles in contract	77.056	117.123	2.00	335.00	70.968	142.182	2.00	595.00
Number of years	3.611	1.092	2.00	6.00	3.742	0.999	2.00	5.00
Cost of savings (%)	-0.028	0.088	-0.12	0.07	-0.052	0.120	-0.13	0.30
Number of bids	3.056	0.236	3.00	4.00	3.161	0.688	1.00	5.00
Cost of overrun (%)	0.321	0.213	0.02	0.71	0.353	0.249	0.01	0.91
Time delay	0.505	0.111	0.27	0.67	0.521	0.131	0.15	0.69
Change of orders	5.889	2.373	2.00	13.00	6.613	2.825	3.00	13.00
Number of lanes	2.167	0.383	2.00	3.00	2.161	0.454	2.00	4.00
Median width (inches)	29.000	45.549	0.00	127.00	24.258	39.524	0.00	142.00
Shoulder width (inches)								
Interior width	6.728	5.190	0.00	14.90	6.513	5.379	0.00	14.00
Outside width	11.761	3.718	4.70	16.60	10.406	3.821	2.90	15.90

CHAPTER 5 RESULTS

5.1 Introduction

This chapter presents and discusses the model estimation results of the 45 models estimated for the six PPP types (Performance-based contracting, cost-plus-time contracting, incentives/disincentives, design-build-operate-maintain, warranties, lane-rental) and the six pavement rehabilitation types [for the functional type: 2-course hot-mix asphalt (HMA) overlay with or without surface milling and concrete pavement restoration; for the structural type: 3-course HMA overlay with or without surface milling; 3-course HMA overlay with crack and seat of PCC Pavement; 3-R (resurfacing, restoration and rehabilitation) and 4-R (resurfacing, restoration, rehabilitation and reconstruction) overlay treatments; and 3-R/4-R pavement replacement treatments]. The endogenous time-lagged pavement condition variables, *t–n*, were regressed on all exogenous variables, and their regression-predicted values were used as instruments to estimate the models. Also, from the results of the aforementioned analysis, Hazard based models were estimated in order to explore the factors that affect the pavement service life, using the same set of independent variables as earlier, and literature-based pavement performance thresholds. The remainder of this Chapter presents the estimation results for the 3SLS models of the pavement performance indicators and the hazard-based duration models of the pavement service life, by each PPP type. The discussion starts with the cost-plus-time contracting and continues with the design-build-operate-maintain contracting, incentives/disincentives, lane rentals, Performance-based contracting and warranties.

5.2 Estimation Results of Cost-plus-time contracting Models

Tables 5.2.1 and 5.2.3 present the descriptive statistics of the variables used for model estimation. Tables 5.2.1 and 5.2.2 represent the A+B with functional treatments, and Tables 5.2.3 and 5.2.4 present the model estimation results of the A+B contracts with structural treatments. In addition, Table 5.2.5 presents the Mean Absolute Prediction Error (MAPE) of both models, and Figures 5.2.1 to 5.2.6 illustrate the observed and predicted values. The hazard-based duration models' estimation results are presented and discussed in Chapter 5.2.3.

Table 5.2.1 Descriptive statistics of the cost-plus-time contracting with Functional treatments (2-course HMA and Concrete PVM restoration)

Variable Description	Mean	Std. Deviation	Min	Max
Dependent variable IRI of year t				
International roughness index (in/mi) in year t-1	104.667	33.356	42.00	199.00
Lanes (1 if greater than 3, 0 otherwise)	0.273	0.452	0.00	1.00
Dependent variable PCR of year t				
Rutting depth (in) in year t (1 if greater than 0.12, 0 otherwise)	0.727	0.452	0.00	1.00
Road class(1 if it is Rural, 0 otherwise)	0.485	0.508	0.00	1.00
State (1 if Florida, 0 otherwise)	0.152	0.364	0.00	1.00
Truck volume (1 if less than 1000 trucks per day, 0 otherwise)	0.636	0.489	0.00	1.00
Dependent variable RUT of year t				
Rutting depth (in) in year t-1	0.153	0.083	0.20	0.44
Drainage(1 if somewhat, poorly, or very poorly drained, 0 otherwise)	0.545	0.506	0.00	1.00
Road system (1 if Non-Interstate and not a National Highway System, 0 otherwise)	0.636	0.489	0.00	1.00

Table 5.2.2 3SLS model estimation of pavement indicators for cost-plus-time contracting with Functional treatments (2-course HMA and Concrete PVM restoration)

Variable Description	Coefficient	t-stat	p value
Dependent variable IRI of year t			
Constant	16.974	2.29	0.029
International roughness index (in/mi) in year t-1	0.904	14.21	0.000
Lanes (1 if greater than 3, 0 otherwise)	12.910	2.84	0.008
Dependent variable PCR of year t			
Constant	83.743	29.14	0.000
Rutting depth (in) in year t (1 if greater than 0.12, 0 otherwise)	-10.416	-3.53	0.001
Road class(1 if Rural, 0 otherwise)	7.668	3.15	0.004
State (1 if Florida, 0 otherwise)	-7.959	-2.30	0.029
Truck volume (1 if less than 1000 trucks per day, 0 otherwise)	7.532	2.73	0.011
Dependent variable RUT of year t			
Rutting depth (in) in year t-1	1.158	28.77	0.000
Drainage(1 if somewhat, poorly, or very poorly drained, 0 otherwise)	0.023	2.99	0.006
Road system (1 if Non-Interstate and not a National Highway System, 0 otherwise)	-0.019	-2.36	0.025
System Weighted MSE	1.4461		
Degrees of freedom	88		
Number of Observation	33		
System Weighted R-square	0.9459		

Table 5.2.3 Descriptive statistics of the cost-plus-time contracting with Structural treatments (3-course HMA overlay with or without surface milling, 3-course HMA with crack and seat of PCC PVM, 3R&4R overlay treatments, 3R/4R PVM replacement treatments)

Variable Description	Mean	Std. Dev.	Min	Max
Dependent variable IRI of year t				
International roughness index (in/mi) in year t-1	110.449	48.952	46.00	299.00
Contract final cost (per miles and per years)	99,698.8	207,038.7	730.94	831,143.2
Drainage(1 if moderately or well drain, 0 otherwise)	0.592	0.497	0.00	1.00
Dependent variable PCR of year t				
Rutting depth (in) in year t (1 if less than 0.1, 0 otherwise)	0.224	0.422	0.00	1.00
Truck volume (trucks per day)	4599.305	6802.000	54.56	23254.17
Low average temperature from October to March in year t (°F)	31.148	2.070	25.43	37.82
Change orders	2.551	2.363	0.00	9.00
Dependent variable RUT of year t				
Rutting depth (in) in year t-1	0.135	0.080	0.02	0.42
Minimum average precipitation from October to March in year t (in)	1.594	0.702	0.21	3.51
Rutting depth (in) in base/rehabilitation year	0.116	0.078	0.01	0.39
High average temperature from October to March in year t (°F)	49.450	2.476	44.87	56.92
State(1 if Texas, 0 otherwise)	0.122	0.331	0.00	1.00

Table 5.2.4 3SLS model estimation of pavement indicators for cost-plus-time contracting with Structural treatments (3-course HMA overlay with or without surface milling, 3-course HMA with crack and seat of PCC PVM, 3R&4R overlay treatments, 3R/4R PVM replacement treatments)

Variable Description	Coefficient	t-stat	p value
Dependent variable IRI of year t			
Constant	15.141	2.00	0.052
International roughness index (in/mi) in year t-1	1.116	17.50	0.000
Contract final cost (per miles and per years)	0.000	-4.09	0.000
Drainage(1 if moderately or well drain, 0 otherwise)	-21.172	-4.61	0.000
Dependent variable PCR of year t			
Constant	47.381	3.52	0.001
Rutting depth (in) in year t (1 if less than 0.1, 0 otherwise)	7.175	3.36	0.002
Truck volume (trucks per day)	-0.001	-4.37	0.000
Low average temperature from October to March in year t (°F)	1.206	2.79	0.008
Change orders	-1.183	-3.13	0.003
Dependent variable RUT of year t			
Rutting depth (in) in year t-1	0.240	1.94	0.059
Minimum average precipitation from October to March in year t (in)	0.027	4.18	0.000
Rutting depth (in) in base/rehabilitation year	1.074	9.23	0.000
High average temperature from October to March in year t (°F)	-0.001	-1.93	0.060
State(1 if Texas, 0 otherwise)	-0.028	-2.10	0.042
System Weighted MSE	2.0044		
Degrees of freedom	133		
Number of Observation	49		
System Weighted R-square	0.8871		

5.2.1 Estimation Results of 3SLS A+B Models: Functional and Structural Characteristics

For A+B projects, Tables 5.2.2.and 5.2.4 show that several traffic, pavement and weather characteristics are found to be influential determinants of the pavement performance.

Traffic characteristics: The model estimation results show that various traffic characteristics constitute significant influential factors of the pavement condition in cost-plus-time projects. Specifically, Tables 5.2.2. and 5.2.4 show that the low truck volume (less than 1,000 trucks per day) is associated with higher PCR in pavements with functional treatments, whereas for the structural treatments, higher truck volume is found to increase the PCR. These findings are in line with past research (Anastasopoulos and Mannering, 2014; Sarwar, 2016) and possibly reflect the effect of the increased trucks' loads on the pavement condition.

Pavement characteristic**:** Turning to the pavement characteristics, Table 5.2.2. shows that for the functional treatments, the poor drainage indicator (reflecting somewhat poorly or very poorly drained pavements) is associated with higher IRI values, indicating that the depression or groove worn into the pavement will increase over time. On the contrary, moderate or good drainage conditions in pavements with structural treatments are found to decrease the IRI. Table 5.2.2. also demonstrates that roadways with 3 or more lanes are associated with higher IRI; this finding may be capturing the impact of high truck volume in cases of large roadways, with wide right-of-ways.

With regard to the time lagged pavement condition variables, the IRI and the rutting depth of the previous year (*t-1*) are found to significantly affect the same pavement condition indicators in the analysis year, *t*. For the structural treatments, poor pavement performance (as indicated by higher values of the IRI and rutting depth) in year *t-1* results in pavement deterioration in the analysis year *t*.

For both functional and structural treatments, the endogenous variable representing the rutting depth in year *t*, is found to be a statistically significant determinant of the PCR, in the same year. Particularly, Table 5.2.2 shows that high rutting depth decreases the PCR, while Table 5.2.4 shows that low rutting depth results in better pavement conditions, as implied by the high values of the PCR. These results support the findings of Sarwar (2016) that the IRI and rutting depth have a strong impact in the determination of the PCR.

<u>Weather characteristics:</u> Table 5.2.4 shows that higher temperature during adverse weather months (October through March), results in a decrease of the rutting depth. This finding can be explained by the fact that higher temperature during this period may decrease the impact of possible snow accumulation on pavements, especially in areas with significamt snowfall during the winter period. In a similar fashion, if the low average temperature during the same period (October through March) increases, it will result in higher PCR value. Table 5.2.4 also shows that higher values of the minimum average precipitation during the same period (October through March) results in higher rutting depth.

Other Factors: A+B contracts with functional treatments in Florida, are shown to reduce the PCR, as indicated in Table 5.2.2. On the other hand, from the Table 5.2.4, if the pavement-related project is located in Texas, the rutting depth decreases. This can be attributed to location-specific characteristics (e.g., the temperature is generally higher in Texas throughout the year). Also, in rural roads, the PCR is found to increase. This can be explained by the fact that the truck load in those roads is likely lower, as compared to interstate highways. Similarly, Table 5.2.2 shows that if the road is not an interstate or not a national highway system, the rutting depth decreases. As mentioned earlier, if the rutting depth reduces, the PCR intuitively increases, indicating, better pavement conditions. From a financial point of view, as shown in the Table 5.2.4, the higher the final contract cost, the higher the IRI value will be. Many variables can increase a contract final cost: the length of the pavement, the amount of required work, the work conditions, complexity, etc. The more time and work there is to be done on a project, the more mistakes or change orders can possibly occur.

5.2.2 Model evaluation for A+B: Functional and structural treatments

In terms of goodness-of-fit measures, the 3SLS model has an overall good statistical fit, as indicated by the system weighted R^2 (0.946 and 0.887 for functional and structural treatments, respectively, as shown in Tables 5.2.2 and 5.2.4). Note that all explanatory parameters of the 3SLS model are statistically significant at a 0.90 level of confidence. To further evaluate the forecasting accuracy of the 3SLS model, the mean absolute percentage error (MAPE) is computed. The MAPE is calculated as follows (Washington at al., 2011):

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}|PE_i| \qquad (3)$$

where, $PEi = 100*(Yi - \hat{Y}i) / Yi$ %, denotes the percentage error for project *i* between the observed pavement indicator *Yi*, and the model-predicted pavement indicator $\hat{Y}i$ (Washington et al., 2011).

The MAPE value shows – in terms of percentage – how much the model over- or under- estimates the observed values. Table 5.2.5 presents the MAPE values by pavement indicator and treatment type. For example, the MAPE value of IRI in pavements with functional treatments (0.071) indicates that the model-predicted IRI value over- or under-estimates the observed IRI value by 7.1 percent. To graphically illustrate the forecasting performance of the estimated 3SLS models, the predicted versus the observed values are plotted in Figures 5.2.1 through 5.2.6. It is worthwhile to note that data points closer to the diagonal line imply better forecasting accuracy of the estimated model.

Table 5.2.5 MAPE of the 3SLS models of the pavement indicators for cost-plus-time contracting with all rehabilitation treatments.

Dependent variables	**Treatment type**	**MAPE**
International Roughness Index (in/mi)	Functional	0.071
Pavement Condition Rating (scale 0 to 100)		0.068
Rutting depth (inches)		0.143
International Roughness Index (in/mi)	Structural	0.114
Pavement Condition Rating (scale 0 to 100)		0.056
Rutting depth (inches)		0.170

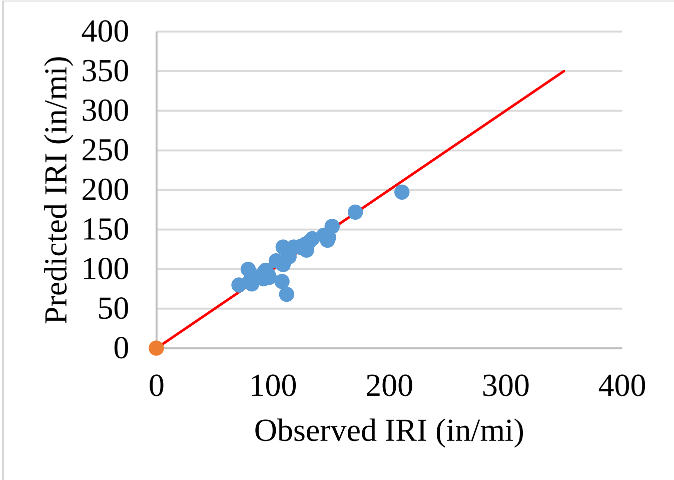

Figure 5.2.1 Predicted and observed values of IRI for cost-plus-time contracting with Functional treatment (2-course HMA and Concrete PVM restoration).

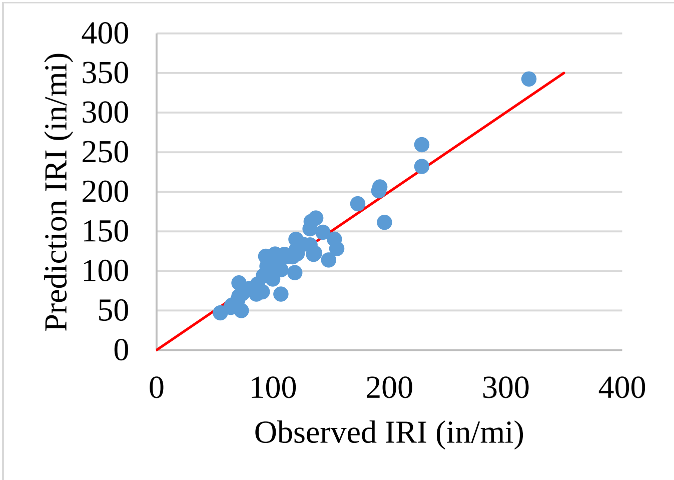

Figure 5.2.2 Predicted and observed values of IRI for cost-plus-time contracting with Structural treatments (3-course HMA overlay with or without surface milling, 3-course HMA with crack and seat of PCC PVM, 3R & 4R overlay treatments, 3R/4R PVM replacement treatments).

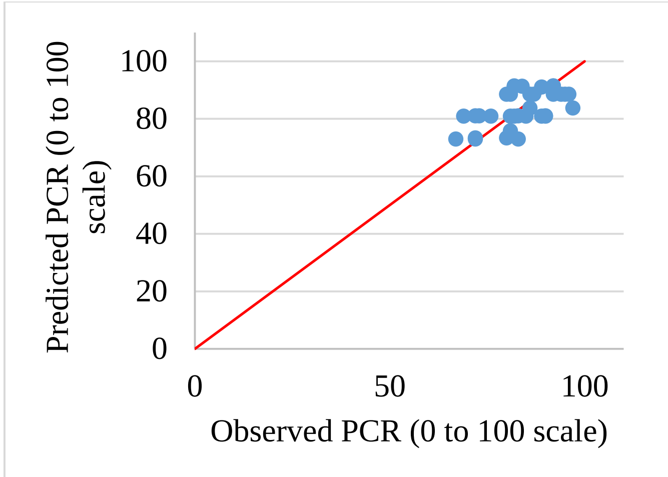

Figure 5.2.3 Predicted and observed values of PCR for cost-plus-time contracting with Functional treatment (2-course HMA and Concrete PVM restoration).

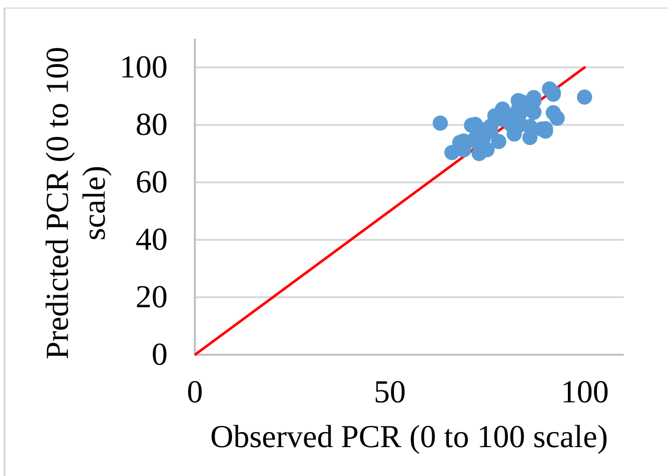

Figure 5.2.4 Predicted and observed values of PCR for cost-plus-time contracting with Structural treatments (3-course HMA overlay with or without surface milling, 3-course HMA with crack and seat of PCC PVM, 3R & 4R overlay treatments, 3R/4R PVM replacement treatments).

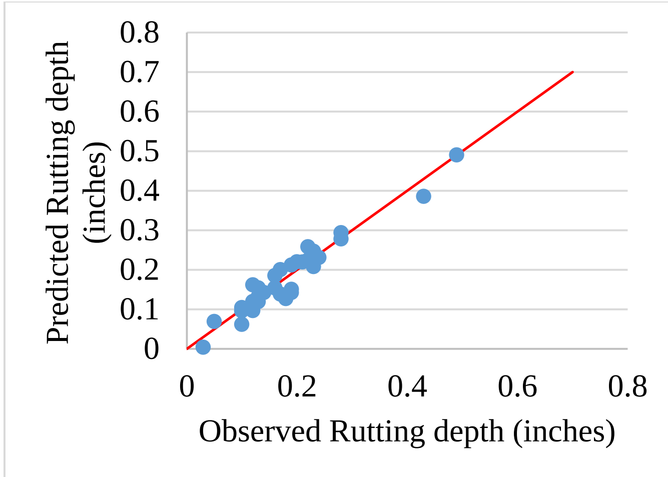

Figure 5.2.5 Predicted and observed values of rutting depth for cost-plus-time contracting with Functional treatment (2-course HMA and Concrete PVM restoration).

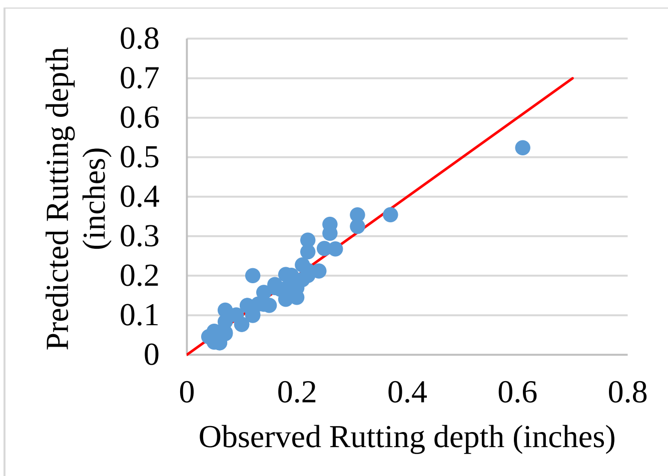

Figure 5.2.6 Predicted and observed values of rutting depth for cost-plus-time contracting with Structural treatments (3-course HMA overlay with or without surface milling, 3-course HMA with crack and seat of PCC PVM, 3R & 4R overlay treatments, 3R/4R PVM replacement treatments).

5.2.3 Hazard Based Duration Models of A+Bs' Pavement Service Life

Various duration models of different functional forms were estimated, such as the Weibull with fixed/random parameters, Log-Logistic and Weibull with Gamma Heterogeneity. The models were estimated using standard maximum likelihood methods, and the best model specifications (in terms of goodness-of-fit) are presented in the subsequent sections. Table 5.2.6 presents the model estimation results for the A+B with functional and structural treatments, followed by a discussion of the results.

Table 5.2.6 Estimation of the pavement service life using Hazard –Based Duration models with cost-plus-time contracting and all rehabilitation treatments (Functional and Structural treatments)

	Functional Treatments		Structural Treatments	
	Weibull with random parameters		Log Logistic	
Variable	Parameter	t-stat	Parameter	t-stat
Constant	2.723	10.53	4.448	15.09
Base (right after rehabilitation) IRI (in/mi)	—	—	-0.023	-6.80
Base (right after rehabilitation) RUT (in)	-6.773	-6.80	—	—
Drainage(1 if somewhat, poorly, or very poorly drained, 0 otherwise)	-0.424	-2.55	-1.226	-5.54
Road system (1 if Non-Interstate and not a National Highway System, 0 otherwise)	0.464	2.00	—	—
Truck Volume (in 10,000 of vehicles per day)	0.221	0.72	—	—
Standard deviation of parameter distribution (in 10,000 of vehicles)	0.238	1.86	—	—
Number of lanes (1 if greater than 3, 0 otherwise)	-0.430	-3.46	—	—
P	4.19	7.18	2.429	9.34
LL(0)	-45.3		-45.3	
LL(β)	-5.7		-25.4	
McFadden pseudo R^2	0.70		0.35	
Number of observations	29			

Since only the best model specification is presented, the functional treatment is represented by a Weibull model with random parameters and the structural treatment is represented with a Log-Logistic model. In terms of parameter interpretation, a negative sign of a parameter estimate shows a decrease of the pavement life and a positive sign denotes an increase in the pavement life. For the functional treatments, it is shown that for roadways with more than 3 lanes, the pavement life is more likely to be shorter. Also, if the base rutting depth is already high and the road is somewhat, poorly, or very poorly drained the same results can be observed. However, if the road system is a non-interstate and not a national highway system, the pavement service life is more likely to be longer. In terms of truck volume, its effect is varying acorss observations since it results in a random parameter; the mean and standard deviation of the parameter indicate that 17.7 percent of the observations are associated with higher pavement service life (and the remaining 82.3 percent with a lower pavement service life). The Weibull model parameter P is significantly different from zero and positive, which indicates a monotonically increasing function. This implies that as time passes, the remaining pavement service life will be shorter, which is intuitive. For the structural treatment, it is shown that if the base IRI is high and that the drainage is somewhat poor, poor, or very poor, the pavement service life will most likely be shorter. The parameter P is positive, which indicates that the hazard increases in duration from zero to an inflection point, and decreases toward zero afterwards; in words, the pavement life is more likely to be shorter before the inflection point but once it surpasses it, it is more likely to be longer.

5.3 Estimation Results of Design-Build-Operate-Maintain Models

Tables 5.3.1 through 5.3.12 present descriptive statistics and model estimation results, respectively, for: Design-Build with functional treatments, and Design-Build with structural treatments. Table 5.3.13 presents the corresponding MAPE values of these models.

Table 5.3.1 Descriptive statistics of the Design-Build with 2-course HMA

Variable Description	Mean	Std. Deviation	Min	Max
Dependent variable IRI of year t				
International roughness index (in/mi) in year t-1	113.182	49.438	39.00	254.00
High average temperature from October to March in year t (°F)	49.249	1.962	45.60	52.85
Dependent variable PCR of year t				
Rutting depth (in) in year t	0.245	0.310	0.05	1.83
Road class(1 if Urban, 0 otherwise)	0.636	0.489	0.00	1.00
Cost Overrun (percentage)	0.151	0.218	-0.16	0.73
State (1 if Florida,0 otherwise)	0.788	0.415	0.00	1.00
Dependent variable RUT of year t				
Rutting depth (in) in year t-1	0.164	0.100	0.02	0.50
Truck Volume (trucks per day)	4420.153	6787.273	0.00	18390.13
Change orders	6.091	1.877	2.00	10.00

Table 5.3.2 3SLS model estimation of pavement indicators for Design-Build with 2-course HMA

Variable Description	Coefficient	t-stat	p value
Dependent variable IRI of year t			
Constant	-136.240	-1.87	0.072
International roughness index (in/mi) in year t-1	1.130	19.82	0.000
High average temperature from October to March in year t (°F)	2.778	1.93	0.063
Dependent variable PCR of year t			
Constant	80.004	22.16	0.000
Rutting depth (in) in year t	-15.808	-3.89	0.001
Road class(1 if Urban, 0 otherwise)	-5.627	-2.54	0.017
Cost Overrun (percentage)	20.895	4.11	0.000
State (1 if Florida,0 otherwise)	5.969	2.24	0.034
Dependent variable RUT of year t			
Constant	-0.254	-2.17	0.038
Rutting depth (in) in year t-1	1.284	4.46	0.000
Truck Volume (trucks per day)	0.000	2.56	0.016
Change orders	0.040	2.46	0.020
System Weighted MSE	1.0002		
Degrees of freedom	87		
Number of Observation	33		
System Weighted R-square	0.861		

Table 5.3.3 Descriptive statistics of the Design-Build with concrete PVM restoration

Variable Description	Mean	Std. Deviation	Min	Max
Dependent variable IRI of year t				
International roughness index (in/mi) in year t-1	104.718	52.272	33.00	307.00
Lanes (1 if greater than 3; 0 otherwise)	0.231	0.427	0.00	1.00
Dependent variable PCR of year t				
Rutting depth (in) in year t (1 if less than 0.105, 0 otherwise)	0.231	0.427	0.00	1.00
High average temperature from October to March in year t (°F)	49.261	3.202	41.23	56.92
Average precipitation from October to March in year t (inches)	3.073	0.559	1.32	4.19
Truck volume (1 if less than 500 trucks per day, 0 otherwise)	0.615	0.493	0.00	1.00
Dependent variable RUT of year t				
Rutting depth (in) in year t-1	0.140	0.068	0.02	0.25
Cost saving (percentage)	0.007	0.024	-0.08	0.10

Table 5.3.4 3SLS model estimation of pavement indicators for Design-Build with concrete PVM restoration

Variable Description	Coefficient	t-stat	p value
Dependent variable IRI of year t			
International roughness index (in/mi) in year t-1	1.078	60.56	0.000
Lanes (1 if greater than 3; 0 otherwise)	10.197	2.44	0.019
Dependent variable PCR of year t			
Constant	48.050	3.08	0.004
Rutting depth (in) in year t (1 if less than 0.105, 0 otherwise)	6.623	3.00	0.005
High average temperature from October to March in year t (°F)	0.832	2.16	0.038
Average precipitation from October to March in year t (in)	-3.893	-1.74	0.091
Truck volume (1 if less than 500 trucks per day, 0 otherwise)	4.842	2.50	0.018
Dependent variable RUT of year t			
Constant	0.022	2.67	0.011
Rutting depth (in) in year t-1	1.012	18.42	0.000
Cost saving (percentage)	0.342	2.39	0.022
System Weighted MSE	2.2527		
Degrees of freedom	107		
Number of Observation	39		
System Weighted R-square	0.9541		

Table 5.3.5 Descriptive statistics of the Design-Build with 3-course HMA overlay with or without surface milling

Variable Description	Mean	Std. Deviation	Min	Max
Dependent variable IRI of year t				
International roughness index (in/mi) in year t-1	106.412	36.516	52.00	203.00
Median (1 if median with no barrier, 0 otherwise)	0.103	0.306	0.00	1.00
Dependent variable PCR of year t				
Road class(1 if Rural, 0 otherwise)	0.265	0.444	0.00	1.00
Number of bids	2.544	0.854	1.00	4.00
Dependent variable RUT of year t				
Rutting depth (in) in year t-1	0.121	0.062	0.02	0.27
Drainage(1 if excessively or somewhat excessively drained, 0 otherwise)	0.088	0.286	0.00	1.00
Truck volume (trucks per day)	1453.881	4905.000	0.00	39557.42
Average precipitation from October to March in year t (inches)	3.196	0.549	2.28	4.45

Table 5.3.6 3SLS model estimation of pavement indicators for Design-Build with 3-course HMA overlay with or without surface milling

Variable Description	Coefficient	t-stat	p value
Dependent variable IRI of year t			
International roughness index (in/mi) in year t-1	1.065	84.49	0.000
Median (1 if median with no barrier, 0 otherwise)	17.490	4.21	0.000
Dependent variable PCR of year t			
Constant	89.107	28.74	0.000
Road class(1 if Rural, 0 otherwise)	5.621	2.52	0.014
Number of bids	-2.553	-2.21	0.031
Dependent variable RUT of year t			
Rutting depth (in) in year t-1	1.014	21.32	0.000
Drainage(1 if excessively or somewhat excessively drained, 0 otherwise)	0.052	5.51	0.000
Truck volume (trucks per day)	0.001	2.41	0.019
Average precipitation from October to March in year t (inches)	0.012	2.49	0.015
System Weighted MSE	3.0027		
Degrees of freedom	195		
Number of Observation	68		
System Weighted R-square	0.9393		

Table 5.3.7 Descriptive statistics of the Design-Build with 3-course HMA with crack and seat of PCC PVM

Variable Description	Mean	Std. Dev.	Min	Max
Dependent variable IRI of year t				
International roughness index (in/mi) in year t-1	114.600	43.186	44.00	257.00
Contract final cost (per miles and per years) (in millions of dollar)	.140	.375	.00076	2.14
Dependent variable PCR of year t				
International roughness index (in/mi) in year t(1 if greater than 120, 0 otherwise)	0.511	0.506	0.00	1.00
Drainage(1 if somewhat, poorly, or very poorly drained, 0 otherwise)	0.511	0.506	0.00	1.00
Change of orders	4.244	2.268	0.00	10.00
Dependent variable RUT of year t				
Rutting depth (in) in year t-1	0.157	0.113	0.02	0.60
Truck volume (1 if greater than 7000 trucks per day, 0 otherwise)	0.289	0.458	0.00	1.00

Table 5.3.8 3SLS model estimation of pavement indicators for Design-Build with 3-course HMA with crack and seat of PCC PVM

Variable Description	Coefficient	t-stat	p value
Dependent variable IRI of year t			
Constant	9.103	2.02	0.050
International roughness index (in/mi) in year t-1	0.999	27.21	0.000
Contract final cost (per miles and per years)	0.001	2.81	0.008
Dependent variable PCR of year t			
Constant	85.874	33.45	0.000
International roughness index (in/mi) in year t (1 if greater than 120, 0 otherwise)	-6.692	-3.11	0.003
Drainage (1 if somewhat, poorly, or very poorly drained, 0 otherwise)	-5.892	-2.77	0.009
Change of orders	0.823	1.75	0.088
Dependent variable RUT of year t			
Rutting depth (in) in year t-1	1.077	49.2	0.000
Truck volume (1 if greater than 7000 trucks per day, 0 otherwise)	0.032	4.23	0.000
System Weighted MSE	3.053		
Degrees of freedom	126		
Number of Observation	45		
System Weighted R-square	0.9044		

Table 5.3.9 Descriptive statistics of the Design-Build with 3R & 4R overlay treatments

Variable Description	**Mean**	**Std. Deviation**	**Min**	**Max**
Dependent variable IRI of year t				
International roughness index (in/mi) in year t-1	94.923	33.688	58.00	167.00
Contract final cost (per miles and per years)(in millions of dollar)	.063	.118	.001	.360
Average temperature from October to March in year t (°F)	44.845	6.509	37.88	60.40
Dependent variable PCR of year t				
Rutting depth (in) in year t	0.182	0.125	0.05	0.53
Median (1 If no median, 0 otherwise)	0.462	0.519	0.00	1.00
Truck volume (trucks per day)(1 if less than 500, 0 otherwise)	0.385	0.506	0.00	1.00
Dependent variable RUT of year t				
Rutting depth (in) in year t-1	0.142	0.095	0.05	0.40

Table 5.3.10 3SLS model estimation of pavement indicators for Design-Build with 3R & 4R overlay treatments

Variable Description	Coefficient	t-stat	p value
Dependent variable IRI of year t			
Constant	71.280	6.07	0.000
International roughness index (in/mi) in year t-1	0.796	22.99	0.000
Contract final cost (per miles and per years)	0.001	4.83	0.001
Average temperature from October to March in year t (°F)	-1.027	-4.73	0.001
Dependent variable PCR of year t			
Constant	82.453	58.00	0.000
Rutting depth (in) in year t	-37.775	-7.62	0.000
Median (1 If no median, 0 otherwise)	8.769	7.55	0.000
Truck volume (1 if less than 500 trucks per day, 0 otherwise)	3.558	2.70	0.025
Dependent variable RUT of year t			
Rutting depth (in) in year t-1	1.273	29.05	0.000
System Weighted MSE	1.0081		
Degrees of freedom	30		
Number of Observation	13		
System Weighted R-square	0.9894		

Table 5.3.11 Descriptive statistics of the Design-Build with 3R/4R PVM replacement treatments

Variable Description	**Mean**	**Std. Deviation**	**Min**	**Max**
Dependent variable IRI of year t				
International roughness index (in/mi) in year t-1	89.286	41.901	50.00	209.00
Truck Volume (trucks per day)	6455.155	6616.000	302.56	19361.85
High average temperature from October to March in year t (°F)	48.707	2.359	45.20	53.06
Dependent variable PCR of year t				
Rutting depth (in) in year t (1 if greater than 0.12, 0 otherwise)	0.381	0.498	0.00	1.00
Road class(1 if Rural, 0 otherwise)	0.571	0.507	0.00	1.00
High average temperature from October to March in year t (°F)	48.707	2.359	45.20	53.06
Dependent variable RUT of year t				
Rutting depth (in) in year t-1	0.116	0.070	0.02	0.32
Average precipitation from October to March in year t (inches)	3.189	0.475	2.60	4.51
Cost saving (percentage)	0.061	0.082	0.00	0.18
Time delay	0.429	0.129	0.07	0.59

Table 5.3.12 3SLS model estimation of pavement indicators for Design-Build with 3R/4R PVM replacement treatments

Variable Description	Coefficient	t-stat	p value
Dependent variable IRI of year t			
Constant	50.114	2.36	0.030
International roughness index (in/mi) in year t-1	1.017	46.91	0.000
Truck Volume (trucks per day)	0.001	4.06	0.001
High average temperature from October to March in year t (°F)	-0.953	-2.22	0.040
Dependent variable PCR of year t			
Rutting depth (in) in year t (1 if greater than 0.12, 0 otherwise)	-9.645	-3.92	0.001
Road class(1 if Rural, 0 otherwise)	-8.382	-3.55	0.002
High average temperature from October to March in year t (°F)	1.856	38.81	0.000
Dependent variable RUT of year t			
Constant	-0.121	-3.31	0.004
Rutting depth (in) in year t-1	1.032	22.71	0.000
Average precipitation from October to March in year t (inches)	0.025	3.47	0.003
Cost saving (percentage)	0.171	3.08	0.007
Time delay	0.108	2.93	0.010
System Weighted MSE	1.0003		
Degrees of freedom	51		
Number of Observation	21		
System Weighted R-square	0.9916		

5.3.1 Estimation Results of 3SLS Design-Build Models: Functional and Structural treatments

This section discusses key findings of the Design-Build models with functional and structural treatments.

Traffic characteristics: Model estimation results demonstrate that the traffic characteristics constitute significant influential factors of the pavement condition. Specifically, lower truck volume is associated with higher PCR. Table 5.3.2 shows that high truck volume is associated with higher IRI and rutting depth values in pavements with functional treatments. These findings are in line with past research (Anastasopoulos and Mannering, 2014) and possibly reflect the effect of heavier truck loads on pavement condition.

Pavement characteristic: Turning to the pavement characteristics, Table 5.3.8. shows that for the functional treatments, the poor drainage indicator (somewhat poorly, poorly or very poorly drained) is associated with lower PCR values. On the contrary, moderate or good drainage conditions in pavements with structural treatments are found to decrease the PCR. Also, trucks with heavier loads will most likely use a highway or a large road to deliver their product. As shown in the Table 5.3.4, if the road has 3 or more lanes the IRI will increase. As the IRI increases, the smoothness of the pavement will decrease, with not desirable subsequent effect on the pavement condition. Table 5.3.4. also demonstrates that roadways with 3 or more lanes are associated with higher IRI; this finding may be capturing the impact of high truck volume in cases of large roadways, with wide right-of-ways.

With regard to the time lagged pavement condition variables, the IRI and the rutting depth of the previous year (*t-1*) are found to significantly affect the same pavement condition indicators in the analysis year, *t*. For the structural treatments, poor pavement performance (as indicated by higher values of the IRI and rutting depth) in year *t-1* results in pavement deterioration in the analysis year *t*.

For both functional and structural treatments, the endogenous variables representing the rutting depth in year *t*, are found to be statistically significant determinants of the PCR in the same year. Particularly, Table 5.3.2 shows that high rutting depth decreases the PCR, while low rutting depth results in better pavement conditions, as implied by the higher values of the PCR. These results support the findings of Sarwar (2016) that the IRI and rutting depth have a strong impact in the determination of the PCR.

<u>Weather characteristics:</u> Table 5.3.4 and 5.3.12 show that higher temperature during adverse weather periods (between October and March) results in a decrease of the IRI value. This finding can be explained by the fact that higher temperature during this period may decrease the impact of possible snow accumulation on pavements, especially in areas with significamt snowfall during the winter period. In a similar fashion, if the low average temperature increases, it results in higher PCR value. Also Tables 5.3.6 and 5.3.12 show that the higher the average precipitation is, the greater the rutting depth value will be.

Other Factors: Table 5.3.2 shows that segments in Florida have higher PCR values, whereas segments in urban areas have lower PCR values. The road class has mixed effects on the pavement performance. Specifically, Tables 5.3.6 and 5.3.12 show that rural roads are associated with higher PCR values for 3-course HMA overlay with or without surface milling treatment; for rural roads with 3R/4R PVM replacement treatments, the PCR value is found to decrease. Turning to the contracts' financial characteristics, Table 5.3.2 shows that higher cost overruns are associated with higher PCR values.

5.3.1 Model evaluation for Design-Build Models: Functional and Structural Treatments

In terms of goodness-of-fit measures, the 3SLS models have an overall good statistical fit, as indicated by the system weighted R^2 in Tables 5.3.2, 5.3.4, 5.3.8, 5.3.10 and 5.3.12, which are 0.861, 0.954, 0.939, 0.904, 0.989, and 0.991, respectively. Note that all the explanatory parameters of the 3SLS model are statistically significant at a 0.90 level of confidence. To further evaluate the forecasting accuracy of the 3SLS model, the mean absolute percentage error (MAPE) is computed (see Equation 3) and the MAPE values are presented in Table 5.3.13. The latter show that the models under- or over-estimate the observed values by 12.75 percent on average.

Table 5.3.13 MAPE of the 3SLS models of the pavement indicators for the Design-Build with all rehabilitation treatments.

Dependent variables	**Treatment type**	**MAPE**
International Roughness Index (in/mi)	2 course HMA	0.085
Pavement Condition Rating (scale 0 to 100)		0.073
Rutting depth (inches)		0.539
International Roughness Index (in/mi)	Concrete PVM restoration	0.065
Pavement Condition Rating (scale 0 to 100)		0.053
Rutting depth (inches)		0.117
International Roughness Index (in/mi)	3course HMA overlay with or without surface milling	0.053
Pavement Condition Rating (scale 0 to 100)		0.085
Rutting depth (inches)		0.524
International Roughness Index (in/mi)	3course HMA with crack and seat of PCC PVM	0.057
Pavement Condition Rating (scale 0 to 100)		0.073
Rutting depth (inches)		0.122
International Roughness Index (in/mi)	3R&4R overlay treatments	0.042
Pavement Condition Rating (scale 0 to 100)		0.024
Rutting depth (inches)		0.153
International Roughness Index (in/mi)	3R/4R PVM replacement treatments	0.051
Pavement Condition Rating (scale 0 to 100)		0.064
Rutting depth (inches)		0.114

To graphically illustrate the forecasting performance of the estimated 3SLS models, the predicted versus the observed values are plotted in the Figures 5.3.1 through 5.3.16. It is worthwhile to note that data points closer to the diagonal line imply better model's forecasting accuracy.

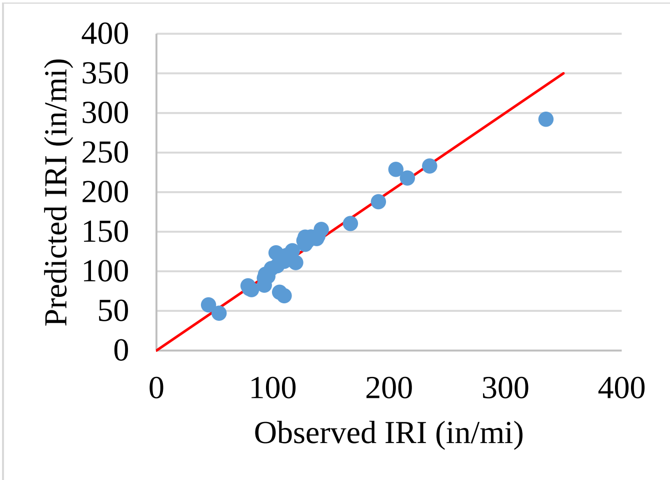

Figure 5.3.1 Predicted and observed value of IRI for Design-Build with 2-course HMA treatment

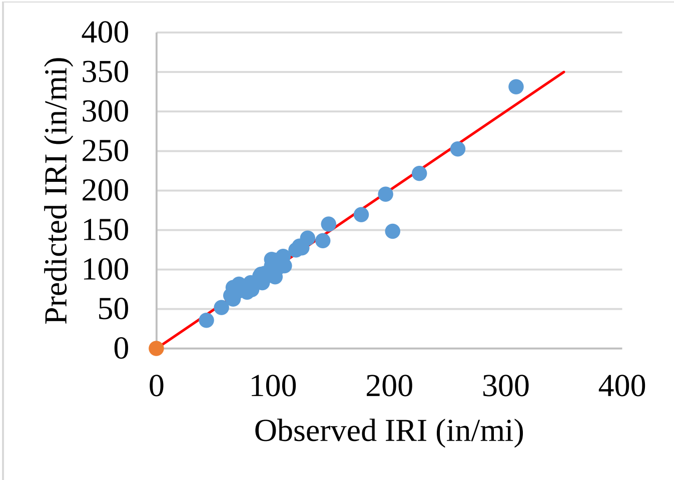

Figure 5.3.2 Predicted and observed values of IRI for Design-Build with Concrete PVM restoration.

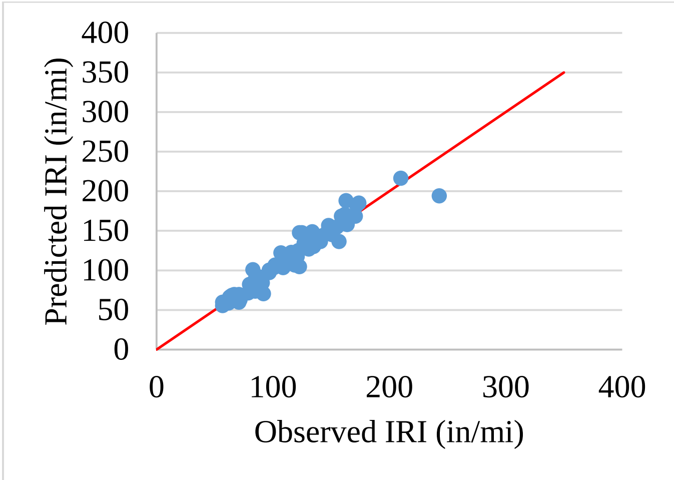

Figure 5.3.3 Predicted and observed values of IRI for Design-Build with 3-course HMA overlay with or without surface milling.

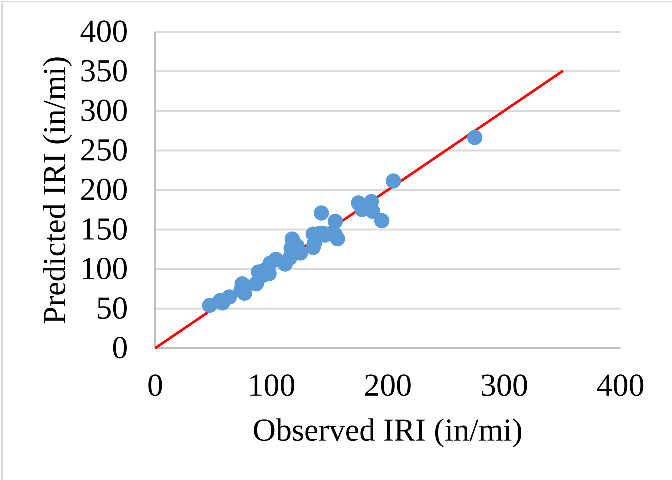

Figure 5.3.4 Predicted and observed values of IRI for Design-Build 3-course HMA with crack and seat of PCC PVM.

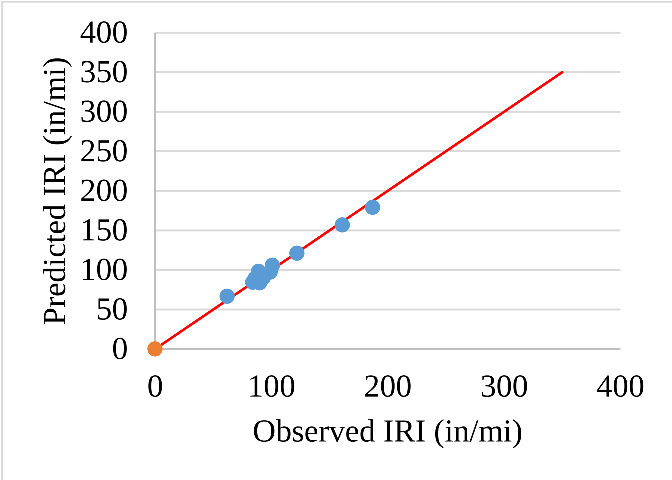

Figure 5.3.5 Predicted and observed values of IRI for Design-Build with 3R&4R overlay treatments.

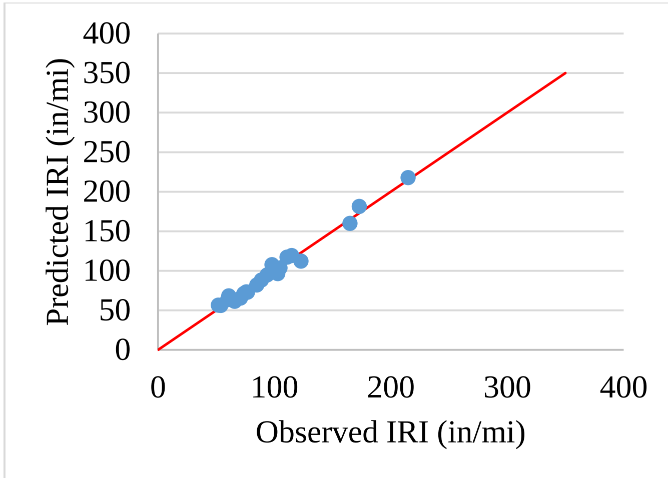

Figure 5.3.6 Predicted and observed values of IRI for Design-Build with 3R/4R PVM replacement treatments.

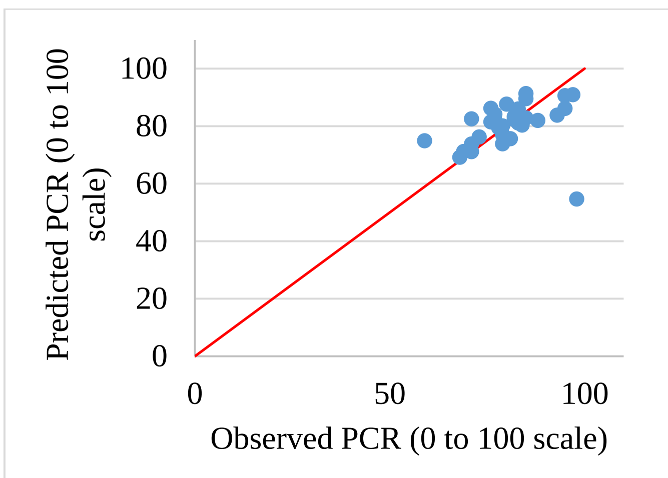

Figure 5.3.7 Predicted and observed values of PCR for Design-Build with 2-course HMA treatment.

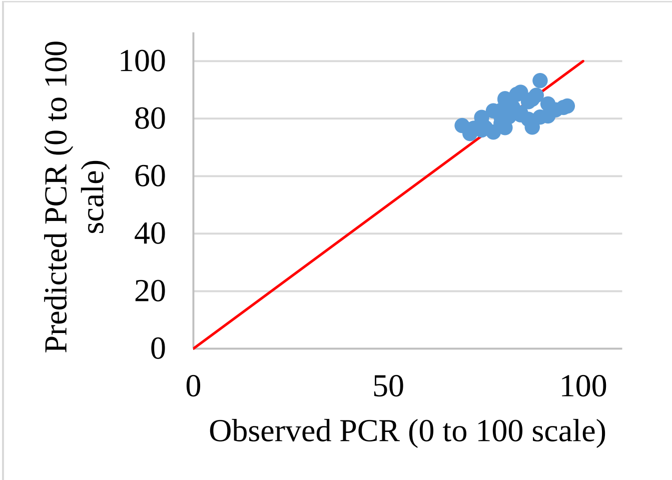

Figure 5.3.8 Predicted and observed values of PCR for Design-Build with Concrete PVM restoration.

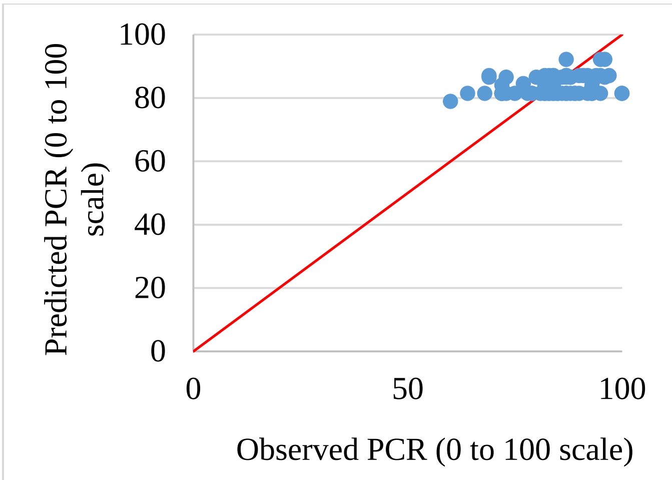

Figure 5.3.9 Predicted and observed values of PCR for Design-Build with 3-course HMA overlay with or without surface milling.

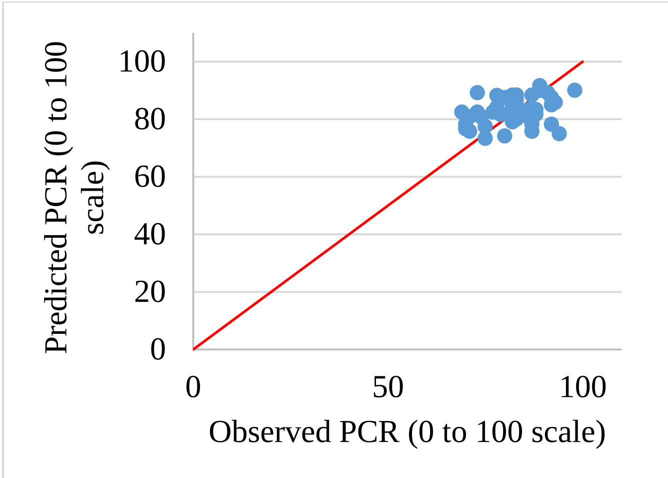

Figure 5.3.10 Predicted and observed values of PCR for Design-Build with 3-course HMA with crack and seat of PCC PVM.

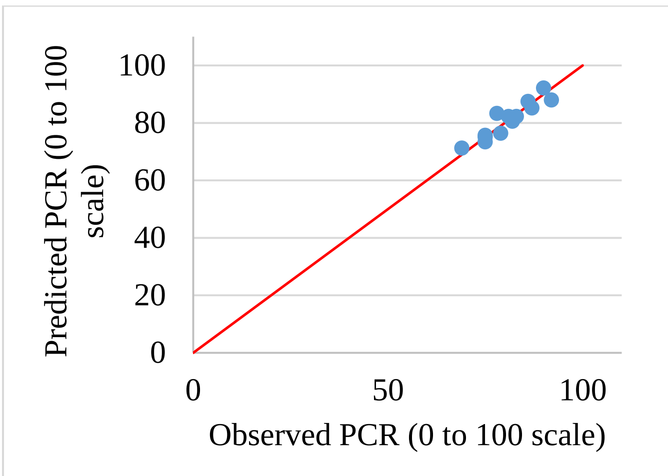

Figure 5.3.11 Predicted and observed values of PCR for Design-Build with 3R&4R overlay treatments.

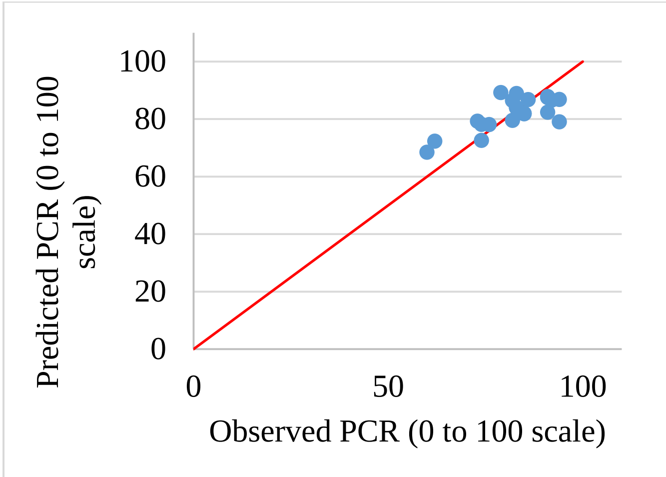

Figure 5.3.12 Predicted and observed values of PCR for Design-Build with 3R/4R PVM replacement treatments.

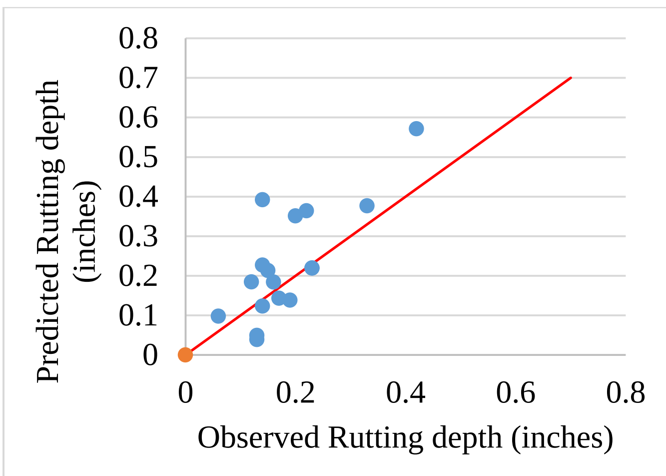

Figure 5.3.13 Predicted and observed values of rutting depth for Design-Build with 2-course HMA treatment.

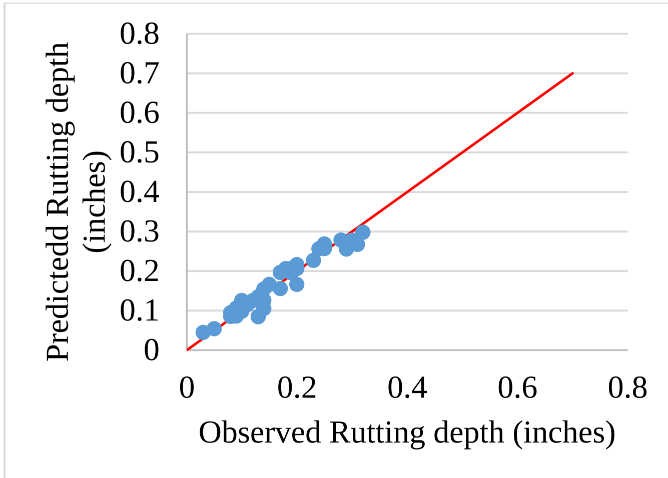

Figure 5.3.14 Predicted and observed value of rutting depth for Design-Build with Concrete PVM restoration

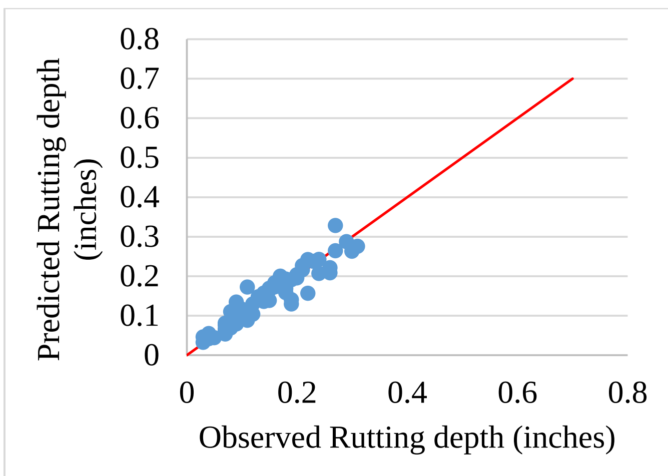

Figure 5.3.15 Predicted and observed values of rutting depth for Design-Build with 3-course HMA overlay with or without surface milling.

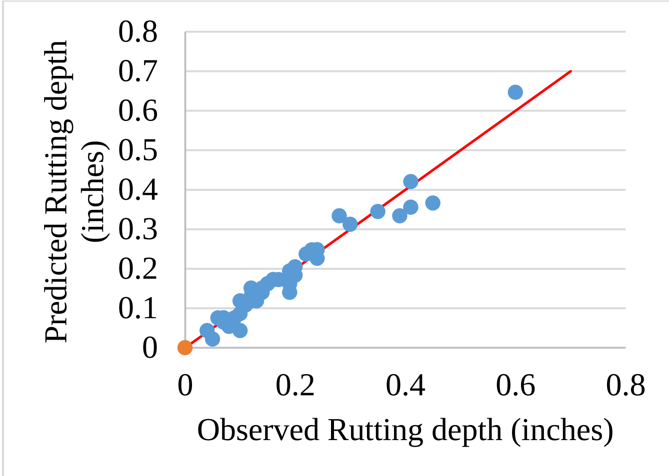

Figure 5.3.16 Predicted and observed values of rutting depth for Design-Build with 3-course HMA with crack and seat of PCC PVM.

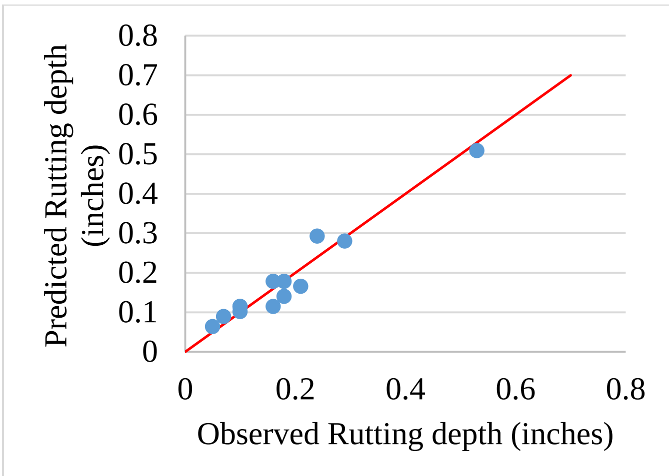

Figure 5.3.17 Predicted and observed values of rutting depth for Design-Build with 3R&4R overlay treatments.

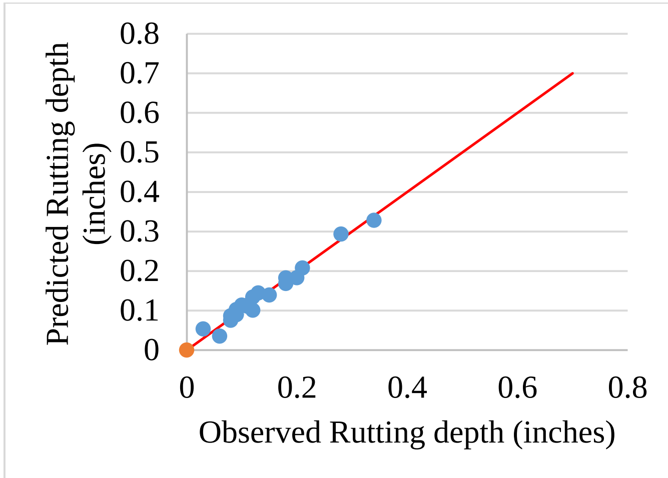

Figure 5.3.18 Predicted and observed values of rutting depth for Design-Build with 3R/4R PVM replacement treatments.

5.3.2 Hazard Based Duration Models of DBOMs' Pavement Service Life

Tables 5.3.14 and 5.3.15 present the hazard-based duration estimation results of the design-build with functional and structural treatments models, respectively, followed by a discussion of key findings.

Table 5.3.14 Estimation of the pavement service life using Hazard –Based Duration models with Design-Build and Functional treatments (2-course HMA and Concrete PVM restoration)

	Functional Treatment			
	Log Logistic		Weibull with Fixed Parameters	
	2-course HMA		Concrete PVM restoration	
Variable Description	Parameter	t-stat	Parameter	t-stat
Constant	3.444	9.26	2.541	8.79
Base (right after rehabilitation) IRI (in/mi)	-0.007	-2.16	-0.013	-6.62
Base (right after rehabilitation) RUT (in)	-2.912	-3.34	—	—
Truck Volume (in 10,000 of vehicles)	-0.555	-4.22	—	—
Change of orders	-0.198	-4.50	—	—
Number of lanes (1 if equal to 2, 0 otherwise)	—	—	0.603	2.70
P	5.96	7.00	4.84	7.60
LL(0)	-27.6		-24.3	
LL(β)	-6.5		-1.2	
McFadden pseudo R^2	0.55		0.79	
Number of observations	27		35	

Table 5.3.15 Estimation of the pavement service life using Hazard –Based Duration models with Design-Build and Functional treatments (2-course HMA and Concrete PVM restoration)

	Structural Treatment							
	Log Logistic		Weibull with random parameters		Weibull with fixed parameters		Log Logistic	
	3-course HMA overlay with or without surface milling		3-course HMA with crack and seat of PCC PVM		3R & 4R overlay treatments		3R/4R PVM replacement treatments	
Variable	Parameter	t-stat	Parameter	t-stat	Parameter	t-stat	Parameter	t-stat
Constant	3.088	13.68	3.110	46.87	2.849	9.62	2.828	11.62
Base (right after rehabilitation) IRI (in/mi)	-0.008	-6.66	-0.008	-13.35	—	—	—	—
Base (right after rehabilitation) RUT (in)	-2.819	-3.26	-3.344	-4.54	—	—	-4.210	-3.14
Standard deviation of parameter distribution	—	—	2.502	14.60	—	—	—	—
Rutting depth (in) in year t	—	—	—	—	-5.047	-3.08	—	—
Road system (1 if Non-Interstate and not a National Highway System, 0 otherwise)	—	—	—	—	-0.471	-2.36	—	—
Number of lanes (1 if greater than 3, 0 otherwise)	-0.293	-3.17	—	—	—	—	—	—
Drainage(1 if excessively or somewhat excessively drained, 0 otherwise)	-0.690	-3.79	—	—	—	—	—	—
Average precipitation from October to March in year t (inches)	-0.153	-1.96	—	—	—	—	—	—
Median (1 if median with a barrier, 0 otherwise)	0.185	2.28	—	—	—	—	—	—

	Structural Treatment							
	Log Logistic		Weibull with random parameters		Weibull with fixed parameters		Log Logistic	
	3-course HMA overlay with or without surface milling		3-course HMA with crack and seat of PCC PVM		3R & 4R overlay treatments		3R/4R PVM replacement treatments	
Variable	Parameter	t-stat	Parameter	t-stat	Parameter	t-stat	Parameter	t-stat
Contract final cost (per miles and per years, in millions of dollar)	—	—	-0.597	-13.20	—	—	—	—
Percentage of trucks per lanes	—	—	-0.982	-4.54	—	—	—	—
Truck Volume (in 10,000 of vehicles per day)	—	—	—	—	—	—	-0.3745	-2.09
P	6.22	9.28	4.06	9.13	4.18	2.42	4.30	5.92
LL(0)	-56.1		-34.9		-6.5		-16.3	
LL(β)	-11.8		-7.7		-1.3		-10.7	
McFadden pseudo R^2	0.65		0.58		0.18		0.10	
Number of observations	66		41		11		19	

The log-logistic distribution yielded the best statistical fit for the 2-course HMA, for the 3-course HMA overlay with or without surface milling, and for the 3R/4R pavement replacement treatments models; while the Weibull model provided the best fit for the concrete pavement restoration model, for the 3R&4R overlay treatments, and for the 3-course HMA with crack and seat of PCC pavement models. In terms of parameter interpretation, a negative sign of a parameter estimate shows a decrease of the pavement life, and a positive sign indicates an increase in the pavement life.

For the 2-course HMA, it is shown that high base rutting depth, high base IRI, high truck volume, and the occurrence of several change orders, are all found to decrease the pavement service life. Also, the parameter P is significantly different from zero and positive, which indicates a monotonically increasing function.

For the Concrete PVM restoration, high IRI intuitively decreases the pavement service life. On the other hand, 2-lane segments (likely picking up lower traffic volume roads, as compared to multi-lane highwas) have longer pavement lives. The Weibull model parameter P is positive (indicating a monotonically increasing function) and is significantly different from zero. This implies that as time passes, the duration of the remaining pavement service life decreases, which is intuitive.

For the 3-course HMA overlay with or without surface milling model, high base IRI, high base rutting depth, roadways with 3 or more lanes, excessively or somewhat excessively drained roadways and high average precipitation in adverse weather pediods (between October and March), are all found to decrease the pavement service life. The parameter P is positive, which indicates a hazard increasing in duration from zero to an inflection point and decreasing toward zero afterwards.

For the 3-course HMA with crack and seat of PCC pavement model, high base IRI, high contract final cost, and high truck percentage per lane, all result in shorter pavement service life. However, the base rutting depth has a variable effect on pavement life, with 90.9 percent of the segments being associated with shorter pavement service life, and the remaining 9.1 percent with longer. The Weibull parameter P is statistically different from zero and positive, indicating a monotonically increasing function.

The Weibull parameter P yields similar results for the 3R&4R overlay treatment. For the 3R&4R overlay treatment model, high rutting depth in year *t*, and non-Interstate roads that do not belong in the National Highway System, have shorter pavement service lives. The Weibull parameter P is statistically different from zero and positive, indicating a monotonically increasing function.

For the 3R/4R pavement replacement treatment model, high base rutting depth, and high truck volume, both decrease the pavement service life. The parameter P is positive which indicates a hazard increasing in duration from zero to an inflection point, and decreasing toward zero afterwards.

5.4 Estimation Results of Incentives/Disincentives (I/D) Models

Tables 5.4.1 through 5.4.36 present descriptive statistics, model estimation results, and MAPE values for the I/D contracts for functional and structural treatments, respectively. Figures 5.4.1 through 5.4.6 illustrate the observed and model-predicted pavement service lives for each subsequent model.

Table 5.4.1 Descriptive statistics of the Incentives/Disincentives with Functional treatments (2-course HMA and Concrete PVM restoration)

Variable Description	**Mean**	**Std. Deviation**	**Min**	**Max**
Dependent variable IRI of year t				
Minimum average precipitation from October to March in year t (inches)	1.594	0.702	0.21	3.51
Number of bids	3.245	0.723	1.00	6.00
Dependent variable PCR of year t				
International roughness index (in/mi) in year t(1 if greater than 120, 0 otherwise)	0.367	0.487	0.00	1.00
State (1 if Texas, 0 otherwise)	0.286	0.460	0.00	1.00
State (1 if Minnesota, 0 otherwise)	0.679	0.476	0.00	1.00
Dependent variable RUT of year t				
Rutting depth (in) in year t-1	0.135	0.080	0.02	0.42
Truck Volume (trucks per day)	4599.305	6802.000	54.56	23254.17
Outside shoulder width (inches)	8.727	4.902	0.00	16.80

Table 5.4.2 3SLS model estimation of pavement indicators for Incentives/Disincentives with Functional treatments (2-course HMA and Concrete PVM restoration)

Variable Description	Coefficient	t-stat	p value
Dependent variable IRI of year t			
Minimum average precipitation from October to March in year t (inches)	28.078	3.38	0.002
Number of bids	24.082	5.17	0.000
Dependent variable PCR of year t			
Constant	67.820	8.70	0.000
International roughness index (in/mi) in year t(1 if greater than 120, 0 otherwise)	-8.249	-2.49	0.020
State (1 if Texas, 0 otherwise)	16.470	2.04	0.052
State (1 if Minnesota, 0 otherwise)	24.010	2.93	0.007
Dependent variable RUT of year t			
Constant	0.022	2.46	0.021
Rutting depth (in) in year t-1	1.017	28.80	0.000
Truck Volume (trucks per day)	0.001	3.65	0.001
Outside shoulder width (inches)	-0.001	-2.01	0.056
System Weighted MSE	1.000		
Degrees of freedom	74		
Number of Observation	28		
System Weighted R-square	0.940		

Table 5.4.3 Descriptive statistics of the cost-plus-time contracting with Structural treatments (3-course HMA overlay with or without surface milling, 3-course HMA with crack and seat of PCC PVM, 3R & 4R overlay treatments, 3R/4R PVM replacement treatments)

Variable Description	**Mean**	**Std. Deviation**	**Min**	**Max**
Dependent variable IRI of year t				
International roughness index (in/mi) in year t-1	109.675	36.446	60.00	210.00
Lanes (1 if greater than 3, 0 otherwise)	0.225	0.423	0.00	1.00
Dependent variable PCR of year t				
Rutting depth (in) in year t (1 if greater than 0.12, 0 otherwise)	0.575	0.501	0.00	1.00
High average temperature from October to March in year t (°F)	49.972	3.114	41.23	56.92
Median (1 if median with a barrier, 0 otherwise)	0.575	0.501	0.00	1.00
Dependent variable RUT of year t				
Rutting depth (in) in year t-1	0.130	0.084	0.02	0.46
Average temperature from October to March in year t (°F)	43.002	3.301	37.88	52.86
Average precipitation from October to March in year t (inches)	3.319	0.506	2.44	4.27
Lanes (1 if greater than 3, 0 otherwise)	0.225	0.423	0.00	1.00

Table 5.4.4 3SLS model estimation of pavement indicators for cost-plus-time contracting with Structural treatments (3-course HMA overlay with or without surface milling, 3-course HMA with crack and seat of PCC PVM, 3R & 4R overlay treatments, 3R/4R PVM replacement treatments)

Variable Description	Coefficient	t-stat	p value
Dependent variable IRI of year t			
International roughness index (in/mi) in year t-1	1.061	98.71	0.000
Lanes (1 if greater than 3, 0 otherwise)	6.035	2.31	0.026
Dependent variable PCR of year t			
Constant	48.732	1.97	0.057
Rutting depth (in) in year t (1 if greater than 0.12, 0 otherwise)	-14.450	-4.92	0.000
High average temperature from October to March in year t (°F)	0.911	1.93	0.062
Median (1 if median with a barrier, 0 otherwise)	-6.414	-2.08	0.045
Dependent variable RUT of year t			
Rutting depth (in) in year t-1	1.014	39.09	0.000
Average temperature from October to March in year t (°F)	-0.001	-2.41	0.021
Average precipitation from October to March in year t (inches)	0.013	3.33	0.002
Lanes (1 if greater than 3, 0 otherwise)	0.017	3.31	0.002
System Weighted MSE	3.844		
Degrees of freedom	109		
Number of Observation	40		
System Weighted R-square	0.980		

5.4.1 Estimation Results of 3SLS I/D Models: Functional and Structural treatments

This section provides key findings for the I/D with functional and structural treatments models.

Traffic characteristics: Model estimation results illustrate that various traffic characteristics constitute significant influential factors of the the pavement condition. Specifically, heavier loads are associated with higher PCR. Table 5.4.2. shows that high truck volume is associated with higher IRI and rutting depth values, in pavements with functional treatments. These findings are in line with past research (Anastasopoulos and Mannering, 2014; Sarwar, 2015).

Pavement characteristic**:** Turning to the pavement characteristics, Table 5.4.8 shows that for the functional treatments, the poor drainage indicator (somewhat poorly, poorly or very poorly drained) is associated with lower PCR values. On the contrary, moderate or good drainage conditions in pavements with structural treatments are found to decrease the PCR. Table 5.4.4. also demonstrates that roadways with 3 or more lanes are associated with higher IRI; this finding may be capturing the impact of high truck volume in cases of large roadways, with wide right-of-ways.

With regard to the time lagged pavement condition variables, the IRI and the rutting depth of the previous year (*t-1*) are found to significantly affect the same pavement condition indicators in the analysis year, *t*. For the structural treatments, poor pavement performance (as indicated by higher values of the IRI and rutting depth) in year *t-1* results in pavement deterioration in the analysis year *t*.

For both functional and structural treatments, the endogenous variables representing the rutting depth in year *t*, are found to be statistically significant determinants of the PCR in the same year. Particularly, Tables 5.4.2 and 5.4.4 show that higher rutting depth results in higher PCR values, at the same year *t*. These results support the findings of Sarwar (2015) that the IRI and rutting depth have a strong impact on the determination of the PCR.

Weather characteristics: Table 5.4.4 shows that higher temperature during adverse weather months (October through March) have lower rutting depth values. This finding can be explained by the fact that higher temperature during this period may decrease the impact of possible snow accumulation on pavements, especially in areas with significamt snowfall during the winter period. In Table 5.4.2, it is shown that the higher minimum average precipitation is, the higher the IRI value will be. Similarly, Table 5.4.4 shows that the higher the average precipitation is, the higher the rutting depth value will be.

5.4.2 Model evaluation for I/D: Functional and Structural treatments

In terms of goodness-of-fit measures, the 3SLS models have an overall good statistical fit, as indicated by the system weighted R^2 in Tables 5.4.2 and 5.4.4, which is 0.94 and 0.98 for functional and structural treatments, respectively. Note that all explanatory parameters of the 3SLS model are statistically significant at a 0.90 level of confidence. To further evaluate the forecasting accuracy of the 3SLS model, the mean absolute percentage error (MAPE) is computed. The MAPE values in Table 5.4.5 show that the models under- or over-estimate the observed values by 11.18 percent on average.

Table 5.4.5 MAPE of the 3SLS models of the pavement indicators for the Design-Build with all rehabilitation treatments.

Dependent variables	**Treatment type**	**MAPE**
International Roughness Index (in/mi)	Functional	0.260
Pavement Condition Rating (scale 0 to 100)		0.092
Rutting depth (inches)		0.092
International Roughness Index (in/mi)	Structural	0.050
Pavement Condition Rating (scale 0 to 100)		0.090
Rutting depth (inches)		0.087

The observed versus the model-predicted values are illustrated in Figures 5.4.1 through 5.4.6.

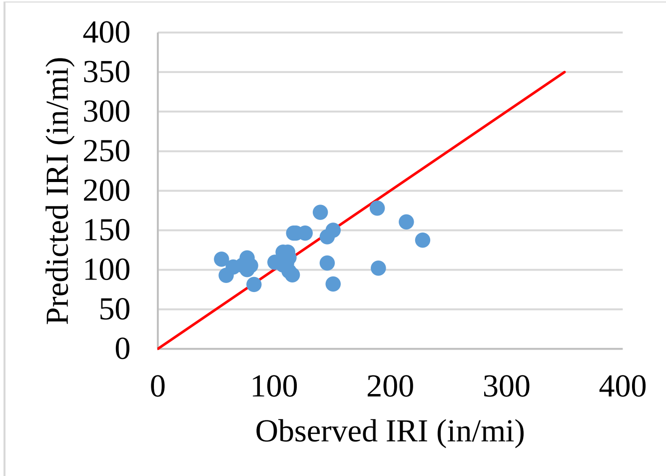

Figure 5.4.1 Predicted and observed value of IRI for I/D with Functional treatments (2-course HMA and Concrete PVM restoration)

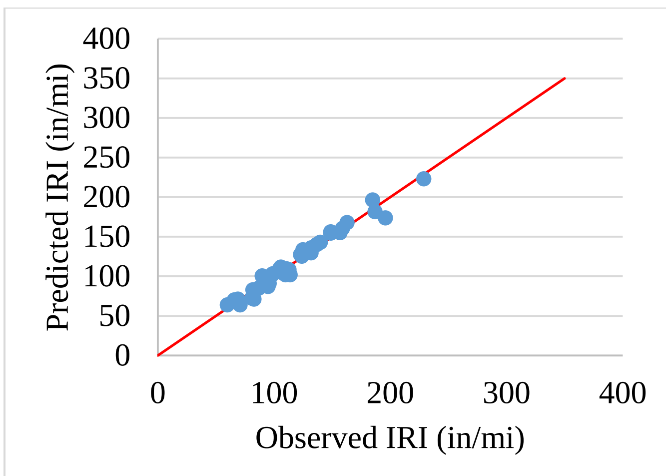

Figure 5.4.2 Predicted and observed value of IRI for I/D with structural treatments (3-course HMA overlay with or without surface milling, 3-course HMA with crack and seat of PCC PVM, 3R&4R overlay treatments, 3R/4R PVM replacement treatments)

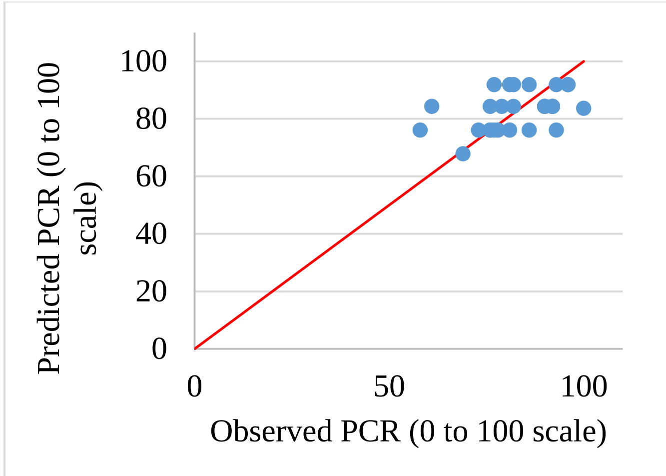

Figure 5.4.3 Predicted and observed values of PCR for I/D with Functional treatments (2-course HMA and Concrete PVM restoration)

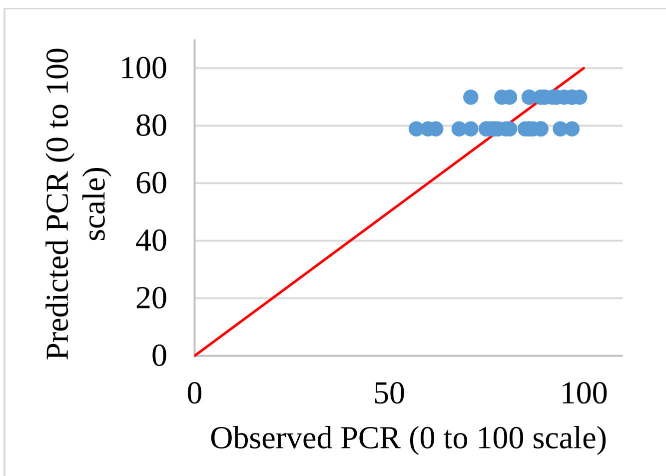

Figure 5.4.4 Predicted and observed values of PCR for I/D with structural treatments (3-course HMA overlay with or without surface milling, 3-course HMA with crack and seat of PCC PVM, 3R&4R overlay treatments, 3R/4R PVM replacement treatments)

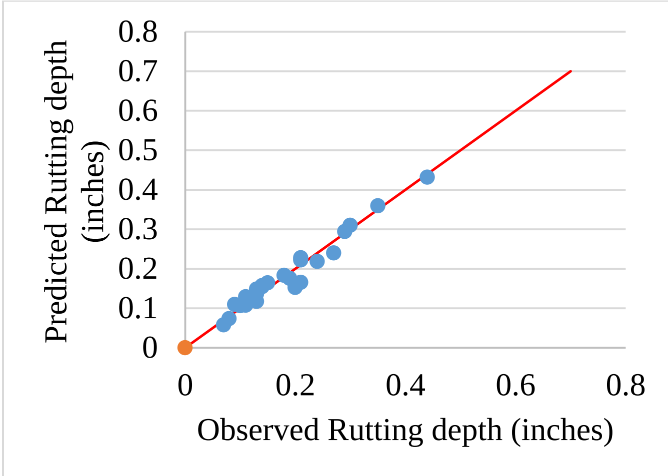

Figure 5.4.5 Predicted and observed values of rutting depth for I/D with functional treatment (2-course HMA and Concrete PVM restoration)

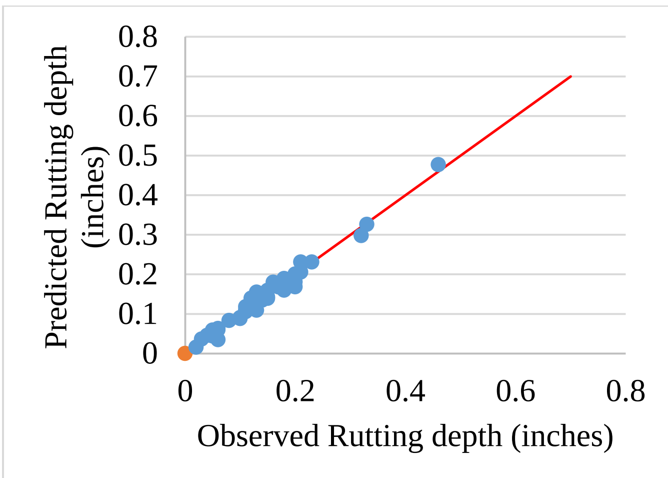

Figure 5.4.6 Predicted and observed values of rutting depth for I/D PPP type with structural treatments (3-course HMA overlay with or without surface milling, 3-course HMA with crack and seat of PCC PVM, 3R&4R overlay treatments, 3R/4R PVM replacement treatments)

5.4.3 Hazard Based Duration Models of I/Ds' Pavement Service Life

Table 5.4.6 presents the hazard-based duration estimation results of the I/D with functional and structural treatments models, respectively, followed by a discussion of key findings.

Table 5.4.6 Estimation of the pavement service life using Hazard –Based Duration models with Incentives/Disincentives and all rehabilitation treatments (Functional and Structural treatments)

	Functional Treatment		Structural Treatment	
	Log Logistic		Log Logistic	
Variable Description	Parameter	t-stat	Parameter	t-stat
Constant	2.864	7.00	2.269	2.33
Base (right after rehabilitation) IRI (in/mi)	—	—	-0.024	-10.89
Base (right after rehabilitation) RUT (in)	-6.712	-4.99	—	—
Truck Volume (in 10,000 of vehicles per day)	-0.741	-2.70	-0.237	-1.67
Outside Shoulder Width (inches)	0.048	2.10	—	—
Average temperature from October to March in year t (°F)	—	—	0.039	2.21
P	5.54	11.55	5.67	4.75
LL(0)	-35.2		-41.9	
LL(β)	-12.8		-9.4	
McFadden pseudo R^2	0.50		0.66	
Number of observations	27		37	

The log-logistic distribution yielded the best statistical fit for both the functional and structural treatments. In terms of parameter interpretation, a negative sign of a parameter estimate shows a decrease of the pavement life, and a positive sign indicates an increase in the pavement life.

For the functional treatments, high base rutting depth, and high truck volume are associated with shorter pavement service lives. With regard to the structural treatments, high base IRI, and high truck volume are found to decrease the pavement service life. On the other hand, if the average temperature from October to March in year *t* is high, the pavement service life will most likely be shorter. The parameter P is positive for both treatments, which indicates a hazard increasing in the duration from zero to an inflection point and decreasing toward zero afterwards.

5.5 Estimation Results of Lane Rental Models

Tables 5.5.1 through 5.5.5 present descriptive statistics, model estimation results, and MAPE vales for lane rental contracts for the functional and structural treatments models, respectively. Figures 5.4.1 and 5.4.2 plot the observed and model-predicted values for the estimated models.

Table 5.5.1 Descriptive statistics of the Lane Rental with Functional treatments (2-course HMA and Concrete PVM restoration)

Variable Description	**Mean**	**Std. Dev.**	**Min**	**Max**
Dependent variable IRI of year t				
International roughness index (in/mi) in year t-1	98.652	47.161	41.00	202.00
Road class(1 if Urban, 0 otherwise)	0.696	0.470	0.00	1.00
Number of lanes (1 if greater than 3, 0 otherwise)	0.217	0.422	0	1
Dependent variable PCR of year t				
Rutting depth (in) in year t (1 if greater than 0.13, 0 otherwise)	0.478	0.511	0.00	1.00
Contract final cost (per miles and per years)	47,199.0	96,685.0	358.6	454,522.3
Change Orders	3.565	1.950	0.00	8.00
Dependent variable RUT of year t				
Rutting depth (in) in year t-1	0.134	0.108	0.02	0.45
Road system (1 if Non-Interstate and not a National Highway System, 0 otherwise)	0.565	0.507	0.00	1.00
Truck volume (1 if less than 300 trucks per day, 0 otherwise)	0.130	0.344	0	1
State (1 if Florida, 0 otherwise)	0.348	0.487	0	1

Table 5.5.2 3SLS model estimation results of pavement indicators for Lane Rentals with Functional treatments (2-course HMA and Concrete PVM restoration)

Variable Description	Coefficient	t-stat	p value
Dependent variable IRI of year t			
Constant	20.973	3.19	0.005
International roughness index (in/mi) in year t-1	1.039	19.23	0.000
Road class(1 if Urban, 0 otherwise)	-18.285	-3.68	0.002
Number of lanes (1 if greater than 3, 0 otherwise)	13.941	2.45	0.024
Dependent variable PCR of year t			
Constant	86.587	40.96	0.000
Rutting depth (in) in year t (1 if greater than 0.13, 0 otherwise)	-4.652	-2.25	0.037
Contract final cost (per miles and per years)	0.001	3.47	0.003
Change Orders	-1.497	-2.93	0.009
Dependent variable RUT of year t			
Rutting depth (in) in year t-1	1.156	51.61	0.000
Road system (1 if Non-Interstate and not a National Highway System, 0 otherwise)	0.042	7.34	0.000
Truck volume (1 if less than 300 trucks per day, 0 otherwise)	-0.056	-5.75	0.000
State (1 if Florida, 0 otherwise)	-0.015	-2.44	0.025
System Weighted MSE	1		
Degrees of freedom	57		
Number of Observation	23		
System Weighted R-square	0.9862		

Table 5.5.3 Descriptive statistics of the Lane Rental with Structural treatments (3-course HMA overlay with or without surface milling, 3-course HMA with crack and seat of PCC PVM, 3R & 4R overlay treatments, 3R/4R PVM replacement treatments)

	Mean	Std. Dev.	Min	Max
Dependent variable IRI of year t				
International roughness index (in/mi) in year t-1	93.296	35.840	41.00	197.00
Truck volume (trucks per day)	3469.114	7433	22.36	46209.38
Drainage(1 if somewhat, poorly, or very poorly drained, 0 otherwise)	0.426	0.499	0.00	1.00
Dependent variable PCR of year t				
Pavement condition rating (0 to 100 scale) in year t	88.278	7.624	65.00	100.00
Dependent variable RUT of year t				
Rutting depth (in) in year t-1	0.134	0.085	0.04	0.39
Road system (1 if Interstate, 0 otherwise)	0.241	0.432	0.00	1.00
Contract final cost (per miles and per years)	68,416	167,817	448	1,144,644
Outside shoulder width (inches)	8.881	4.437	0.00	16.80

Table 5.5.4 3SLS model estimation results of pavement indicators for Lane Rental with Structural treatments (3-course HMA overlay with or without surface milling, 3-course HMA with crack and seat of PCC PVM, 3R & 4R overlay treatments, 3R/4R PVM replacement treatments)

	Coefficient	t-stat	p value
Dependent variable IRI of year t			
International roughness index (in/mi) in year t-1	1.054	94.17	0.000
Truck volume (trucks per day)	0.001	2.67	0.010
Drainage(1 if somewhat, poorly, or very poorly drained, 0 otherwise)	5.819	3.60	0.001
Dependent variable PCR of year t			
Pavement condition rating (0 to 100 scale) in year t	0.930	138.20	0.000
Dependent variable RUT of year t			
Constant	0.038	3.48	0.001
Rutting depth (in) in year t-1	1.015	19.47	0.000
Road system (1 if Interstate, 0 otherwise)	0.027	3.15	0.003
Contract final cost (per miles and per years)	-0.001	-2.16	0.036
Outside shoulder width (inches)	-0.001	-1.86	0.069
System Weighted MSE	7.7373		
Degrees of freedom	153		
Number of Observation	54		
System Weighted R-square	0.9628		

5.5.1 Estimation Results of 3SLS Lane Rental Models: Functional and Structural Treatments

This section provides key findings with regard to the model estimation results for the lane rental with functional and structural treatments models.

Traffic characteristics: The model estimation results demonstrate that various traffic characteristics play a significant role on the pavement condition. Table 5.5.2 shows that low truck traffic (less than 300 trucks per day) results in low rutting depth, and as truck volume increases, the rutting depth also increases. These findings are in line with past research (Anastasopoulos and Mannering, 2014; Sarwar, 2016).

Pavement characteristics: As mentioned earlier, greater truck volume imposes greater loads on the pavement. Several variables (e.g., multi-lane roadways, and roadways with wide outside shoulders) that possibly reflect segments with high truck volumes result in rougher pavements (as indicated by higher IRI), and higher rutting depth.

Weather characteristics: Table 5.5.4 shows that pavements with somewhat poor, poor, or very poor drainage are associated with worse pavement performance and particularly with higher IRI.

<u>Other factors:</u> With regard to the time lagged pavement condition variables, the IRI and the rutting depth of the previous year (*t-1*) are found to significantly affect the same pavement condition indicators in the analysis year, *t*. For the structural treatments, poor pavement performance (as indicated by higher values of the IRI and rutting depth) in year *t-1* results in pavement deterioration in the analysis year *t*.

In this model, the endogenous rutting depth variable is found to be statistically significant in the PCR equation. Table 5.5.2 shows that the greater the rutting depth is, the lower the PCR will be. Those results support the findings of Sarwar (2016) that rutting depth has a strong impact in the PCR.

5.5.2 Model evaluation for Lane Rentals: Functional and Structural treatments

In terms of goodness-of-fit measures, the 3SLS model has an overall good statistical fit, as indicated by the system weighted R^2, which is 0.986 and 0.976, for functional and structural treatments, respectively. Note that all explanatory parameters of the 3SLS model are statistically significant at a 0.90 level of confidence. To further evaluate the forecasting accuracy of the 3SLS model, the mean absolute percentage error (MAPE) is computed. The MAPE values illustrated in Table 5.5.5 show that the model-predicted values under- or over-estimate the observed values by 7.17 percent on average. Figures 5.5.1 through 5.5.6 plot the observed and predicted values.

Table 5.5.5 MAPE of the 3SLS models of the pavement indicators for the Lane Rental with all rehabilitation treatments

Dependent variables	**Treatment type**	**MAPE**
International Roughness Index (in/mi)	Functional	0.072
Pavement Condition Rating (scale 0 to 100)		0.046
Rutting depth (inches)		0.080
International Roughness Index (in/mi)	Structural	0.051
Pavement Condition Rating (scale 0 to 100)		0.043
Rutting depth (inches)		0.138

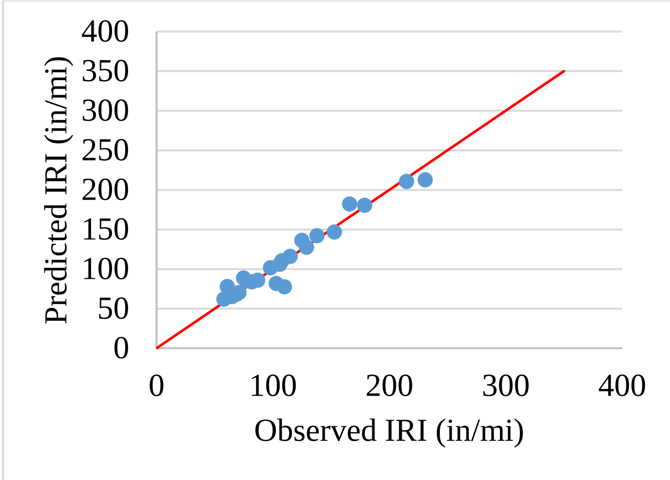

Figure 5.5.1 Predicted and observed value of IRI for Lane Rental with functional treatment (2-course HMA and Concrete PVM restoration)

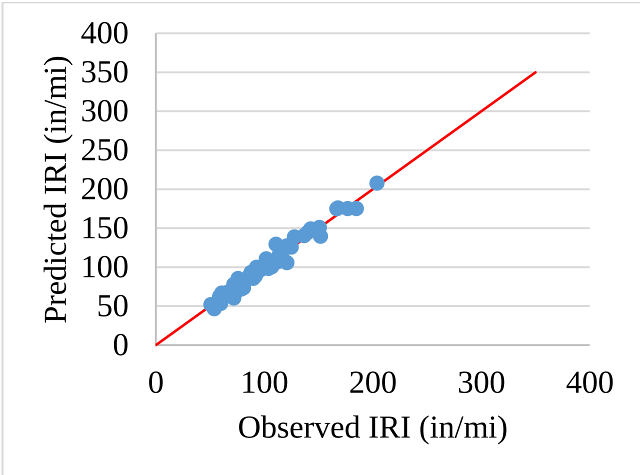

Figure 5.5.2 Predicted and observed values of IRI for Lane Rental PPP type with structural treatments (3-course HMA overlay with or without surface milling, 3-course HMA with crack and seat of PCC PVM, 3R&4R overlay treatments, 3R/4R PVM replacement treatments)

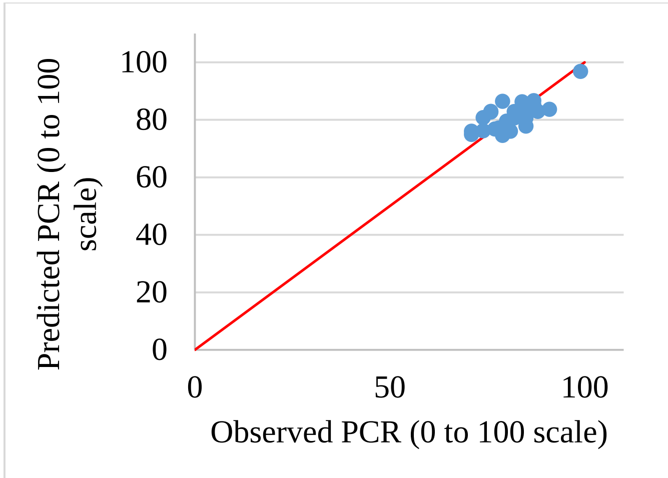

Figure 5.5.3 Predicted and observed values of PCR for Lane Rental PPP type with functional treatment (2-course HMA and Concrete PVM restoration).

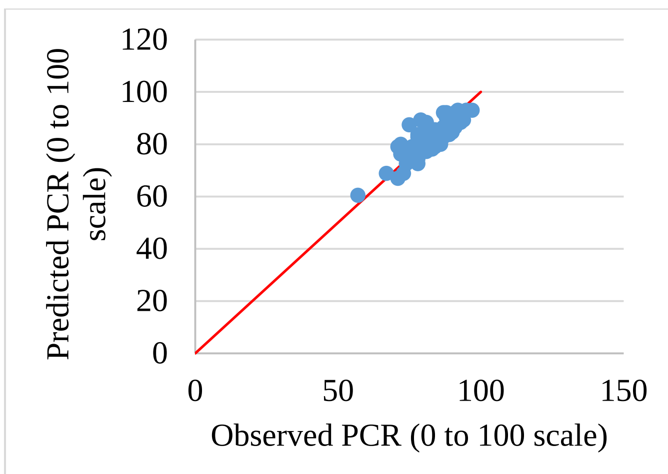

Figure 5.5.4 Predicted and observed values of PCR for Lane Rental PPP type with structural treatments (3-course HMA overlay with or without surface milling, 3-course HMA with crack and seat of PCC PVM, 3R&4R overlay treatments, 3R/4R PVM replacement treatments).

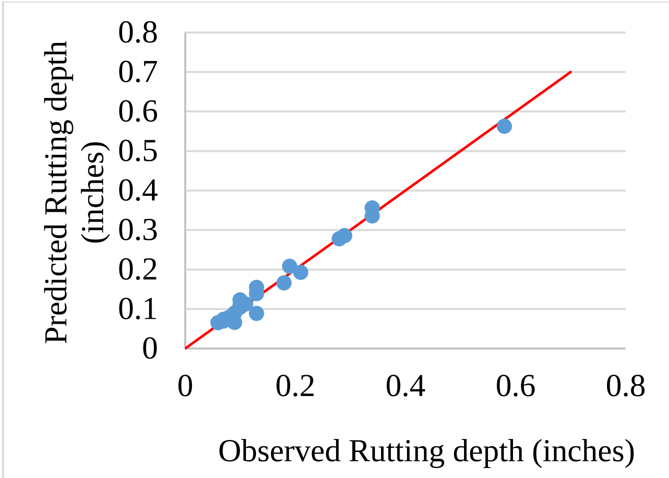

Figure 5.5.5 Predicted and observed values of rutting depth for Lane Rental PPP type with functional treatments (2-course HMA and Concrete PVM restoration).

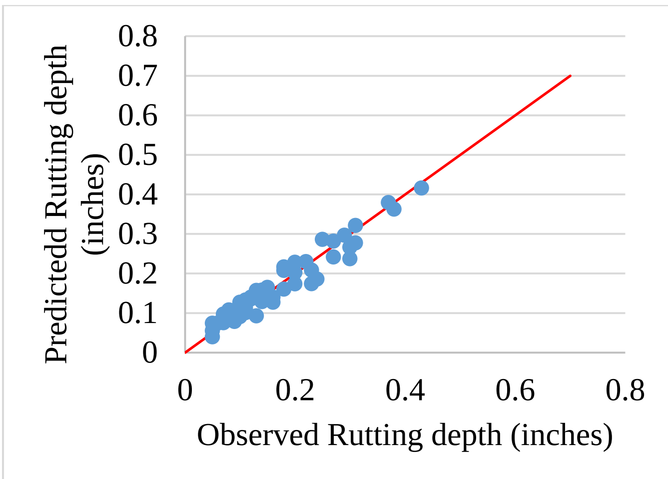

Figure 5.5.6 Predicted and observed values of rutting depth for Lane Rental PPP type with structural treatment (3-course HMA overlay with or without surface milling, 3-course HMA with crack and seat of PCC PVM, 3R&4R overlay treatments, 3R/4R PVM replacement treatments).

5.5.3 Hazard Based Duration Models of Lane Rentals' Pavement Service Life

Table 5.5.6 presents the hazard-based duration estimation results of the lane rentals with functional and structural treatments models, respectively, followed by a discussion of key findings.

Table 5.5.6 Estimation of the pavement service life using Hazard –Based Duration models with Lane Rental and all rehabilitation treatments (Functional and Structural treatments)

	Functional Treatment		Structural Treatment	
	Log Logistic		Log Logistic	
Variable	Parameter	t-stat	Parameter	t-stat
Constant	3.614	20.90	3.606	21.53
Base (right after rehabilitation) IRI (in/mi)	-0.014	-4.20	-0.011	-6.39
Standard deviation of parameter distribution	—	—	0.001	2.41
Base (right after rehabilitation) RUT (in)	-3.625	-2.39	-3.711	-4.65
Number of lanes (1 if greater than 3, 0 otherwise)	-1.107	-5.88	—	—
Drainage(1 if somewhat, poorly, or very poorly drained, 0 otherwise)	-0.799	-3.51	-0.372	-3.72
Contract final cost (per miles and per years, in millions of dollar)	-1.962	-1.86	—	—
Truck Volume (in 10,000 of vehicles per day)	—	—	-0.248	-3.28
Minimum average precipitation from October to March in year t (inches)	—	—	-0.116	-1.71
P	3.68	5.23	3.59	8.12
LL(0)	-23.0		-40.7	
LL(β)	-6.6		-14.5	
McFadden pseudo R^2	0.41		0.47	
Number of observations	21		52	

The log-logistic distribution yielded the best statistical fit for both models. In terms of parameter interpretation, a negative sign of a parameter estimate shows a decrease of the pavement life, and a positive sign indicates an increase in the pavement life.

For the functional treatments model, high base IRI, high base RUT, roadways with 3 or more lanes, high contract final cost (per miles and per year), and generally poor drainage conditions (somewhat, poorly, or very poorly drained segments), are found to decrease pavement service life.

For the structural treatments model, high base RUT, high truck volume, poor drainage conditions, and high minimum average precipitation from October to March in year *t* result in shorter pavement service life. The effect of the base IRI on pavement service life, however, is mixed, with 99 percent of the segments being associated with shorter pavement service life, and only 1 percent with longer. The parameter P is positive for both models, which indicates a hazard increasing in duration from zero to an inflection point and decreasing toward zero afterwards.

5.6 Estimation Results of Performance-Based Contracting (PBC) Models

Tables 5.6.1 through 5.6.13 present desricptive statistics, model estimation results, and MAPE values for PBCs with 2-course HMA, concrete pavement restoration, 3-course HMA overlay with or without surface milling, 3-course HMA with crack and seat of PCC pavement, 3R&4R overlay, and 3R/4R PVM replacement treatments models, respectively. Figures 5.6.1 through 5.6.16, plot the observed and predicted values for these models.

Table 5.6.1 Descriptive statistics of the Performance-Based contracting with 2-course HMA

Variable Description	Mean	Std. Deviation	Min	Max
Dependent variable IRI of year t				
International roughness index (in/mi) in year t-1	115.450	38.897	58.00	197.00
Road class(1 if Urban, 0 otherwise)	0.650	0.489	0.00	1.00
Truck volume (trucks per day per lanes)	1598.627	2328.000	17.26	7424.33
Dependent variable PCR of year t				
Rutting depth (in) in year t (1 if greater than 0.2, 0 otherwise)	0.500	0.513	0.00	1.00
Average temperature from October to March in year t (°F)	42.634	3.140	37.15	50.63
Dependent variable RUT of year t				
Rutting depth (in) in year t-1	0.169	0.091	0.02	0.34
State (1 if Florida, 0 otherwise)	0.850	0.366	0.00	1.00

Table 5.6.2 3SLS model estimation of pavement indicators for Performance-Based contracting with 2-course HMA treatment

Variable Description	Coefficient	t-stat	p value
Dependent variable IRI of year t			
International roughness index (in/mi) in year t-1	1.162	30.76	0.000
Road class(1 if Urban, 0 otherwise)	-18.375	-3.12	0.006
Truck volume (trucks per day per lanes)	0.003	2.58	0.020
Dependent variable PCR of year t			
Constant	42.759	2.27	0.037
Rutting depth (in) in year t (1 if greater than 0.2, 0 otherwise)	-5.535	-1.99	0.063
Average temperature from October to March in year t (°F)	1.005	2.26	0.037
Dependent variable RUT of year t			
Rutting depth (in) in year t-1	0.937	21.73	0.000
State (1 if Florida, 0 otherwise)	0.041	4.69	0.000
System Weighted MSE	1.000		
Degrees of freedom	52.000		
Number of Observation	20		
System Weighted R-square	0.992		

Table 5.6.3 Descriptive statistics of the Performance-Based contracting with Concrete PVM restoration

Variable Description	Mean	Std. Deviation	Min	Max
Dependent variable IRI of year t				
International roughness index (in/mi) in year t-1	99.458	30.300	40.00	146.00
Truck volume (trucks per day)	2593.317	5210.000	50.58	18139.26
Contract Final Cost (per miles and per years)	3,300,950	5,402,573	367,200	18,289,095
Time delay	-0.183	0.343	-0.66	0.42
Dependent variable PCR of year t				
Rutting depth (in) in year t (1 if less than 0.1, 0 otherwise)	0.292	0.464	0.00	1.00
Number of lanes (1 if less than 3, 0 otherwise)	0.833	0.381	0.00	1.00
Dependent variable RUT of year t				
Rutting depth (in) in year t-1	0.160	0.093	0.04	0.38
Percentage of truck per lanes	0.080	0.059	0.02	0.38

Table 5.6.4 3SLS model estimation of pavement indicators for Performance-Based contracting with Concrete PVM restoration

Variable Description	Coefficient	t-stat	p value
Dependent variable IRI of year t			
International roughness index (in/mi) in year t-1	1.121	66.44	0.000
Truck volume (trucks per day)	0.001	3.41	0.003
Contract Final Cost (per miles and per years)	-0.001	-2.22	0.038
Time delay	9.062	2.17	0.042
Dependent variable PCR of year t			
Constant	73.633	15.96	0.000
Rutting depth (in) in year t (1 if less than 0.1, 0 otherwise)	9.494	2.47	0.022
Number of lanes (1 if less than 3, 0 otherwise)	9.013	1.93	0.068
Dependent variable RUT of year t			
Rutting depth (in) in year t-1	1.054	65.59	0.000
Percentage of truck per lanes	0.069	2.33	0.029
System Weighted MSE	1.000		
Degrees of freedom	63.000		
Number of Observation	24		
System Weighted R-square	0.995		

Table 5.6.5 Descriptive statistics of the Performance-Based contracting with Structural 3-course HMA overlay with or without surface milling

Variable Description	Mean	Std. Deviation	Min	Max
Dependent variable IRI of year t				
International roughness index (in/mi) in year t-1	108.375	43.337	55.00	253.00
Dependent variable PCR of year t				
Rutting depth (in) in year t (1 if greater than 0.2, 0 otherwise)	0.250	0.440	0.00	1.00
International roughness index (in/mi) in year t(1 if greater than 130, 0 otherwise)	0.313	0.471	0.00	1.00
High average temperature from October to March in year t (°F)	50.326	2.766	46.72	58.89
Dependent variable RUT of year t				
Rutting depth (in) in year t-1	0.143	0.129	0.02	0.56

Table 5.6.6 3SLS model estimation of pavement indicators for Performance-Based contracting with 3-course HMA overlay with or without surface milling

Variable Description	Coefficient	t-stat	p value
Dependent variable IRI of year t			
International roughness index (in/mi) in year t-1	1.076	95.02	0.000
Dependent variable PCR of year t			
Constant	41.442	2.02	0.053
Rutting depth (in) in year t (1 if greater than 0.2, 0 otherwise)	-7.733	-2.80	0.009
International roughness index (in/mi) in year t(1 if greater than 130, 0 otherwise)	-5.638	-2.42	0.022
High average temperature from October to March in year t (°F)	0.899	2.20	0.036
Dependent variable RUT of year t			
Constant	0.022	4.06	0.000
Rutting depth (in) in year t-1	0.990	36.66	0.000
System Weighted MSE	1.000		
Degrees of freedom	89.000		
Number of Observation	32		
System Weighted R-square	0.992		

Table 5.6.7 Descriptive statistics of the Performance-Based contracting 3-course HMA with crack and seat of PCC PVM

Variable Description	Mean	Std. Deviation	Min	Max
Dependent variable IRI of year t				
International roughness index (in/mi) in year t-1	116.250	50.326	48.00	244.00
Dependent variable PCR of year t				
International roughness index (in/mi) in year t(1 if less than 95, 0 otherwise)	0.250	0.452	0.00	1.00
Rutting depth (in) in year t (1 if less than 0.1, 0 otherwise)	0.250	0.452	0.00	1.00
Percentage of truck (per lanes)	0.061	0.029	0.03	0.11
Dependent variable RUT of year t	0.250	0.452	0.00	1.00
Rutting depth (in) in year t-1	0.139	0.086	0.03	0.30
State (1 if New York, 0 otherwise)				

Table 5.6.8 3SLS model estimation of pavement indicators for Performance-Based contracting 3-course HMA with crack and seat of PCC PVM

Variable Description	**Coefficient**	**t-stat**	**p value**
Dependent variable IRI of year t			
International roughness index (in/mi) in year t-1	1.075	44.28	0.000
Dependent variable PCR of year t			
Constant	79.234	43.51	0.000
International roughness index (in/mi) in year t(1 if less than 95, 0 otherwise)	3.976	2.71	0.027
Rutting depth (in) in year t (1 if less than 0.1, 0 otherwise)	12.428	9.25	0.000
Percentage of truck (per lanes)	-45.428	-2.45	0.040
Dependent variable RUT of year t			
Rutting depth (in) in year t-1	1.079	41.72	0.000
State (1 if New York, 0 otherwise)	0.019	4.57	0.001
System Weighted MSE	1.0986		
Degrees of freedom	29		
Number of Observation	12		
System Weighted R-square	0.9889		

Table 5.6.9 Descriptive statistics of the Performance-Based contracting with 3R & 4R overlay treatments

Variable Description	Mean	Std. Dev.	Min	Max
Dependent variable IRI of year t				
Contract final cost (per miles and per years)	47,321.5	51,821.0	429.6	196,071.3
Road class(1 if Urban, 0 otherwise)	0.560	0.507	0.00	1.00
Road system(1 If interstate, 0 otherwise)	0.320	0.476	0.00	1.00
Truck volume (trucks per day)	3547.165	4681	48.43	16180.36
Dependent variable PCR of year t				
International roughness index (in/mi) in year t(1 if less than 95, 0 otherwise)	0.240	0.436	0.00	1.00
Rutting depth (in) in year t (1 if less than 0.1, 0 otherwise)	0.200	0.408	0.00	1.00
Dependent variable RUT of year t				
Rutting depth (in) in year t-1	0.163	0.100	0.05	0.40
High average temperature from October to March in year t (°F)	50.082	3.125	44.87	58.89
Cost overrun (percentage)	-0.006	0.168	-0.41	0.21

Table 5.6.10 3SLS model estimation of pavement indicators for Performance-Based contracting with 3R & 4R overlay treatments

Variable Description	**Coefficient**	**t-stat**	**p value**
Dependent variable IRI of year t			
Constant	189.672	14.70	0.000
Contract final cost (per miles and per years)	-0.001	-2.52	0.020
Road class(1 if Urban, 0 otherwise)	-60.963	-3.99	0.001
Road system(1 If interstate, 0 otherwise)	-67.372	-3.80	0.001
Truck volume (trucks per day)	0.004	1.87	0.076
Dependent variable PCR of year t			
Constant	74.714	44.26	0.000
International roughness index (in/mi) in year t(1 if less than 95, 0 otherwise)	8.104	2.69	0.014
Rutting depth (in) in year t (1 if less than 0.1, 0 otherwise)	11.103	3.51	0.002
Dependent variable RUT of year t			
Constant	0.202	5.31	0.000
Rutting depth (in) in year t-1	1.052	43.76	0.000
High average temperature from October to March in year t (°F)	-0.004	-5.14	0.000
Cost overrun (percentage)	-0.027	-2.01	0.057
System Weighted MSE	1.0002		
Degrees of freedom	63		
Number of Observation	25.000		
System Weighted R-square	0.9726		

Table 5.6.11 Descriptive statistics of the Performance-Based contracting with Structural 3R/4R PVM replacement treatments

Variable Description	Mean	Std. Deviation	Min	Max
Dependent variable IRI of year t				
International roughness index (in/mi) in year t-1	90.097	36.169	42.00	161.00
Contract final cost (per miles and per years)	133,113.9	281,933	294.2	1,413,872.3
Cost savings (percentage)	0.087	0.083	-0.08	0.25
Time delay	0.012	0.324	-0.61	0.48
Dependent variable PCR of year t				
Rutting depth (in) in year t (1 if less than 0.1, 0 otherwise)	0.387	0.495	0.00	1.00
Truck volume (trucks per day)	5227.289	5701.000	38.18	16682.90
High average temperature from October to March in year t (°F)	49.123	2.589	41.23	53.25
Dependent variable RUT of year t				
Rutting depth (in) in year t-1	0.122	0.071	0.01	0.28
Truck volume (trucks per day)	5227.289	5701.000	38.18	16682.90
Number of lanes (1 if less than 3, 0 otherwise)	0.806	0.402	0.00	1.00

Table 5.6.12 3SLS model estimation of pavement indicators for Performance-Based contracting with Structural 3R/4R PVM replacement treatments

Variable Description	**Coefficient**	**t-stat**	**p value**
Dependent variable IRI of year t			
Constant	-5.966	-1.85	0.075
International roughness index (in/mi) in year t-1	1.085	35.27	0.000
Contract final cost (per miles and per years)	0.001	5.78	0.000
Cost savings *(percentage)*	49.413	3.32	0.003
Time delay	8.747	2.41	0.024
Dependent variable PCR of year t			
Rutting depth (in) in year t (1 if less than 0.1, 0 otherwise)	5.172	2.51	0.018
Truck volume (trucks per day)	-0.001	-3.89	0.001
High average temperature from October to March in year t (°F)	1.730	52.31	0.000
Dependent variable RUT of year t			
Constant	0.022	2.58	0.016
Rutting depth (in) in year t-1	1.172	29.44	0.000
Truck volume (trucks per day)	0.001	2.14	0.042
Number of lanes (1 if less than 3, 0 otherwise)	-0.027	-3.95	0.001
System Weighted MSE	1.002		
Degrees of freedom	81		
Number of Observation	31		
System Weighted R-square	0.9899		

5.6.1 Estimation Results of 3SLS PBC Models: Functional and Structural Treatments

This section provides a discussion of the key findings with regard to the model estimation results of the PBC with functional and structural treatments models.

Traffic characteristics: Tables 5.6.2, 5.6.4, 5.6.8, 5.6.10, 5.6.12 show that higher truck volume is found to reduce the PCR. These findings are in line with past research (Anastasopoulos and Mannering, 2014, Sarwar, 2016) and possibly reflect the effect of the increased trucks' loads on the pavement condition.

Pavement characteristic: Tables 5.6.4 and 5.6.12 show that segments with 2 or fewer lanes have higher PCR and lower rutting depth, possibly picking up the effect of lower truck loadings that are expected in such lowere traffic volume roads (as opposed to multi-lane roadways).

With regard to the time lagged pavement condition variables, the IRI and the rutting depth of the previous year (*t-1*) are found to significantly affect the same pavement condition indicators in the analysis year, *t*. For the structural treatments, poor pavement performance (as indicated by higher values of the IRI and rutting depth) in the previous year, *t-1*, results in pavement deterioration in the analysis year *t*.

In this model, the endogenous rutting depth variable is found to be statistically significant determinant of the PCR. Tables 5.6.2, 5.6.4, 5.6.8, 5.6.10, and 5.6.12 show that the greater the rutting depth value or the IRI value are, the greater the PCR will be. These results are in line with the findings of Sarwar (2016), that rutting depth has a strong impact on the PCR.

Weather characteristics: Tables 5.6.2 and 5.6.6 show that higher temperature during months with anticipated adverse weather (October through March) are associated with an increase for the PCR. Intuitively, higher temperatures during these months is found to decrease the rutting depth. This finding can be explained by the fact that higher temperature during this period may decrease the impact of possible snow accumulation on pavements, especially in areas with significamt snowfall during the winter period.

5.6.2 Model evaluation for PBC: Functional and Structural treatments

In terms of goodness-of-fit measures, the 3SLS model has an overall good statistical fit, as indicated by the system weighted R^2 (0.992, 0.995, 0.995, 0.989, 0.972, and 0.990, for functional and structural treatments, as shown in Tables 5.6.2, 5.6.4, 5.6.8, 5.6.10 and 5.6.12, respectively). Note that all the explanatory parameters of the 3SLS model are statistically significant at a 0.90 level of confidence. To further evaluate the forecasting accuracy of the 3SLS model, the mean absolute percentage error (MAPE) is computed. Table 5.6.13 shows that the observed values are under- or over-estimated by the predicted values by 9.72 percent on average. Figures 5.6.1 through 5.6.16 presented the observed versus the model predicted values.

Table 5.6.13 MAPE of the 3SLS models of the pavement indicators for the Performance-Based contracting with all rehabilitation treatments

Dependent variables	**Treatment type**	**MAPE**
International Roughness Index (in/mi)	2 course HMA	0.293
Pavement Condition Rating (scale 0 to 100)		0.064
Rutting depth (inches)		0.098
International Roughness Index (in/mi)	Concrete PVM restoration	0.054
Pavement Condition Rating (scale 0 to 100)		0.093
Rutting depth (inches)		0.053
International Roughness Index (in/mi)	3course HMA overlay with or without surface milling	0.048
Pavement Condition Rating (scale 0 to 100)		0.066
Rutting depth (inches)		0.156
International Roughness Index (in/mi)	3course HMA with crack and seat of PCC PVM	0.065
Pavement Condition Rating (scale 0 to 100)		0.037
Rutting depth (inches)		0.074
International Roughness Index (in/mi)	3R&4R overlay treatments	0.233
Pavement Condition Rating (scale 0 to 100)		0.069
Rutting depth (inches)		0.081
International Roughness Index (in/mi)	3R/4R PVM replacement treatments	0.054
Pavement Condition Rating (scale 0 to 100)		0.059
Rutting depth (inches)		0.153

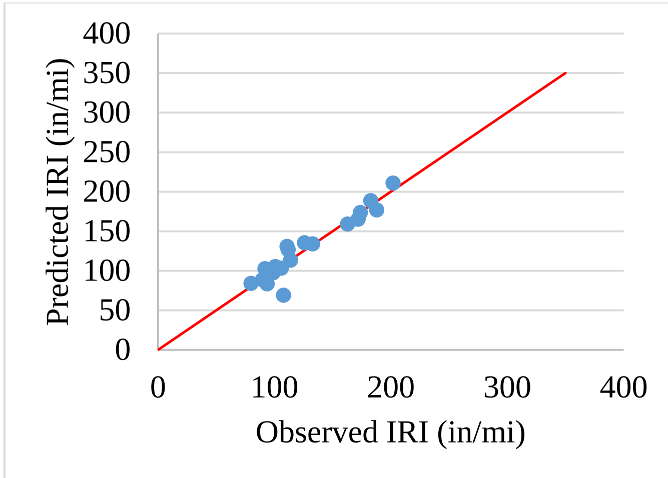

Figure 5.6.1 Predicted and observed values of IRI for PBC with 2-course HMA treatment.

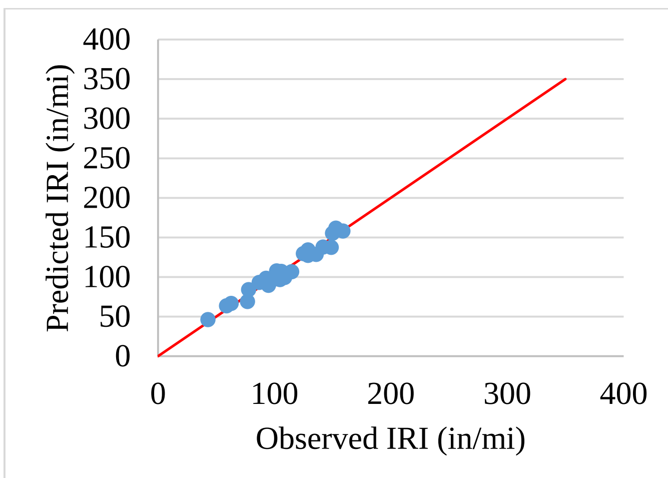

Figure 5.6.2 Predicted and observed values of IRI for PBC with Concrete PVM restoration.

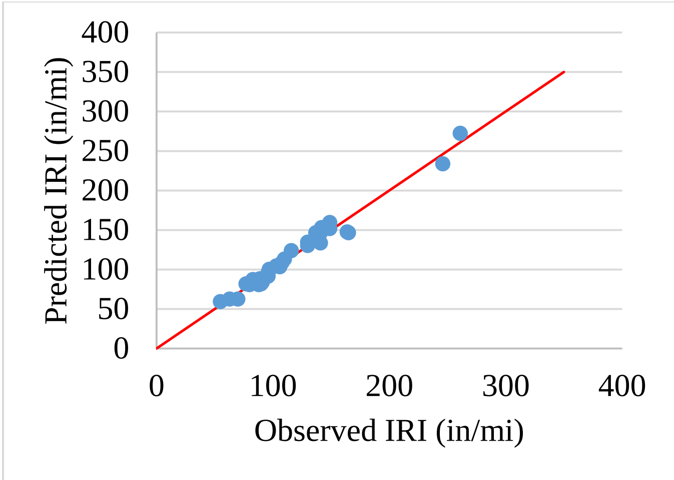

Figure 5.6.3 Predicted and observed values of IRI for PBC with 3-course HMA overlay with or without surface milling.

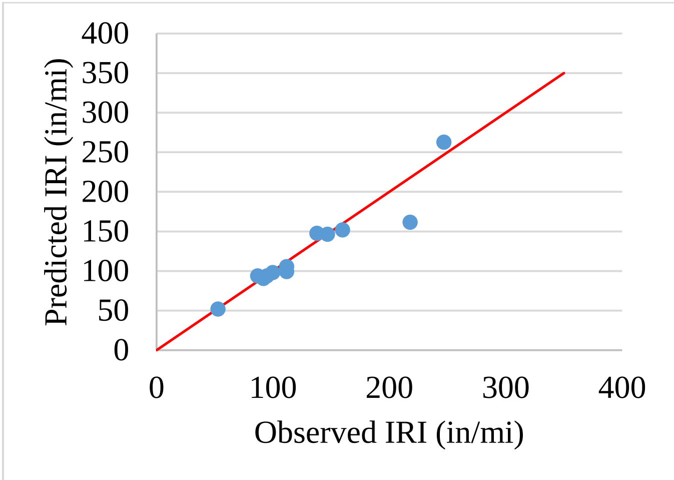

Figure 5.6.4 Predicted and observed values of IRI for PBC with 3-course HMA with crack and seat of PCC PVM.

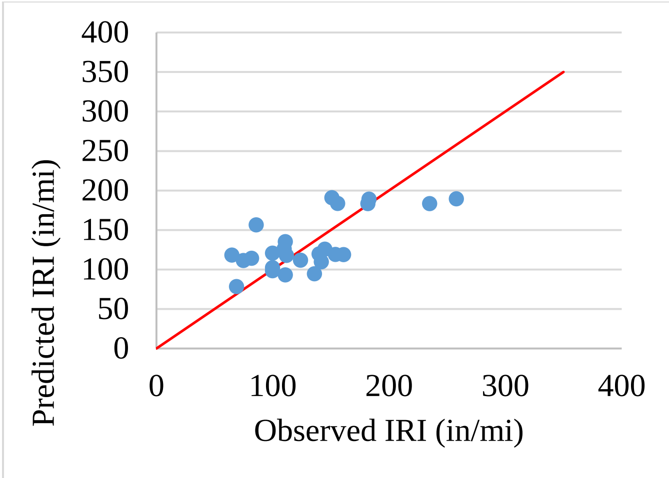

Figure 5.6.5 Predicted and observed values of IRI for PBC with 3R&4R overlay treatments.

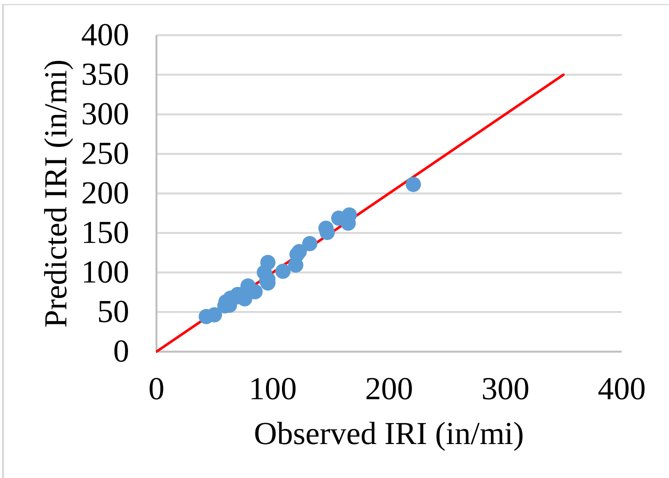

Figure 5.6.6 Predicted and observed values of IRI for PBC PPP type with 3R/4R PVM replacement treatments.

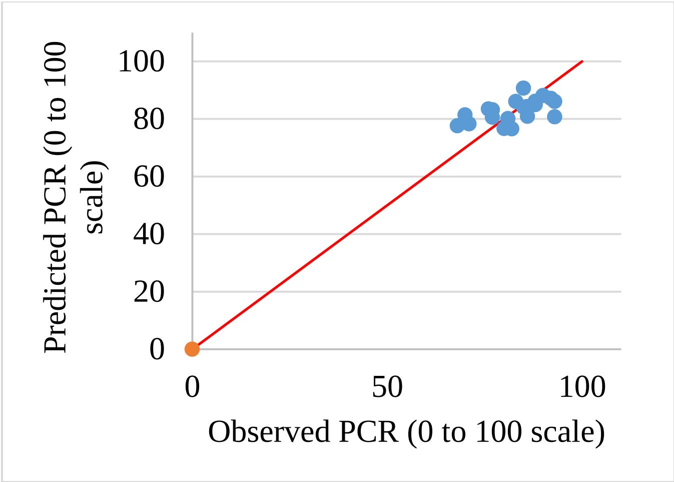

Figure 5.6.7 Predicted and observed values of PCR for PBC with 2-course HMA treatment

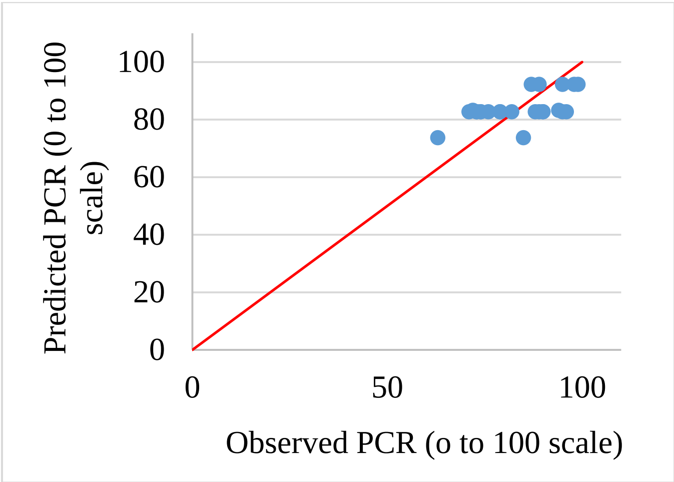

Figure 5.6.8 Predicted and observed values of PCR for PBC PPP type with Concrete PVM restoration.

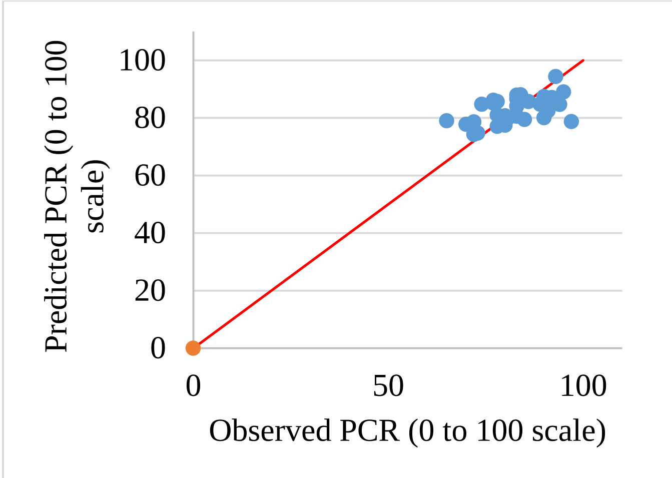

Figure 5.6.9 Predicted and observed values of PCR for PBC with 3-course HMA overlay with or without surface milling.

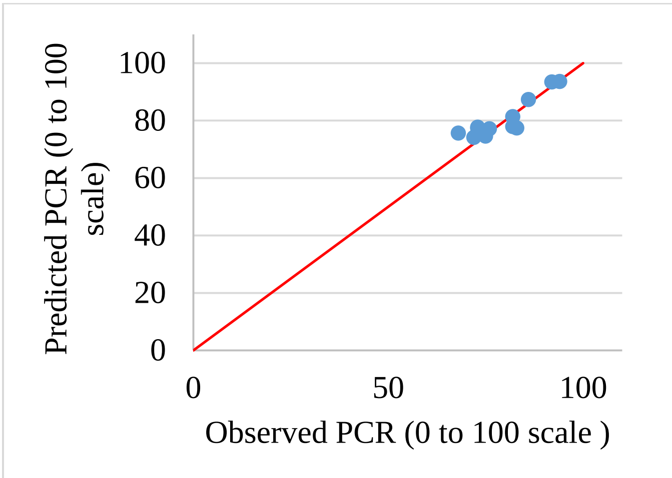

Figure 5.6.10 Predicted and observed values of PCR for PBC with 3-course HMA with crack and seat of PCC PVM.

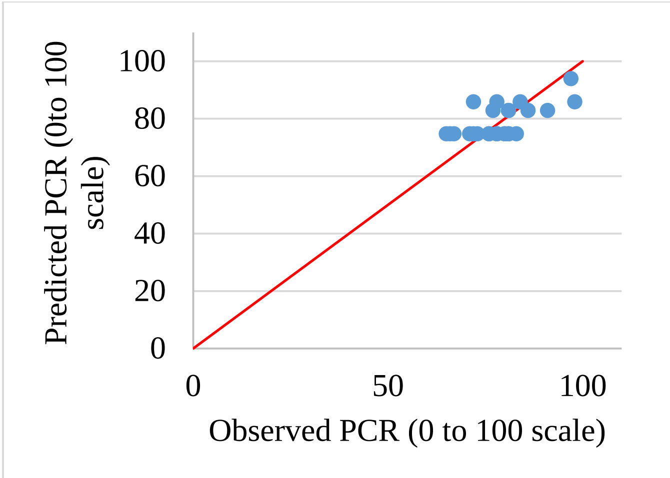

Figure 5.6.11 Predicted and observed values of PCR for PBC with 3R&4R overlay treatments.

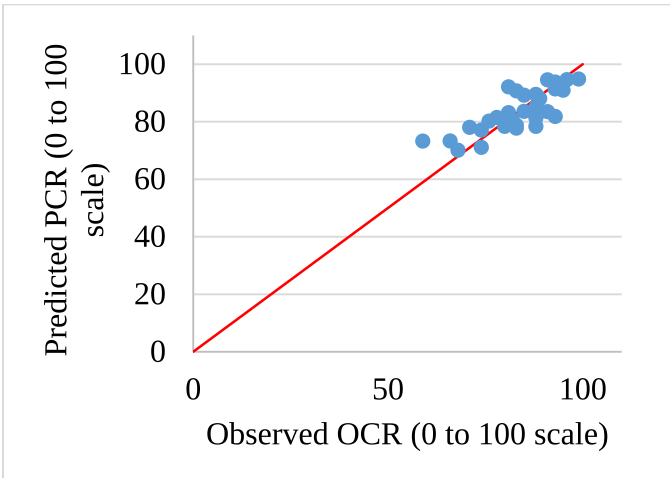

Figure 5.6.12 Predicted and observed value of PCR for PBC with 3R/4R PVM replacement treatments.

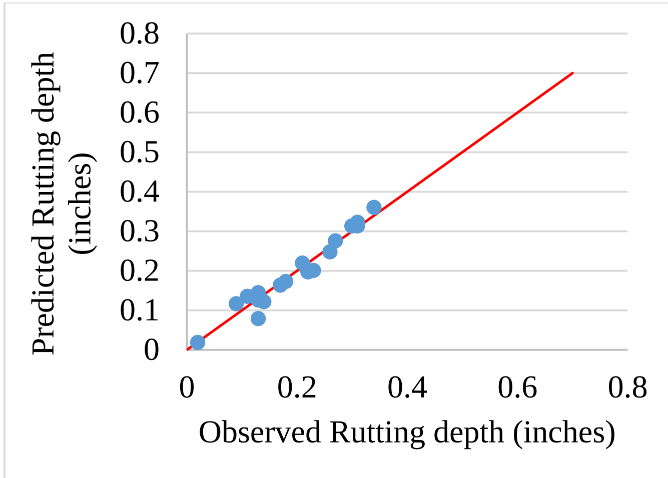

Figure 5.6.13 Predicted and observed values of rutting depth for PBC with 2 course HMA treatment

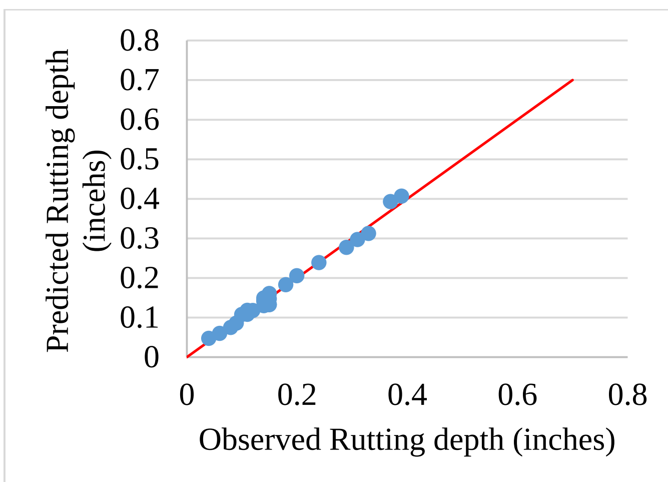

Figure 5.6.14 Predicted and observed value of rutting depth for PBC PPP type with Concrete PVM restoration

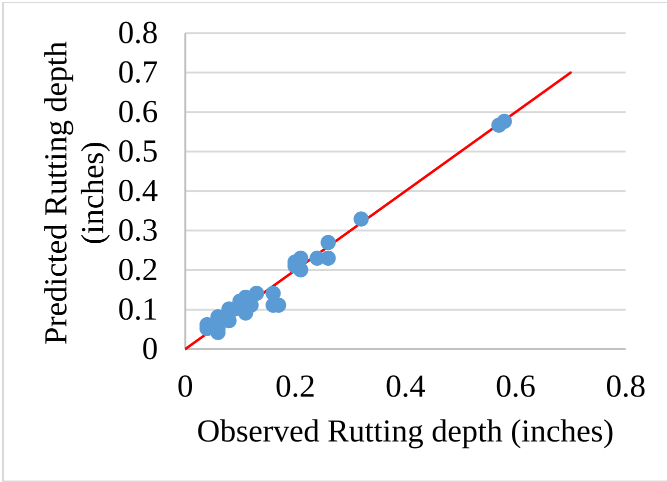

Figure 5.6.15 Predicted and observed values of rutting depth for PBC with 3-course HMA overlay with or without surface milling.

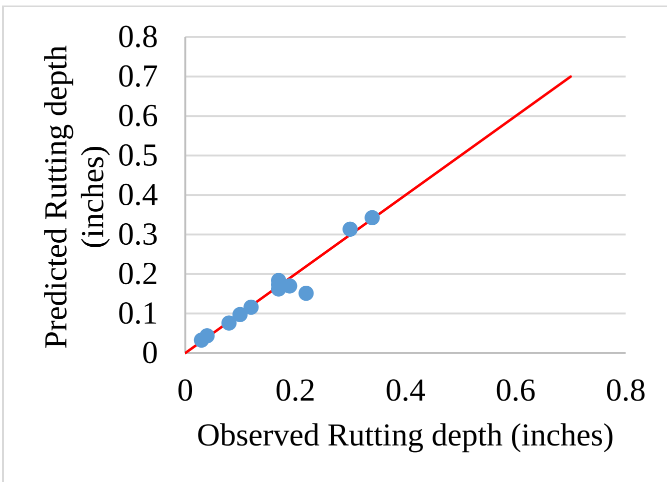

Figure 5.6.16 Predicted and observed values of rutting depth for PBC with 3-course HMA with crack and seat of PCC PVM.

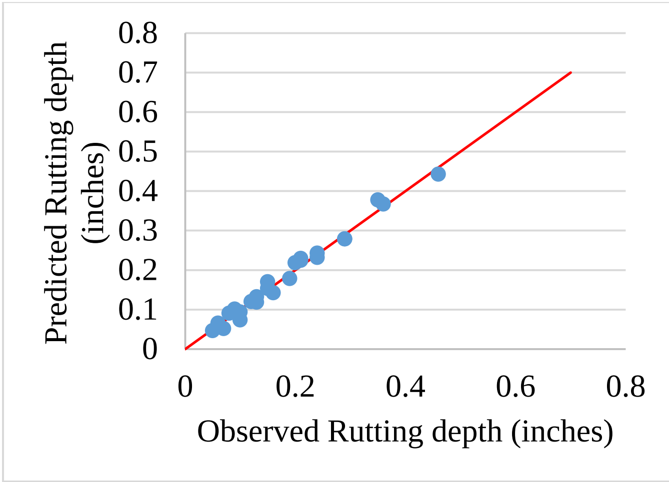

Figure 5.6.17 Predicted and observed values of rutting depth for PBC with 3R&4R overlay treatments.

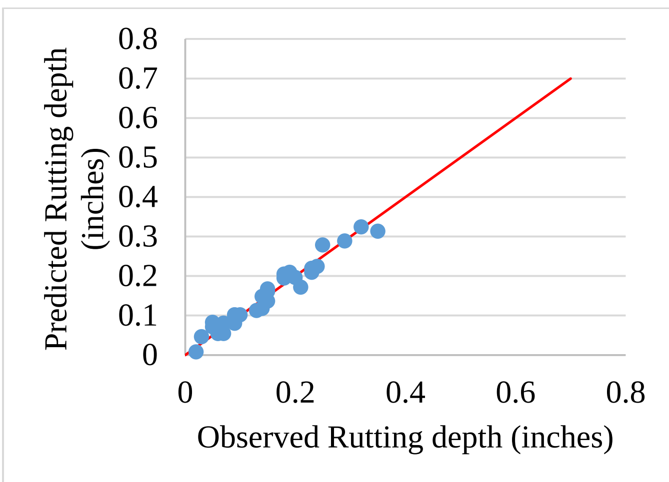

Figure 5.6.18 Predicted and observed values of rutting depth for PBC PPP type with 3R&4R overlay treatments.

5.6.3 Hazard Based Duration Models of PBCs' Pavement Service Life

Tables 5.6.14 and 5.6.15 present the hazard-based duration estimation results of the PBC with 2-course HMA, concrete pavement restoration, 3-course HMA overlay with or without surface milling, 3-course HMA with crack and seat of PCC pavement, 3R&4R overlay, and 3R/4R PVM replacement treatments models, respectively models, respectively, followed by a discussion of key findings.

Table 5.6.14 Estimation of the pavement service life using Hazard –Based Duration models with Performance-Based contracting and 2-course HMA and Concrete PVM restoration.

	Functional Treatment			
	Weibull with fixed parameters		Log Logistic	
	2-course HMA		Concrete PVM restoration	
Variable	Parameter	t-stat	Parameter	t-stat
Constant	2.427	12.00	4.073	17.56
Base (right after rehabilitation) IRI (in/mi)	—	—	-0.023	-9.29
Base (right after rehabilitation) RUT (in)	-4.705	-4.30	—	—
Truck Volume (in 10,000 of vehicles per day)	—	—	-0.679	-5.87
Cost overrun (percentage)	—	—	0.899	2.27
P	1.78	5.62	7.17	5.35
LL(0)	-18.1		-19.3	
LL(β)	-12.6		-1.2	
McFadden pseudo R^2	0.14		0.68	
Number of observations	18		22	

Table 5.6.15 Estimation of the pavement service life using Hazard –Based Duration models with Performance-Based contracting and Structural treatments (3-course HMA overlay with or without surface milling, 3-course HMA with crack and seat of PCC PVM, 3R & 4R overlay treatments and 3R/4R PVM replacement treatments)

	Structural Treatment							
	Log Logistic		Log Logistic		Log Logistic		Weibull with fixed parameters	
	3-course HMA overlay with or without surface milling		3-course HMA with crack and seat of PCC PVM		3R & 4R overlay treatments		3R/4R PVM replacement treatments	
Variable	Parameter	t-stat	Parameter	t-stat	Parameter	t-stat	Parameter	t-stat
Constant	1.869	4.49	3.018	6.61	—	—	3.361	18.56
Base (right after rehabilitation) IRI (in/mi)	—	—	—	—	—	—	-0.011	-5.70
Base (right after rehabilitation) RUT (in)	-4.511	-2.40	-7.830	-2.45	-7.605	-9.92	-5.924	-5.32
Truck Volume (trucks per day, log value)	0.123	1.68	—	—	—	—	—	—
Truck Volume (1 if less than 200 trucks per day, 0 otherwise)	—	—	-0.000	-1.86	—	—	—	—
Truck Volume (in 10,000 of vehicles per day)	—	—	—	—	—	—	-0.255	-2.26
Number of lanes (1 if greater than 3, 0 otherwise)	—	—	—	—	—	—	-0.492	-3.24
Road class(1 if it is Rural, 0 otherwise)	—	—	—	—	—	—	0.291	2.05

	Structural Treatment							
	Log Logistic		Log Logistic		Log Logistic		Weibull with fixed parameters	
	3-course HMA overlay with or without surface milling		3-course HMA with crack and seat of PCC PVM		3R & 4R overlay treatments		3R/4R PVM replacement treatments	
Variable	Parameter	t-stat	Parameter	t-stat	Parameter	t-stat	Parameter	t-stat
Average temperature from October to March in year t (°F)	—	—	—	—	0.067	26.14	—	—
Cost saving (percentage)	—	—	—	—	-1.357	-2.14	—	—
P	4.07	5.93	4.31	3.52	6.80	4.58	5.39	4.65
LL(0)	-23.9		-11.2		-19.3		-37.0	
LL(β)	-17.0		-5.9		-1.5		-9.0	
McFadden pseudo R^2	0.12		0.11		0.72		0.57	
Number of observations	28		11		22		31	

The log-logistic distribution yielded the best statistical fit for the concrete pavement restoration, 3-course HMA overlay with or without surface milling, 3-course HMA with crack and seat of PCC pavement, and 3R&4R overlay treatments models; while the Weibull distribution provided the best fit for the 2-course HMA, and 3R/4R pavement replacement treatments models. In terms of parameter interpretation, a negative sign of a parameter estimate shows a decrease of the pavement life, and a positive sign indicates an increase in the pavement life.

For the 2-course HMA model, high base rutting depth results in shorter pavement service life. The Weibull model parameter P is statistically different from zero and positive, indicating a monotonically increasing function; the hazard function implies that as times passes, the remaining pavement service life is more likely to end soon.

For the concrete pavement restoration model, high base IRI and high truck volume are found to decrease the pavement service life. On the other hand, high cost overrun increases the pavement service life. Also, the parameter P is positive, which indicates that the hazard increases in duration from zero to an inflection point and decreases toward zero afterwards.

For the 3-course HMA overlay with or without surface milling model, high base rutting depth decreases the pavement service life. The parameter P is positive which indicates a hazard increasing in duration from zero to an inflection point and decreasing toward zero afterwards.

For the 3-course HMA with crack and seat of PCC pavement model, high base rutting depth and high truck volume, both reduce the pavement service life. The Weibull parameter P is statistically different from zero and positive.

For the 3R&4R overlay treatments model, high base rutting depth and high cost savings are found to decrease the pavement service life; whereas, high average temperature during adverse weather months (October through March) in year *t*, is found to increase the pavement service life.

For the 3R/4R PVM replacement treatment model, high base rutting depth, high IRI, high truck volume, and segments with more than three lanes are associated with shorter pavement service life. The Weibull model parameter P is again positive and statistically different from zero, which again implies a monotonically increasing hazard function.

5.7 Estimation Results of Warranty Models

Tables 5.7.1 through 5.7.11 present desricptive statistics, model estimation results, and MAPE values for warranty contracts with 2-course HMA, concrete pavement restoration, 3-course HMA with crack and seat of PCC pavement, 3R&4R overlay, and 3R/4R PVM replacement treatments models, respectively. Figures 5.7.1 through 5.7.15, plot the observed and predicted values for these models.

Table 5.7.1 Descriptive statistics for Warranties with 2-course HMA treatment

Variable Description	Mean	Std. Dev.	Min	Max
Dependent variable IRI of year t				
International roughness index (in/mi) in year t-1	102.769	41.885	41.00	182.00
Average precipitation from October to March in year t (inches)	3.281	0.455	2.63	3.99
Median (1 if median with a barrier, 0 otherwise)	0.615	0.506	0.00	1.00
Road system (1 if Non-Interstate and not a National Highway System, 0 otherwise)	0.692	0.480	0.00	1.00
Truck volume (trucks per day per lanes)	1012.975	2131	30.10	7925.05
Dependent variable PCR of year t				
International roughness index (in/mi) in year t	122.615	32.694	74.00	200.00
Change of orders	3.923	1.382	2.00	6.00
Dependent variable RUT of year t				
Rutting depth (in) in year t-1	0.183	0.104	0.04	0.38
Cost overrun (percentage)	0.314	0.240	0.00	0.82

Table 5.7.2 3SLS model estimation of pavement indicators for Warranty with 2-course HMA treatment

Variable Description	Coefficient	t-stat	p value
Dependent variable IRI of year t			
Constant	-62.280	-4.85	0.002
International roughness index (in/mi) in year t-1	0.730	18.48	0.000
Average precipitation from October to March in year t (inches)	25.542	8.01	0.000
Median (1 if median with a barrier, 0 otherwise)	9.605	3.48	0.010
Road system (1 if Non-Interstate and not a National Highway System, 0 otherwise)	27.557	7.50	0.000
Truck volume (trucks per day per lanes)	0.002	3.01	0.020
Dependent variable PCR of year t			
Constant	96.397	25.53	0.000
International roughness index (in/mi) in year t	-0.240	-7.75	0.000
Change of orders	3.894	6.40	0.000
Dependent variable RUT of year t			
Rutting depth (in) in year t-1	1.211	31.87	0.000
Cost overrun (percentage)	0.041	2.75	0.019
System Weighted MSE	1.026		
Degrees of freedom	29.000		
Number of Observation	13		
System Weighted R-square	0.983		

Table 5.7.3 Descriptive statistics for Warranties with Concrete PVM restoration

Variable Description	Mean	Std. Dev.	Min	Max
Dependent variable IRI of year t				
International roughness index (in/mi) in year t-1	102.974	34.920	53.00	238.00
Truck Volume (trucks per day)	2735.705	6825	28.13	46053.02
International roughness index (in/mi) Base	91.961	36.218	46.00	229.00
Drainage(1 if somewhat, poorly, or very poorly drained, 0 otherwise)	0.461	0.502	0.00	1.00
Dependent variable PCR of year t				
Rutting depth (in) in year t (1 if less than 0.105, 0 otherwise)	0.316	0.468	0.00	1.00
Truck Volume (trucks per day)	2735.705	6825	28.13	46053.02
Dependent variable RUT of year t				
Rutting depth (in) in year t-1	0.126	0.077	0.02	0.48
Annual average daily traffic (vehicles per day)	16233.720	32108	541	140407
Rutting depth (in) Base	0.108	0.070	0.01	0.47

Table 5.7.4 3SLS model estimation of pavement indicators for Warranty with Concrete PVM restoration

Variable Description	Coefficient	t-stat	p value
Dependent variable IRI of year t			
International roughness index (in/mi) in year t-1	0.307	5.49	0.000
Truck Volume (trucks per day)	0.001	3.59	0.001
International roughness index (in/mi) Base	0.834	14.58	0.000
Drainage(1 if somewhat, poorly, or very poorly drained, 0 otherwise)	6.092	2.34	0.022
Dependent variable PCR of year t			
Constant	81.252	59.58	0.000
Rutting depth (in) in year t (1 if less than 0.105, 0 otherwise)	6.276	2.85	0.006
Truck Volume(in 1,000 of vehicles per day)	-0.280	-1.77	0.081
Dependent variable RUT of year t			
Rutting depth (in) in year t-1	0.384	4.28	0.000
Truck Volume (in 1,000 of vehicles per day)	0.002	2.04	0.045
Rutting depth (in) Base	0.924	10.25	0.000
System Weighted MSE	1.0097		
Degrees of freedom	217		
Number of Observation	76		
System Weighted R-square	0.8949		

Table 5.7.5 Descriptive statistics for Warranties 3-course HMA with crack and seat of PCC PVM.

Variable Description	**Mean**	**Std. Dev.**	**Min**	**Max**
Dependent variable IRI of year t				
International roughness index (in/mi) in year t-1	114.222	43.228	46.00	226.00
Contract final cost (per miles and per years)	43,789.7	63,128.0	1,204.0	232,644.8
Average temperature from October to March in year t (°F)	43.300	5.060	38.97	60.40
Change of orders	5.556	2.595	1.00	11.00
Dependent variable PCR of year t				
Rutting depth (in) in year t	0.214	0.138	0.06	0.60
Cost saving (percentage)	-0.051	0.129	-0.24	0.18
Dependent variable RUT of year t				
Rutting depth (in) in year t-1	0.172	0.107	0.02	0.42
Outside shoulder width (inches)	7.111	4.767	0.00	15.10

Table 5.7.6 3SLS model estimation of pavement indicators for Warranty with 3-course HMA with crack and seat of PCC PVM.

Variable Description	Coefficient	t-stat	p value
Dependent variable IRI of year t			
Constant	-43.584	-7.80	0.000
International roughness index (in/mi) in year t-1	1.186	84.75	0.000
Contract final cost (per miles and per years)	1.000	9.69	0.000
Average temperature from October to March in year t (°F)	0.499	4.04	0.001
Change of orders	1.597	6.77	0.000
Dependent variable PCR of year t			
Constant	89.195	89.19	0.000
Rutting depth (in) in year t	-36.910	-36.91	0.019
Cost saving (percentage)	31.878	31.88	0.050
Dependent variable RUT of year t			
Rutting depth (in) in year t-1	1.337	49.51	0.000
Outside shoulder width (inches)	-0.003	-5.05	0.000
System Weighted MSE	1.0344		
Degrees of freedom	44		
Number of Observation	18		
System Weighted R-square	0.9944		

Table 5.7.7 Descriptive statistics for Warranties with 3R & 4R overlay treatments.

Variable Description	Mean	Std. Dev.	Min	Max
Dependent variable IRI of year t				
International roughness index (in/mi) in year t-1	106.389	52.292	54	294
Contract final cost (per miles and per years)	138,607.1	377,932.0	400.9	1,602,040.0
Outside shoulder width (inches)	11.761	3.718	4.7	16.6
Dependent variable PCR of year t				
Rutting depth (in) in year t (1 if less than 0.1, 0 otherwise)	0.222	0.428	0	1
Dependent variable RUT of year t				
Rutting depth (in) in year t-1	0.133	0.079	0.02	0.31
Drainage(1 if somewhat, poorly, or very poorly drained, 0 otherwise)	0.500	0.515	0	1

Table 5.7.8 3SLS model estimation of pavement indicators for Warranty with 3R & 4R overlay treatments.

Variable Description	Coefficient	t-stat	p value
Dependent variable IRI of year t			
International roughness index (in/mi) in year t-1	0.984	72.99	0.000
Contract final cost (per miles and per years)	0.001	4.09	0.001
Outside shoulder width (inches)	0.743	5.87	0.000
Dependent variable PCR of year t			
Constant	76.894	40.98	0.000
Rutting depth (in) in year t (1 if less than 0.1, 0 otherwise)	9.160	2.35	0.032
Dependent variable RUT of year t			
Rutting depth (in) in year t-1	1.077	22.85	0.000
Drainage(1 if somewhat, poorly, or very poorly drained, 0 otherwise)	0.030	2.99	0.009
System Weighted MSE	1		
Degrees of freedom	47		
Number of Observation	18		
System Weighted R-square	0.9976		

Table 5.7.9 Descriptive statistics for Warranties with 3R/4R PVM replacement treatments

Variable Description	**Mean**	**Std. Dev.**	**Min**	**Max**
Dependent variable IRI of year t				
International roughness index (in/mi) in year t-1	99.548	46.996	54.00	279.00
Truck Volume (trucks per day)	4224.43	4351	12.97	14234.84
Outside shoulder width (inches)	10.406	3.821	2.90	15.90
Dependent variable PCR of year t				
Rutting depth (in) in year t (1 if greater than 0.25, 0 otherwise)	0.161	0.374	0.00	1.00
Contract final cost (per miles and per years)	169,179	346,303	347.99	1,785,689
Outside shoulder width (inches)	10.406	3.821	2.90	15.90
State (1 if Indiana, 0 otherwise)	0.774	0.425	0.00	1.00
Dependent variable RUT of year t				
Rutting depth (in) in year t-1	0.142	0.092	0.04	0.38
Low average temperature from October to March in year t (°F)	30.977	1.752	28.15	36.89

Table 5.7.10 3SLS model estimation of pavement indicators for Warranty with Structural 3R/4R PVM replacement treatments

Variable Description	Coefficient	t-stat	p value
Dependent variable IRI of year t			
International roughness index (in/mi) in year t-1	1.033	40.50	0.000
Truck Volume (trucks per day)	0.001	2.10	0.045
Outside shoulder width (inches)	0.559	2.33	0.027
Dependent variable PCR of year t			
Constant	97.444	24.56	0.000
Rutting depth (in) in year t (1 if greater than 0.25, 0 otherwise)	-4.255	-1.76	0.091
Truck Volume (trucks per day)	-0.001	-4.25	0.000
Contract final cost per miles and per years	0.001	4.78	0.000
Outside shoulder width (inches)	-0.902	-3.56	0.002
State (1 if Indiana, 0 otherwise)	-4.946	-2.35	0.027
Dependent variable RUT of year t			
Constant	0.178	2.37	0.025
Rutting depth (in) in year t-1	1.005	21.70	0.000
Low average temperature from October to March in year t (°F)	-0.005	-2.11	0.044
System Weighted MSE	1.0001		
Degrees of freedom	81		
Number of Observation	31		
System Weighted R-square	0.9891		

5.7.1 Estimation results of 3SLS Warranty Models: Functional and Structural treatments

This section provides key findings with regard to the model estimation results for the warranty contracts with 2-course HMA, concrete pavement restoration, 3-course HMA with crack and seat of PCC pavement, 3R&4R overlay, and 3R/4R PVM replacement treatments models.

<u>Traffic characteristics:</u> Tables 5.7.2, 5.7.4 and 5.7.10 show that higher truck volume decreases the PCR, for all functional and structural treatments. This finding is in line with past research (Anastasopoulos and Mannering, 2014; Sarwar, 2016) and possibly reflects the effect of larger truck loadings on the pavement condition.

<u>Pavement characteristic:</u> Tables 5.7.4 and 5.7.8 show that poorly drained pavements have higher IRI. With regard to the time lagged pavement condition variables, the IRI and the rutting depth of the previous year (*t-1*) are found to significantly affect the same pavement condition indicators in the analysis year, *t*. For the structural treatments, poor pavement performance (as indicated by higher values of the IRI and rutting depth) in year *t-1* results in pavement deterioration in the analysis year *t*.

The endogenous rutting depth variable is found to be a statistically significant determinant of the PCR. Particularly, Tables 5.6.2, 5.6.4, 5.6.8, 5.6.10, and 5.6.12 show that the higher the rutting depth or the IRI value are, the higher the PCR will be. These results are supported by the findings of Sarwar (2016), in that the IRI and rutting depth have strong impact in the determination of the PCR.

Weather characteristics: Table 5.7.10 shows that high temperature during adverse weather months (October through March) results in a decrease of the rutting depth. This finding can be explained by the fact that higher temperatures during this period may decrease the impact of possible snow accumulation on pavement condition, especially in areas with significamt snowfall during the winter period. In a similar fashion, low average temperature is associated with higher PCR value, and higher average precipitation results in higher rutting depth.

5.7.2 Model evaluation for Warranties: Functional and Structural treatments

In terms of goodness-of-fit measures, the 3SLS model has an overall good statistical fit, as indicated by the system weighted R^2 presented in Tables 5.7.2, 5.7.4, 5.7.8, and 5.7.10 (0.983, 0.895, 0.994, 0.998, and 0.989, respectively). To further evaluate the accuracy of the model, the mean absolute percentage error (MAPE) was computed. Table 5.7.11 shows that the observed values are under- or over-estimated by the predictors by 9.4 percent on average. Figures 5.7.1 through 5.7.15 plot the observed versus the predicted values for these models.

Table 5.7.11 MAPE for Warranties PPP type with functional and structural treatments

Dependent variables	**Treatment type**	**MAPE**
International Roughness Index (in/mi)	2 course HMA	0.045
Pavement Condition Rating (scale 0 to 100)		0.059
Rutting depth (inches)		0.192
International Roughness Index (in/mi)	3course HMA overlay with or without surface milling	0.081
Pavement Condition Rating (scale 0 to 100)		0.093
Rutting depth (inches)		0.180
International Roughness Index (in/mi)	3course HMA with crack and seat of PCC PVM	0.040
Pavement Condition Rating (scale 0 to 100)		0.082
Rutting depth (inches)		0.153
International Roughness Index (in/mi)	3R&4R overlay treatments	0.029
Pavement Condition Rating (scale 0 to 100)		0.059
Rutting depth (inches)		0.169
International Roughness Index (in/mi)	3R/4R PVM replacement treatments	0.063
Pavement Condition Rating (scale 0 to 100)		0.042
Rutting depth (inches)		0.118

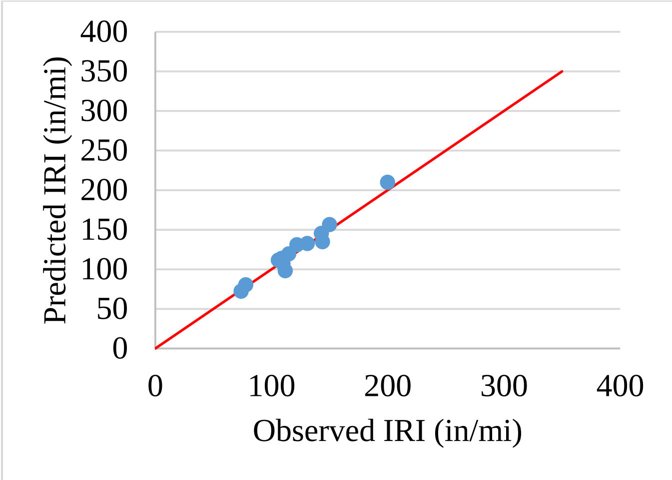

Figure 5.7.1 Predicted and observed values of IRI for Warranties with 2-course HMA treatment.

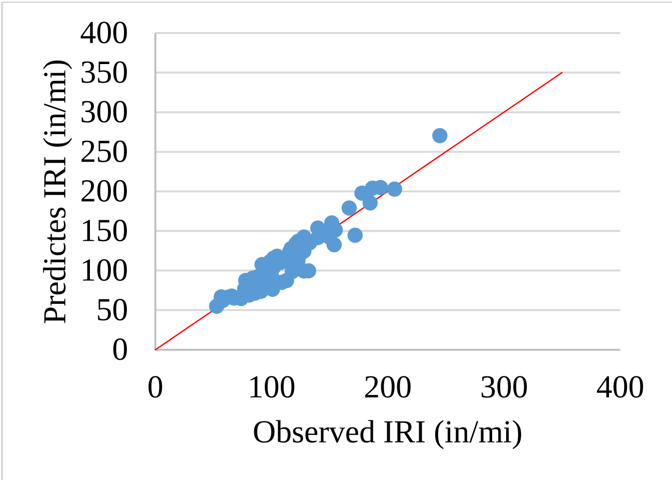

Figure 5.7.2 Predicted and observed values of IRI for Warranties with 3-course HMA overlay with or without surface milling.

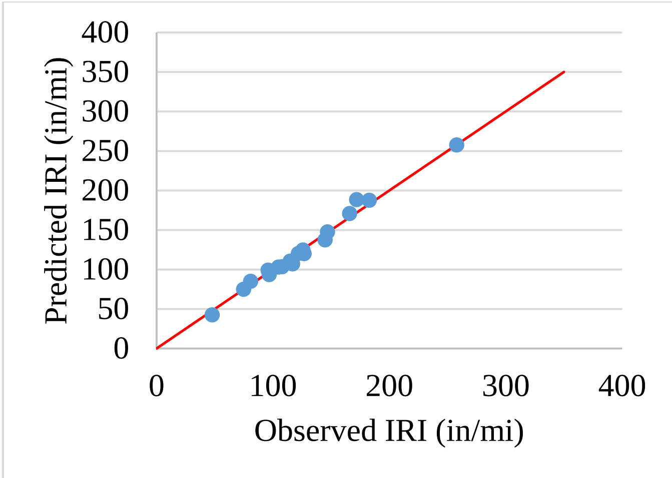

Figure 5.7.3 Predicted and observed value of IRI for Warranties with 3-course HMA with crack and seat of PCC PVM.

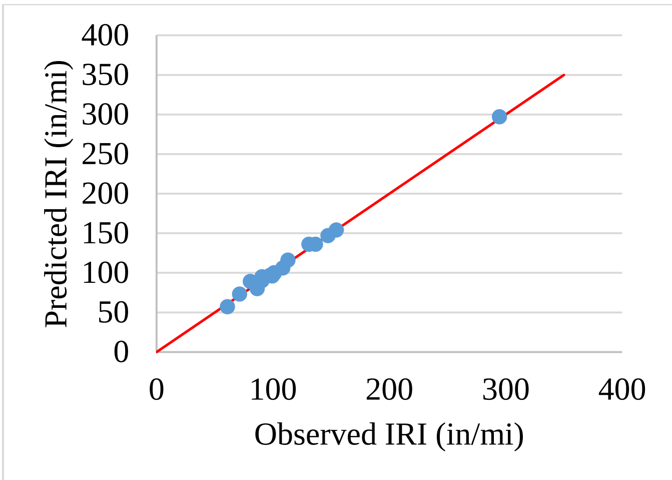

Figure 5.7.4 Predicted and observed values of IRI for Warranties with 3R&4R overlay treatment.

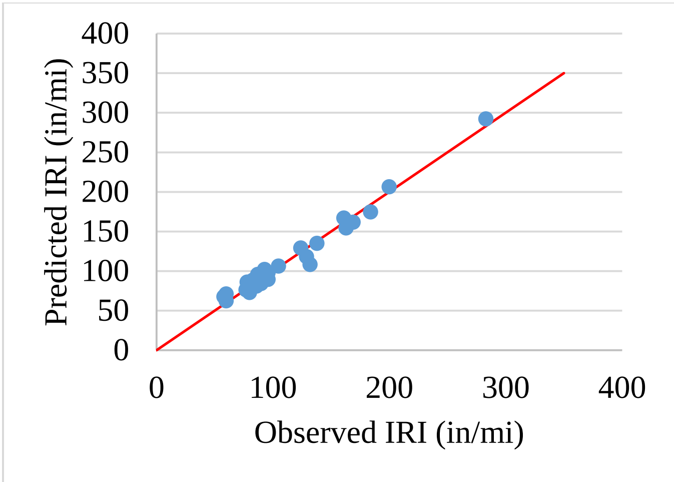

Figure 5.7.5 Predicted and observed values of IRI for Warranties with 3R/4R PVM replacement treatment.

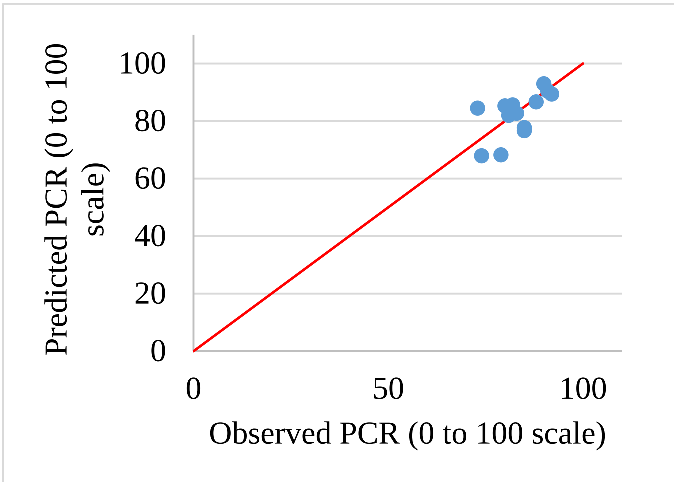

Figure 5.7.6 Predicted and observed values of PCR for Warranties with 2 course HMA treatment.

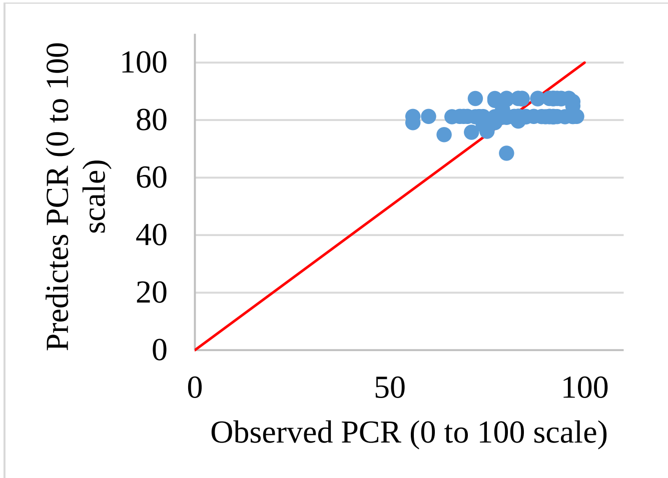

Figure 5.7.7 Predicted and observed values of PCR for Warranties with 3-course HMA overlay with or without surface milling.

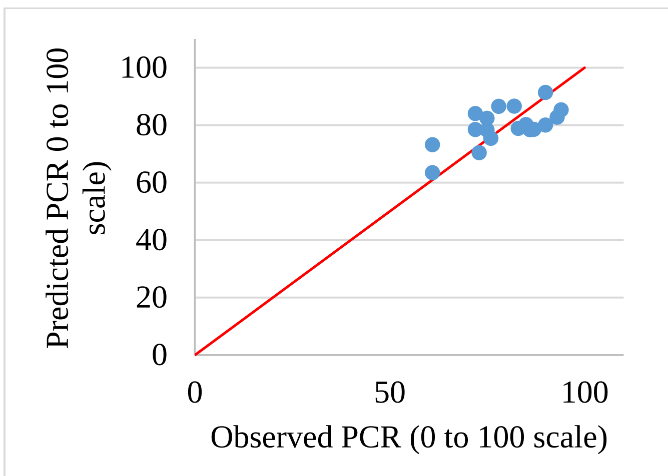

Figure 5.7.8 Predicted and observed values of PCR for Warranties with 3-course HMA with crack and seat of PCC PVM.

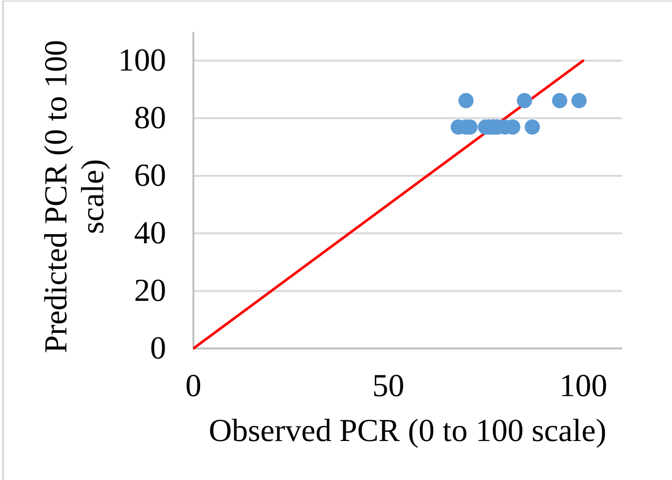

Figure 5.7.9 Predicted and observed values of PCR for Warranties with 3R&4R overlay treatments.

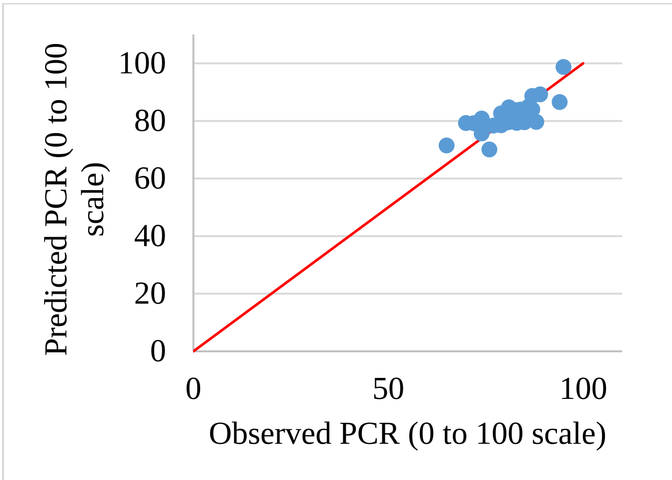

Figure 5.7.10 Predicted and observed values of PCR for Warranties with 3R/4R PVM replacement treatments.

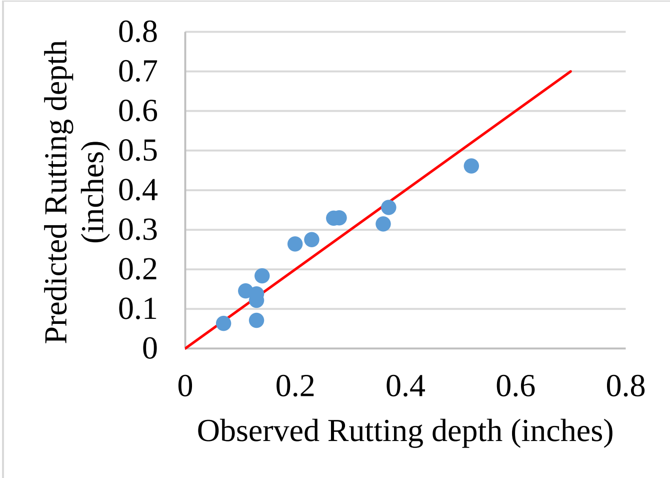

Figure 5.7.11 Predicted and observed values of rutting depth for Warranties with 2 course HMA treatment.

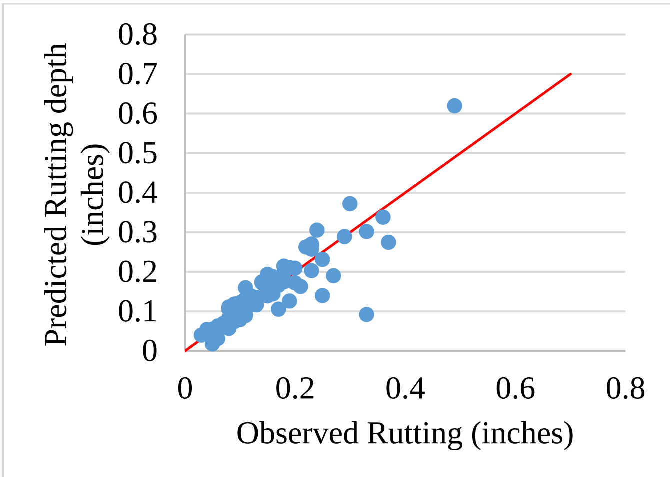

Figure 5.7.12 Predicted and observed values of rutting depth for Warranties PPP type with 3-course HMA overlay with or without surface milling.

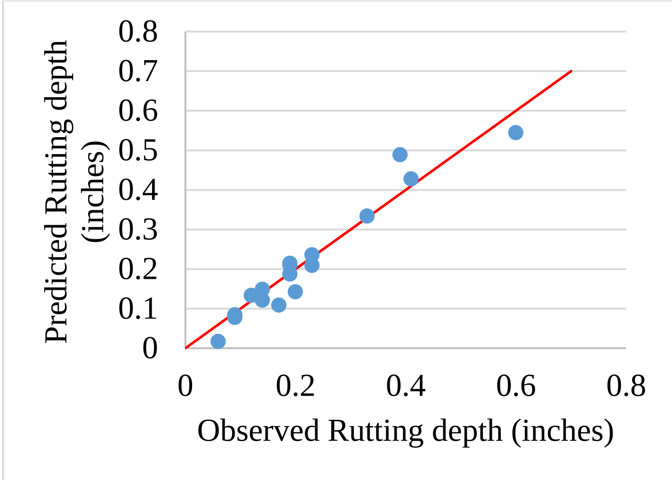

Figure 5.7.13 Predicted and observed values of rutting depth for Warranties with 3-course HMA with crack and seat of PCC PVM.

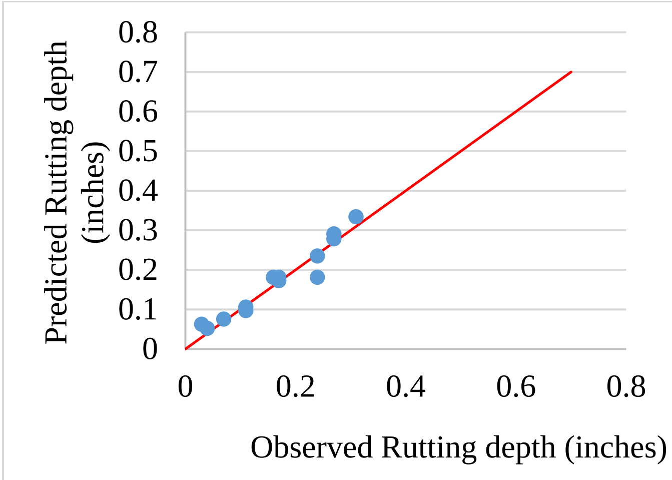

Figure 5.7.14 Predicted and observed values of rutting depth for Warranties with 3R&4R overlay treatments.

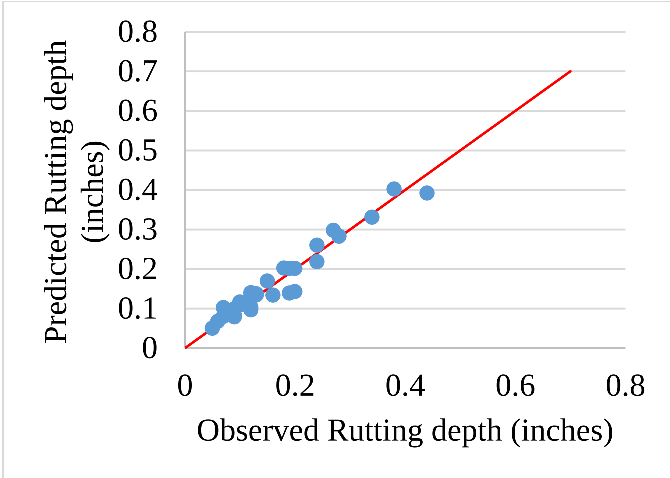

Figure 5.7.15 Predicted and observed values of rutting depth for Warranties with 3R/4R PVM replacement treatments.

5.7.3 Hazard Based Duration Models of Warranties' Pavement Service Life

Table 5.7.12 presents the hazard-based duration estimation results of the warranty contracts with 2-course HMA, concrete pavement restoration, 3-course HMA with crack and seat of PCC pavement, 3R&4R overlay, and 3R/4R PVM replacement treatments models, followed by a discussion of key findings.

Table 5.7.12 Estimation of the pavement service life using Hazard –Based Duration models with Warranty and 2-course HMA and 3-course HMA with crack and seat of PCC PVM

	Functional Treatments		Structural Treatments					
	Log Logistic		Weibull with fixed parameters		Weibull with fixed parameters		Weibull with fixed parameters	
	2-course HMA		3-course HMA with crack and seat of PCC PVM		3R & 4R overlay treatments		3R/4R PVM replacement treatments	
Variable	Parameter	t-stat	Parameter	t-stat	Parameter	t-stat	Parameter	t-stat
Constant	2.052	7.64	3.413	7.32	3.387	20.38	3.312	17.73
Base (right after rehabilitation) IRI (in/mi)	—	—	-0.015	-3.53	—	—	-0.015	-5.96
Base (right after rehabilitation) RUT (in)	-6.103	-3.24	—	—	-6.452	-6.50	-2.064	-2.24
Number of lanes (1 if greater than 3, 0 otherwise)	-0.696	-3.85	—	—	—	—	—	—
Truck Volume (1 if less than 200 trucks per day, 0 otherwise)	—	—	0.001	2.48	—	—	—	—
Contract final cost (per miles and per years, in millions of dollar)	—	—	—	—	-0.980	-2.59	—	—
Drainage(1 if somewhat, poorly, or very poorly drained, 0 otherwise)	—	—	—	—	-0.902	-7.16	—	—
Road class(1 if it is Rural, 0 otherwise)	—	—	—	—	—	—	0.291	3.03
Truck Volume (in 10,000 of vehicles per day)	—	—	—	—	—	—	-0.244	-2.42

	Functional Treatments		Structural Treatments					
	Log Logistic		Weibull with fixed parameters		Weibull with fixed parameters		Weibull with fixed parameters	
	2-course HMA		3-course HMA with crack and seat of PCC PVM		3R & 4R overlay treatments		3R/4R PVM replacement treatments	
Variable	Parameter	t-stat	Parameter	t-stat	Parameter	t-stat	Parameter	t-stat
P	7.04	3.32	3.00	3.15	4.59	3.91	4.68	4.56
LL(0)	-8.2		-10.9		-17.8		-22.1	
LL(β)	-0.5		-6.5		-0.6		-2.5	
McFadden pseudo R^2	0.45		0.04		0.69		0.61	
Number of observations	11		14		17		29	

The log-logistic distribution yielded the best statistical fit for the 2-course HMA model; while the Weibull model provided the best fit for the 3R&4R overlay treatments, for the 3R/4R pavement replacement, and for the 3-course HMA with crack and seat of PCC pavement models. In terms of parameter interpretation, a negative sign of a parameter estimate shows a decrease of the pavement life, and a positive sign indicates an increase in the pavement life.

For the 2-course HMA, it is shown that high base rutting depth and roadways with more than two lanes are associated with shorter pavement service life. The parameter P is positive, which indicates a hazard function increasing in duration from zero to an inflection point and decreasing toward zero afterwards.

For the 3-course HMA with crack and seat of PCC pavement model, high base IRI is found to decrease the pavement service life, whereas low truck volume results in longer duration of the pavement service life. The Weibull model parameter P is statistically different from zero and positive, indicating a monotonically increasing function. The form of the hazard function implies that as time is passing, the more likely it is for the pavement life to end soon.

For the 3R&4R overlay treatments model, high base rutting depth, high contract final cost, and generally poor drainage conditions (somewhat poor, poor or very poor drained segments) decrease the pavement service life.

For the 3R/4R PVM replacement treatment model, high base rutting depth, high base IRI, and high truck volume, are all associated with shorter pavement service life. On the contrary, rural roadways are found to be associated with longer pavement service life.

Finally, the Weibull model parameter P is statistically different from zero and positive, indicating a monotonically increasing function; thus, as time passes, the pavement life is more likely to end soon.

5.8 Chapter Summary

This Chapter presented the model estimation results for the 3SLS models of pavement performance – using IRI, rutting depth, and PCR as pavement condition indicators – and for the hazard-based duration models of pavement service life. Due to data limitations, several treatment types needed to be combined in functional or structural treatment groups. However, the model results are consistent with the literature, and show that a variety of traffic, pavement, and weather characteristics play in both pavement performance, and in the duration of pavement service life.

CHAPTER 6 CONCLUSION

6. 1 Summary and Contribution of this study

Using big data informatics methods, the intent of this study was to conduct a detailed statistical assessment of pavement rehabilitation treatments. More specifically, the following treatments were investigated: 2-course hot-mix asphalt (HMA) overlay, concrete pavement restoration, 3-course HMA overlay with or without surface milling, 3-course HMA overlay with crack and seat of PCC pavement, 3-R (resurfacing, restoration and rehabilitation) and 4-R (resurfacing, restoration, rehabilitation and reconstruction) overlay treatments, and 3-R/4-R pavement replacement treatments. The analysis was conducted by various PPP approaches: performance-based contracting (PBC), cost-plus-time contracting (A+B), incentives/disincentives (I/D), design-build-operate-maintain (DBOM), warranties (WARR), and lane-rentals (LR). All combinations of treatment and PPP approach were evaluated, in terms of pavement performance indicators (International roughness index, Rutting Depth and Pavement Condition Rating) and in terms of extending their pavement service lives. To better model and forecast pavement performance, a three-stage least squares (3SLS) approach was employed. For the pavement service life, the elapsed time until the pavement crosses a literature-based threshold (identified in Sarwar, 2016) was investigated, using random parameters hazard-based duration models. The data included 812 pavement segments, of which 200 were from New York, 104 from Texas, 138 from Virginia, 195 from Indiana, 45 from Minnesota, 91 from Florida and 39 from Alaska. The model estimation results show that several influential factors, such as traffic characteristics, weather characteristics, pavement characteristics, and drainage condition, affect the pavement performance indicators and the pavement service life.

This study primarily contributes in a two-fold manner: through the use of a unique database, in order to investigate simultaneously various public private partnership and pavement rehabilitation treatment types. This is a first analysis of this kind, to the best of the author's knowledge.

6. 2 Key Findings and Insights

As mentioned earlier, the intent of this study is to model the performance of the pavement rehabilitation treatments by PPP type in terms of pavement indicators and extending pavement service lives. The 3SLS approach was used, for modeling pavement indicators. Concerning the estimation of the pavement service life, hazard-based duration models were estimated. Below are the key findings and insights from this Study:

- Pavement performane modeling with 3SLS: This system of equation approach allows to simultaneously consider multiple dependent variables. The dependent variables used in this Study are the international roughness index (IRI), rutting depth (RUT), and pavement condition rating (PCR). The three-stage least squares (3SLS) is used in this Study since it can take into account the cross-equation error correlation. For the three pavement condition indicators, pavement condition rating (PCR) is detected by a pavement engineer, who observed any distress on the pavement. The distress can be characterized by depression in the pavement or excessive roughness, since the PCR is a function of either the rutting depth, or the IRI, or of both. The data are available for six public-private partnership type: Performance-based contracting (PBC), Cost-plus, time contracting (A+B), Incentives/disincentives (I/D), design-build, operate-maintain (DBOM), Warranties (WARR) and Lane-rentals (LR); they are also available for six pavement rehabilitation treatments: 2-course HMA, Concrete pavement restoration, 3-course HMA overlay with or without surface milling, 3-course HMA with crack and seat of PCC pavement, 3R&4R overlay, and 3R/4R pavement replacement treatment. These are the most commonly used pavement rehabilitation treatments in the USA. Using those PPP types and pavement rehabilitation treatments, it was demonstrated that the pavement performance indicators are affected by traffic characteristics (AADT, truck traffic, etc), pavement characteristics (pavement indicators, pavement drainage), weather characteristics (temperature, precipitation) and other characteristics (road system).

- Pavement service life modeling with hazard-based duration models: The pavement service life can be defined as the time period between two consecutive rehabilitation treatments. To achieve an estimation of the pavement service life, which is the dependent variable, three parametric forms of the hazard-based duration model were explored: Weibull distribution (with fixed or random parameters), log-logistic, and Weibull with Gamma heterogeneity. The data were available for the same six public-private partnership types and six rehabilitatin types, as previously described. The results show that the pavement service life is affected by several factors, such as traffic characteristics, pavement characteristics, weather characteristics and other factors. For the traffic characteristics, the truck volume has a significant influence on the pavement service life for any type of treatment or PPP type, with higher truck volumes resulting in shorter pavement service life. For the pavement characteristics, two variables were found as statistically significant: the variables representing the pavement's drainage conditions, and number of lanes. Poor drainage was intuitively found to decrease the pavement service life. Similarly, multi-lane roadways – likely picking up high truck traffic – were also found to reduce pavement service life. The variables reflecing adverse weather conditions (in terms of adverse weather months – October through March – and temperature and precipitation) were intuitively found to reduce pavement service life. Other influential factors affecting the pavement service life included contract- and roadway-specific characteristics. As a last point, the endogenous variables representing the measurable pavement performance indicators (IRI and rutting depth) were also found to be statistically significant determinants of the PCR, in all estimated models.

6. 3 Directions for future Research

Even though the database used in this Study is unique and contains significant information about the PPP types and reahabilitation treatments, it was not built with the purpose of investigating pavement performance and pavement service life by PPP and rehabilitation treatment type. To that end, the database can be complimented with more s pavement-specific infomation, including sub-base materials for the pavement, and layer thickness, to name a few. Truck loading weights could also shed more light on the effect of truck traffic on pavement performance and service life. From a methodological point of view, unobserved heterogeneity was accounted for, but not to the pavement segment level in the 3SLS modeling. This is another extension of this work, which could reveal interesting findings, in terms of the variable effect of the factors affecting pavement performance.

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