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Framework of Performance-Based Contracting for Chip Seal and Striping Maintenance Activities

Kishor Shrestha
University of Nevada, Las Vegas, kishor.shrestha@unlv.edu

FRAMEWORK OF PERFORMANCE-BASED CONTRACTING FOR CHIP SEAL AND STRIPING MAINTENANCE ACTIVITIES

By

Kishor Shrestha

Bachelor in Civil Engineering
Tribhuvan University
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Master of Science – Construction Management
University of Nevada, Las Vegas
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The Graduate College

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Pramen P. Shrestha, Ph.D.
Examination Committee Chair

David R. Shields, Ph.D.
Examination Committee Member

Aly Said, Ph.D.
Examination Committee Member

Hualiang Teng, Ph.D.
Examination Committee Member

Neil Opfer, M.S.
Examination Committee Member

Ashok K. Singh, Ph.D.
Graduate College Faculty Representative

Kathryn Hausbeck Korgan, Ph.D.
Graduate College Interim Dean

Abstract

Framework of Performance-Based Contracting for Chip Seal and Striping Maintenance Activities

By

Kishor Shrestha, B.E., M.S.C.M.

Pramen P. Shrestha, Ph.D., Committee Chair

In the United States, there are more than four million miles of road network and new roads are being constructed every year. Most of the road networks were constructed more than two decades ago. Therefore, the age of the majority of the pavement inventory has exceeded original design life. This results in increased work load for the maintenance division of the state Departments of Transportation (DOTs). To maintain the road system, state DOTs use In-House or outsource maintenance works to private contractors using Method Based Contracting (MBC), or Performance Based Contracting (PBC), or any combination of these three. Literature reviews shows that outsourcing the road maintenance works are increasing every year and some transportation agencies are moving from using MBC to PBC due to various reasons—to improve quality of asset condition, to save cost considering life-cycle cost analysis, to transfer risk to the contractor, to improve road users satisfaction level, etc. To execute the PBC, which is a comparatively newer method, the state DOTs are facing problems identifying implementation issues. Therefore, it is important to prepare a framework for the implementation of PBC method. In this dissertation, two important road maintenance activities, chip seal and striping, were selected to develop the framework. The primary contribution of this dissertation was to develop the framework to guide the transportation agencies to execute the chip seal and striping using performance-based specification. This will help state DOT engineers effectively implement the PBC for chip seal and striping. The framework consists of three phases—contract document preparation, contract procurement, and contract implementation. All the three phases consisted of detailed investigation of works to be considered in the implementation of the chip seal and striping. The framework is developed by conducting a Delphi study with state DOT maintenance engineers and academicians. This dissertation also provides some recommendations for future study so that PBC can be successfully implemented in all road maintenance works.

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Dedication

I would like to dedicate my dissertation work to my lovely wife Geeta Shrestha and my son Aayush Shrestha, who constantly encouraged me to learn more and drive to the success. I would also like to dedicate this work to my late mother Ram Devi Shrestha, father Gokul Das Shrestha, and my sister Rachana Shrestha. I appreciate for their supports.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

AADT	Average Annual Daily Traffic
ADT	Average Daily Traffic
ADOT	Arizona Department of Transportation
AM	Asset Management
ANOVA	Analysis of Variances
CE	Cost Efficiency
CREMA	Contrato de recuperacion y mantenimiento
DCDPW	Washington, D.C. Department of Public Works
DOT	Department of Transportation
DRB	Dispute Review Board
ENR	Engineering New Record
ESALs	Equivalent Single Axle loads
ESDA	Exploratory Spatial data analysis
FDOT	Florida Department of Transportation
FHWA	Federal Highway and Administration
GPS	Global Positioning System
HH	High-High
HL	High-Low
INDOT	Indiana Department of Transportation
IRI	International Roughness Index
JLARC	Joint Legislative Audit and Review Commission
LCCA	Life Cycle Cost Analysis
LH	Low-High

LL	Low-Low
LOS	Level of Service
MB	Method Based
MBC	Method Based Contracting
MBS	Method Based Specification
MHD	Massachusetts Highway Department
MMS	Maintenance Management Reporting System
MQA	Maintenance Quality Assurance
MRP	Maintenance Rating Program
NAASRA	National Association of Australian State Roading Authorities
NCDOT	North Carolina Department of Transportation
NCHRP	National Cooperative Highway Research Program
NDOT	Nevada Department of Transportation
NHS	National Highway System
NJDOT	New Jersey Department of Transportation
NZTA	New Zealand Transportation Agency
OM	Office of Maintenance
PB	Performance Based
PBC	Performance Based Contracting
PBMC	Performance Based Maintenance Contract
PBRM	Performance Based Road Maintenance
PBRMC	Performance Based Road Maintenance Contract
PBS	Performance Based Specification
PCI	Pavement Condition Index
PMMR	Performance-Based contracts for the Maintenance and Management of Roads

PSMC	Performance Specified Maintenance Contract
QOS	Quality of Service
RFP	Request for Proposal
RM	Rehabilitation/Maintenance
RP	Relative performance
SP	Safety Procedures
SCDOT	South Carolina Department of Transportation
TA	Transportation Agency
TAMS	Trunkey Asset Maintenance Services
TOR	Timeliness of Response
TxDOT	Texas Department of Transportation
U.S.	The United States
UDOT	Utah Department of Transportation
VDOT	Virginia Department of Transportation

Chapter 1: Introduction

1.1 Background

The road network in the United States is shown in Figure 1.1. There were nearly 50,000-mile in the U.S. national highway system and more than four million miles of city and other public roadways (USDOT 2014, USDOT 2015). Except some lengths of the highway system, a majority of highways were constructed before two decades ago; and so life of the pavement were at the end of their design period (SAIC 2006). Therefore, the road maintenance work volume in the state DOT maintenance division is increasing every year (NCHRP 2003). The state DOTs basically use three road maintenance methods for their road network – In-House method, outsourcing under Method-Based Contracting (MBC), and outsourcing under Performance-Based Contracting (PBC).

Figure 1.1 National Highway System in the United States (FHWA 2015)

The selection of the methods depends on several factors. They were project site conditions, availability of skilled resources, cost effectiveness, requirement immediate response, scope of work, budget constraint, time constraint, time and schedule complexity, availability of long-term budget, risk transfer to the contractor, increased Level of Service (LOS), packaging of maintenance activities, size of projects, in duration of projects, and length of projects (Anastasopoulos et al. 2014, Anastasopoulos et al. 2010, NCHRP 2003, NCHRP 2009, Ribreau 2003, Zietlow 2004, and Zietsman 2004). With In-house method, state DOTs use their staff and equipment to maintain roads. Under this method, comparatively, state DOTs are free to plan and execute the maintenance projects because they use their own resources. Therefore, the In-house method is used for activities that demand a quick response, such as snow and ice removal. According to Anastasopoulos et al. (2010), NCHRP (2009), and Ribreau (2003) the In-house method is appropriate for bridge and tunnel maintenance, landscape works, shoulder maintenance, and debris and litter pick-up works.

The MBC method is a traditional outsourcing method, which uses the method based specification. In this specification, a contractor is bound for 'what to do', when to do', and 'how to do' works (Stankevich et al. 2009). The MBC method usually uses the 'Lowest-Bid Method' to select a contractor for public projects. According to the NCHRP (2003), most of the state DOTs use MBC method when the work scope is out of their capacity, there is lack of skilled workforce, and there are time constraints. The state DOTs pay the contractor based on the bid unit rate of activities and the measurement of the completed work.

The PBC method is comparatively a newer method, which was introduced in British Columbia, Canada in 1988 to maintain road systems and bridges (Zietlow 2004). The PBC method uses performance-based specification. Usually, the performance-based specification offers incentives and disincentives based on performance of the contractor (Popescu and Monismith 2006, Schexnayder and Ohrn 1997). Unlike in method-based specification, this method does not focus on the method of execution, but does focus on the performance or output of the work (Stankevich et al. 2009, SAIC 2006).

Most of the clients use 'Best-Value Method' or a 'Qualification-Based Process' for the selection of a contractor in the PBC method. Studies show various benefits of using PBC method: risk transfer to the contractor, availability of maintenance fund for longer duration (more than three years), an increased LOS, bundling of maintenance activities, less probability of cost overrun in large-sized projects, and cost-effectiveness (NCHRP 2003, NCHRP 2009, Ribreau 2003, Zietlow 2004, Anastasopoulos et al. 2014, Zietsman 2004). In this method, the contractor must deliver the minimum Level of Service (LOS) of the activities for the certain period of time (Anastasopoulos et al. 2014). The payment to the PBC contractor is tied with the target performance standards (Zietlow 2004), and payment is generally issued on a monthly basis; however, the payment is not issued necessarily in equal amounts for every month (Liautaud 2001).

To collect depth information regarding the use of road maintenance methods, a national questionnaire survey was conducted with state DOT maintenance engineers. This survey also identified the factors affecting the selection of the maintenance methods, collected satisfaction levels of state DOT engineers on using the maintenance methods, and collected lessons learned from using the methods. The state DOTs were using basically three types of road maintenance contracting methods—In-House, MBC, and PBC methods. Studies also showed that PBC method increased the LOS of the asset condition and achieved a cost saving up to 40% (NCHRP 2003).

In Nevada, to see whether the cost and quality (LOS) benefits of PBC existed, a cost and quality comparison study was conducted. For this comparison study, two maintenance activities were selected – chip seal and striping, which were extensively used by NDOT. Chip seal is commonly used as a preventive maintenance treatment and it is normally used in low volume roads (less than 3,000 AADT). For chip sealing, hot asphalt is sprayed over a prepared road surface, and then chips or aggregates is sprayed, followed by immediate compaction using pneumatic-tired rollers. Nevada DOT performs the chip seal work using two methods – In-house and outsourcing through private contractors under MBC method. Striping is a pavement marking line provided on the surface of roadways for road users for safe and efficient use of roads. Nevada DOT performs the striping work using three methods: In-house, and outsourcing through private contractors under MBC and PBC methods.

In order to compare cost of chip seal and striping works, historical cost data of these activities were collected from Nevada DOT maintenance and asset management division; then, life-cycle maintenance costs of these activities performed by In-house and private contractors were determined and compared. To compare the quality of the maintenance activities performed by the maintenance methods, an on-site investigation was carried out in various parts of Nevada. Then, their qualities were compared.

Finally, to execute the performance-based chip seal and striping, which is comparatively a newer method, it is very important to identify issues regarding the implementation of the PBC method. To identify the issues, a framework was developed using a Delphi study. The Delphi study was conducted with subject experts of state DOTs and academicians (Delphi study panel members) who have experience with PBC chip seal and striping. The Delphi study is a structured group communication, where panel members provide their views in multiple rounds, and their responses are kept anonymous (Linstone and Turoff 2002). In the Delphi study, the panel members were not obligated to get together physically for the communication and so, multiple rounds of survey were conducted to communicate with the panel members. Usually, the first round started with open ended questions to collect panel members' ideas. Based on the responses of the first round, a second round survey was developed and distributed. The survey is conducted until a required consensus is established, and then important issues are identified based on the panel members score given for each of the issues.

1.2 Dissertation Objectives

The primary objective of this dissertation is to develop a framework to implement chip seal and striping work using performance-based specification. The following tasks were performed to achieve the primary objective:

1. Conducted national survey to identify the best practices in performing road maintenance work;

2. Collected and analyzed cost data of In-house and private contractors performed chip seal and stripping;
3. Conducted site investigation to evaluate quality of In-house and private contractors-performed chip seal and stripping; and
4. Conducted Delphi study with state DOTs road maintenance engineers and academicians to identify the important issues related to various phases during implementation of PBC for chip seal and striping.

Chapter 2: Literature Review

Various literature review were conducted that were closely pertinent to this study. The literatures were divided into five sections – related to PBMC in new construction, PBMC in road maintenance, preparing specifications and bidding documents, performance-based maintenance contracts, and cost comparison among In-House, MBC, and PBC methods.

2.1 Out-Sourcing to Private Contractors

The literatures related to the new road construction with performance based specifications are summarized in Table 2.1.

Table 2.1. Summary of Literature Related to PBMC in New Construction

No.	Reference	State or Country	Major Findings
1	Ribreau (2003)	Washington State DOT (WSDOT)	The authors reviewed highway maintenance Out-Sourcing programs in five states in the United States and British Columbia of Canada. The study found that due to outsourcing, the maintenance costs were increased, and services were deteriorated in the majority of the states.
2	NCHRP (2003)	State DOTs	A survey results showed that the outsourcing in State DOTs in increasing. The main three reasons behind outsourcing a contract are policy issues of a state; workforce constraints; and the need for special knowledge, skills, and other resources for road maintenance.

Detailed Literature Review

2.1.1 WSDOT's Review of Highway Maintenance Outsourcing

Ribreau (2003) reviewed performances of outsourcing highway maintenance works in five states in the U.S. – Massachusetts, Virginia, Oklahoma, Texas, Florida – and in British Columbia, Canada. On the review of typical projects, it was found that the major problems of the outsourcing were increased costs, services deterioration, and inefficient administration and supervision. In Massachusetts, in the year 1992, a pilot project was undertaken for outsourcing a highway maintenance work; however, the contractor's performance was poor. The cost analysis performed was inadequate and caused the state of Massachusetts to lose over $1 million. In Virginia, a PBC of a 246-mile road maintenance project, estimated cost saving of $23 million was not supported by documentation.

Oklahoma Department of Transportation (ODOT) outsourced a 2,576 mile lane of highway for routine maintenance work with snow removal, and preparation was not done before outsourcing. Due to the payment issues, the contractor did not clear a 7-inch-thick snowstorm, and faced public criticism. In Texas, the contractor did not remove the ice for three years due to the payment issue. In addition, the contractor had a poor knowledge of materials and the contract was terminated. Florida Department of transportation (FDOT) gave a contractor a routine road maintenance contract for 15 years, in order to save cost by the reduction of the number of employees and the transfer of risks to private contractor. FDOT claimed that outsourcing saved $5.9 million in maintenance works. In the late years of the 1980s, British Columbia contracted highway maintenance work to the private sector. However, the maintenance cost increased from $15 to $29 million per year.

2.1.2 Out-sourcing Road Maintenance Contracts to Private-sector

NCHRP (2003) analyzed several studies, and suggested reasons for outsourcing road maintenance contracts in state DOTs. The study by NCHRP focused on the area of engineering, and design elements of road maintenance that were out-sourced. The NCHRP suggested three main reasons behind the outsourcing: policy issues of a state, workforce constraints; and the need for special knowledge, skills, and other resources for road maintenance.

A survey was conducted to determine the outsourcing trends in state DOTs. It showed that the practice of outsourcing increased, and continued to rise. In state DOTs, the outsourcing of four activities increased: roadway design, right-of-way maintenance, operations, and planning for road network. The result of the survey showed that the three main reasons of outsourcing were DOT lacked special skills and equipment for activities, it reduced the number of employees, and it was cost effective. The survey discovered that the staff constraints and specialty skills influenced the decision to choose outsourcing.

Legal requirements and cost comparisons were the least influential factors in outsourcing a contract for road maintenance.

2.2 Performance Based Specifications with Incentives/Disincentives (Pay Factors)

The literatures related to the new road construction with performance based specifications are summarized in Table 2.2.

Table 2.2. Summary of Literature Related to PBMC in New Construction

No.	Reference	State or Country	Major Findings
1	Popescu and Monismith (2006)	U.S.A.	Established pay factors for the construction of asphalt pavement using performance models for rutting and fatigue. The authors calculated the pay factors ranging from 0.50 to 1.20. However, the pay factor that was determined using the existing performance model, Caltrans, did not exceed 1.05.
2	Schexnayder and Ohrn (1997)	Arizona	Determined pay factors for three sections of roads constructed in Arizona using four different specifications of Federal Highway and Administration (FHWA) 85 and 92 versions, Arizona Department of Transportation (ADOT), and New Jersey Department of Transportation (NJDOT). The analysis showed that these four types of specifications resulted different pay factors for the same section of roads.

Detailed Literature Review

2.2.1 Pay Factors for the Construction of Asphalt Concrete Pavement

Popescu and Monismith (2006) conducted a study to determine the pay factors for new construction of asphalt concrete pavement that use two performance models, rutting and fatigue. The pay factors were defined as awarding incentives for superior quality of work and charging disincentives, or penalties, for inferior quality of work. Caltrans measured the performance of the constructed pavement based on the amount of pavement defects. However, this research suggested using the relative performance (RP) of the constructed asphalt concrete pavement. The RP was determined by taking a ratio of off-target traffic

(Equivalent Single Axle loads, ESALs) to target traffic (ESALs). The off-target traffic ESAL was determined by using a Simulator and WesTrack experiment based on fatigue and rutting. The pay factor was calculated based on combined RPs for fatigue and rutting failure of the pavement. The pay factor used in this research ranged from 0.50 to +1.30. However, Caltrans now is using a pay factor that does not exceed 1.05.

During calculation of the pay factor, the life-cycle cost analysis of the pavement also was conducted. To calculate the life-cycle cost, factors considered were the project's present cost value, the pavement-maintenance cost, one-time rehabilitation cost, inflation cost, and traffic increments. The authors prepared a chart of RPs and pay factors, from which the pay factor easily could be determined for any pavement based upon the RP values. The authors calculated the pay factors developed in this research with the existing Caltrans method to compare 80 pavement-construction projects. The analysis showed that, on average, the proposed method gave a higher payment than the existing Caltrans method.

2.2.2 The Use of Performance-Type Specifications for New Asphalt Concrete Pavement

In order to compare pay factors, Schexnayder and Ohrn (1997) examined the use of three performance-specifications for new pavement using asphalt concrete: Federal Highway Administration (FHWA) specification, Arizona Department of Transportation (ADOT), and New Jersey Department of Transportation (NJDOT). Case studies of three pavement-construction projects built in Arizona were used to determine these pay factors. The first project was constructed under the 1985 version of specifications from the FHWA (Standard 1985); the other two projects were constructed under the 1992 version of the FHWA specifications (Standard 1992). For purposes of comparison, the authors chose the specifications from ADOT and calculated pay factors because the project was constructed in Arizona. Further, they chose the specifications of the NJDOT because NJDOT is progressive in the field of performance-related specifications.

The FHWA specifications used three primary characteristics – asphalt content, gradation, and density – to calculate pay factors. However, ADOT used density and NJDOT used air voids and thickness of the asphalt pavement to calculate the pay factors. Based on the criteria, the pay factors were calculated for three sections of roads using four different specifications. The analysis indicates that there was no consistency in the calculation of the pay factors among these four types of specifications. For the first project, the ADOT specifications resulted the highest pay factor and the FHWA-92 specifications resulted the lowest pay factor. The FHWA specification resulted the highest pay factor for second and third projects. However, NJDOT had the lowest pay factors for these two projects. ADOT and NJDOT did not have any pay factor more than 1.0, which showed that they did not provide the contractors incentives if the quality of the constructed asphalt pavement was higher than the design standard.

2.3 Performance-Based Road Maintenance Contract (PBRMC)

The literatures related to the road maintenance with various types of specifications are summarized in Table 2.3.

Table 2.3. Summary of Literature Related to PBMC in Road Maintenance

No.	Reference	State or Country	Major Findings
1	Zietlow (2004)	Latin America	This study identified the advantages of the Performance-Based Contract (PBC) and differentiated this method from the traditional contracting method.
2	Hartwig et al. (2005)	Chad, Africa	One of the major reasons for poor road conditions in Chad was the use of Method-Based contracts. After the introduction of PBC, the condition of the roads became excellent and road users were highly satisfied with this method.
3	Baker (1999)	District of Columbia	In this study, a baseline survey was conducted to measure the quality of road maintenance activities before PBC was executed. Then the performance measures were prepared and the contractors' performance was measured.
4	Joint Legislative Audit and Review Commission (2001)	Virginia, U.S.A.	The commission found that an evaluation process of the contractor prepared by the Virginia Department of Transportation (VDOT), contained several errors. The cost analysis performed by VDOT was not supported by documentation.
5	Florida Department of Transportation (2007)	Florida, U.S.A.	This study prepared a guideline for a departmental process to execute asset maintenance using PBC method. It also prepared Maintenance Rating Programs.
6	Grandsberg et al. (2010)	New Zealand	The authors described types of PBCs used in road maintenance activities. The authors provided suggestions to make a PBC successful.
7	Anastasopoulos et al. (2010a)	Worldwide	This study determined the spatial and non-spatial average cost savings for a country when using a PBC method versus a traditional method. It also determined the mean and standard deviation of cost savings in the U.S., Europe, Africa, and worldwide.
8	McCullouch et al. (2009)	Indiana, U.S.A.	The author evaluated the feasibility of PBC, determined the cost savings, described reasons for using PBC method, and suggested lessons learned on using PBC.
9	Garza et al. (2009)	U.S.A.	The authors developed a framework to evaluate PBC in road maintenance activities. They focused their evaluation on key five performance measures of PBC.
10	Pinero (2003)	Virginia, U.S.A.	This study developed a conceptual framework to serve as a guideline to evaluate the effectiveness and efficiency of the PBC method. The author identified a statistically valid procedure to evaluate PBC and suggested the lessons learned from it.
11	Anastasopoulos et al. (2010b)	Various Countries	The authors presented a methodology to estimate the probability and dollar amount of cost savings using the PBC over the traditional contracts. The authors developed a model to compare PBC and other several contracting methods.
12	Liautaud (2004)	Argentina	The study collected lessons learned from PBC in road maintenance contract in Argentina. The Argentine government shifted away from traditional Input-Based contracts to Outcome-based contracts.
13	Menches et al. (2010)	Texas, U.S.A.	The authors developed a 'decision tree' to select an appropriate contracting method for road maintenance works. In addition, this study carried out 11 case studies and identified lessons learned from the termination of PBC projects.
14	Stankevich et al. (2009)	Washington, D.C.	This study differentiated PBC with the traditional contracting method and discussed two types of PBC.
15	Pakkala (2005)	Several countries	The authors mentioned that PBC were started in 1990. In PBC, five performance measures of a pavement were considered.
16	National Cooperative Highway Research Program (NCHRP, 2009)	Washington, D.C., U.S.A.	The authors described the reasons for using PBC. Some of the reasons for using PBC are cost effectiveness, improved LOS, and transfer of risk to the contractors.
17	Zietsman (2004)	Texas, U.S.A.	The author identified advantages and disadvantages of PBC. He also highlighted the issues to be considered while using PBC.
18	Gharaibeh et al. (2011)	Texas, USA	The authors developed performance standards, timeliness requirements, condition assessment procedures for PBC. They also developed a pay-adjustment formula for PBC.
19	The World Bank (2002)	Washington, D.C.	The study prepared a PBC specification for unpaved and paved roads. The specification consists of service quality standards, inspection criteria, and their timeliness. It also consists of Pay Reduction method for non-compliance of service-quality level requirements.
20	SAIC (2006)	U.S.A.	The study developed a framework for the performance-based rehabilitation works. The authors explained types of performance measurement, performance goal menu, and performance measurement process.
21	Ellevset (2001)	Chad, Africa	The author discuss about performance-based road contracting methods. The goal of PBC is to improve the LOS of road. The author set LOS for unpaved road-maintenance work activities and described key barriers of Chad PBC projects.
22	Berkland and Bell (2007)	South Carolina, U.S.A.	Studied about PBC to suggest improvement of the current maintenance contracting process of South Carolina DOT (SCDOT). This study also examined the shift from MBC to PBC.

Detailed Literature Review

2.3.1 Implementing Performance-Based Road Management and Maintenance Contracts in Developing Countries - An Instrument of German Technical Cooperation

A synthesis study conducted by Zietlow (2004) differentiated between traditional contracting methods and the PBMC method for road maintenance. Traditional contracting refers to the completion of a task as well as payment based on the bid price and a measured quantity. In contrast, PBMC deals with the minimum conditions of the assets that have to be satisfied by the contractor, no matter how the task is achieved. The author suggested four advantages of PBMC — it reduces agency costs, it offers transparency, and it increases asset conditions and road user satisfaction.

In addition, this study considered the performance measures and response times to rectify the defects (timeliness) as well as performance monitoring and payment procedures for maintenance items. The author suggested the following lessons learned from the study were: because the contract period in PBMC is usually longer than the traditional period, a secure financing throughout the contract period is necessary; pilot schemes are recommended for contracting road maintenance based on performance measures, which should be carefully scheduled and executed; whenever it is possible, performance contracts should be more than five years and should include periodic maintenance in order to gain greater benefits; well-qualified contractors and their supervisors are very important to making the PBMC approach a success; appropriate performance monitoring and price charges for not meeting target performance have proven that they are important to success of the project as well; it was recommended that performance measures should be developed further; and performance contracts might not produce cost savings immediately.

2.3.2 Output-based aid in Chad using performance-based contracts to improve roads

Hartwig et al. (2005) studied the reasons behind poor road conditions in Chad, Africa, and described experiences in using performance-based contracts. The authors who studied the road conditions and the government's road maintenance contracting methods were consultants in the Africa Transport Department of the World Bank.

However, since 1994, all of Chad's roads have been contracted out by means of outsourcing, and the results for road conditions have been poor. According to this study, the reason for poor road conditions in that country have been because they used traditional method-based contracting, by which contractors were paid on the basis of the execution of contract items; therefore, in order to receive large payments, contractors focused only on the huge items. Some huge-quantity works were completed; however, other important items necessary to keep the overall road conditions good were left undone due to the contractors' lack of interest.

After getting unsatisfactory results from the traditional contracting method, the Chad government launched a pilot project based on Performance-Based contracts for the Maintenance and Management of Roads (PMMR). This contract added to the contractors' role and responsibilities the maintenance and management the overall condition of the road for a long time. Normally, the PMMR contract was awarded by means of competition; added to this was a fixed amount of monthly payment per kilometer to maintain a specified condition. To maintain good road conditions, four criteria were assumed: pass-ability (road must be opened), average speed attainable, user comfort, and durability (long-term sustainability). In the long term, the PMMR contract saved money and created incentives for the efficient work performed.

For monitoring purposes, the PMMR contract used two mechanisms. First, the contractor conducted internal monitored and prepared monthly reports that were submitted with a monthly invoice to the government office. Second, a third-party consultant checked the contractor's monitoring report by means of monthly inspections. If the contractor failed to maintain the road conditions, a fixed-dollar amount was deducted from the billed invoice; if that failure was repeated, then the contract could be suspended.

The authors also provided some lessons learned from the output-based contracts: to save money, assign less ambitious targets for the road maintenance; a reliable source of funds for PMMR contracting gave more confidence to the contractor; for performance-based contracts, the road conditions should not be extremely bad; if the initial rehabilitation cost is over 40% to 45% of the total cost of the contract, it was suggested to rehabilitate first and then go to a PMMR contract; and to award PMMR contracts to the better-quality providers, pre-qualification was recommended.

2.3.3 Asset Preservation Plan for the District of Columbia National Highway System

Baker Jr. (1999) conducted a study to maintain and preserve highway assets in the District of Columbia. A management company was hired by the District of Columbia Department of Public Works (DCDPW) and the Federal Highway Administration (FHWA to maintain and preserve approximately 75 miles of the National Highway System (NHS) and streets. The company maintained and preserved most of features of the roads, e.g., pavement surface, shoulders, drains, sidewalk, median, and guardrails, etc. These assets were categorized into 14 categories, and maintenance activities conducted by the company were identified for each category.

Before the contractor started maintaining the roads, a baseline survey was conducted to assess the condition of road assets of the National Highway System and streets. This baseline survey was prepared with the help of a field-walk survey and DCDPW assets records. For major assets, a sample of the asset was inspected and then statistical methods were used to represent the population. All the assets were categorized into three sub-categories; the assets that met the performance standards were categorized as ‘Good’; those that did not meet the standard were categorized as ‘Poor’; and those that were marginal were categorized as ‘Fair’.

The performance measures of each asset were prepared so that the company’s performance could be evaluated. For example, the performance measures to assess the pavement surface were International Roughness Index (IRI), Pavement Condition Index (PCI), Friction Number (Skid Number), the number of potholes, the rutting depth, and the number of cracks. The IRI for the roads reconstructed in past five years should be less than 18. If the roads were not reconstructed within the last five years, then the percentage of pavement in good condition should remain same or increase, and poor conditions must remain the same or decrease.

A performance monitoring and project oversight program was prepared to evaluate the quality of the maintenance and preservation works. The contractor had a quality control plan, which was reviewed by DCDPW personnel to check whether the contractor was performing the work satisfactorily according to the performance criteria, guidelines, rules, and regulations. The performance-monitoring plan was divided into three levels: daily, monthly, and yearly. A project engineer was assigned by the DCDPW to monitor the contractor's work progress daily; however, documentation of the work was done by the contractor. For monthly monitoring, the project engineer traveled to the site on a random day. On these days, the engineer rated the asset condition as 'Good', 'Poor', or 'Fair'. The results of the monthly inspections were talked about with the management company to report the recommendations and concerns, if any. Annual inspection was conducted once a year, and the contractor's performance was assessed for every asset. The performance of each asset will be compared with the prior years' inspections or with baseline conditions to verify whether the company was successful in meeting the performance standards. If any asset is found not to be maintained according to the standards, then the management company will propose a plan to rectify it as soon as possible.

Furthermore, this study described the timeliness of the work to be completed, the quality of workmanship, safety to the public during the maintenance period, aesthetics, and minimum impact to the traffic during the maintenance period.

2.3.4 Evaluation of Interstate Highway Maintenance Contracting in Virginia

Through VMS Inc., the Joint Legislative Audit and Review Commission (JLARC 2001) reviewed 250 miles of interstate highway maintenance contracting with VDOT. JLARC conducted interviews with VDOT personnel and contractor staff, visited site offices, analyzed contractor performance, and reviewed documents. JLARC found that VDOT's annual evaluation of contractors' performance used pre-existing and unmodified instruments that did not reflect the contract criteria and tolerances. JLARC advised that VDOT should evaluate their entire assets instead of their current practice of random sample tests gathered only at specific chainages. The baseline prepared by VDOT for the contractor contained several errors.

Regarding VDOT's annual evaluation of contractors' asset management, this work did not represent actual asset conditions throughout the year. For instance, asset conditions that changed just after the evaluation would not have been detected until the next evaluation; therefore, the mean asset condition was neglected for a year. As a result, a joint quarterly evaluation, which is cost effective, too was recommended.

The commission reported that the guidelines followed by the field coordinators for routine monitoring were not consistent and needed to be improved. For example, there was lack of consistency and clarity regarding how a coordinator should report snow removal work. Regarding the cost effectiveness of the asset management contract carried out by VDOT in 1996, JLARC commented that the estimated cost savings of $23 million was not supported by documentation, and a cost analysis was not carried out. The basis was not correct in showing a cost saving by comparing the total contract amount with the VDOT's estimate.

After the JLARC's comments, VDOT contracted the faculty at Virginia Polytechnic Institute and State University to compare the costs of VDOT's in-house expenses against out-sourcing; however, due to the narrow scope, a decisive finding was not anticipated by JLARC. Therefore, two issues were addressed regarding the review of the VDOT's asset management contract: 1) VDOT's ability to evaluate the asset management contract and 2) the cost-saving document prepared by VDOT. JLARC recommended the five major points that VDOT: 1) Develop comprehensive written guidelines for consistent data collection by field staff, 2) Develop a database that would be capable of linking the interim performance report and contract's asset management requirements, 3) Quarterly evaluation of the contractor should be done, 4) Continue monitoring, and refine the process of evaluating the timeliness requirement, and 5) Use the proposed redesign performance report.

2.3.5 Guidelines for Executing Asset Maintenance Contracts in Florida

FDOT (2007) prepared the guidelines for the implementation of Asset Management (AM) contracts. The FDOT guidelines covered contract development, contract selection, contract administration, training required, and forms required for administering AM contracts and inspection/monitoring of AM contracts. The AM contract was referred to as a PBC. FDOT used AM contracts for maintenance and management of FDOT's state roadways for the first time in the year 2000. The AM contracts were used for some or all activities of road maintenance. The type of contract used has longer contract duration – 5-10 years. A technical evaluation committee did the AM contractor selection. The study also prepared Maintenance Rating Program (MRP) that evaluated a contractor's work. The guideline proposed two different methods for an evaluation or assessment of performances of the maintenance contract – the department performed MRP in the presence of a contractor, or the contractor performed the MRP as per the MRP handbook and procedures.

2.3.6 Performance-Specified Maintenance Contracting in New Zealand

Grandsberg et al. (2010) synthesized the Performance-Specified Maintenance Contract (PSMC) studies, and explained the experiences of PSMC in New Zealand and in the U.S.A. The authors categorized PSMC into two methods, a 'pure PSMC' method and a 'hybrid PSMC' method. The 'pure PSMC' contract covers design, construction, and maintenance; for this, generally, a consortium of a design consultant and contractor is formed. The 'hybrid PSMC' contract is the combination of 'pure PSMC' contract and the traditional Prescriptive-Based Contracting or Method-Based Contracting; it comprises many or all the activities of a certain section of a road. The authors described that although both forms of PSMC contracts were successful in accomplishing the pavement preservation goals, the 'hybrid method' had additional advantages over the traditional contracts and 'pure PSMC.'

In order to make PSMC contracts successful, the authors explained some bottom-line points. First, litigation was necessary for long-term PSMC contracting. Second, a holistic approach should be developed in order to deliver the necessary LOS during construction and maintenance phases. Third, the pay should be for outcomes, not inputs, of the contractor. Finally, the authors recommended that research must be conducted to determine a practical tool to measure outcomes. Moreover, a high level of integration between agencies and contractors was considered very important for the public works environment.

2.3.7 Contracting in Highway Maintenance and Rehabilitation: Are Spatial Effects Important?

Anastasopoulos et al. (2010a) conducted a study to determine the cost savings of countries by using innovative contracting methods, such as PBC contracts, instead of traditional method (in-house) for highway maintenance and rehabilitation works. This study also determined the spatial variables on cost savings of PBC contracting policies of a country. The cost data were collected from 449 innovative rehabilitation/maintenance (RM) contracts from 49 countries, and then grouped by type of contracts, scope of contracts, and characteristics of contracts. In this study, the cost savings of a country was described as the difference between traditional method costs and PBC contract costs of a country. Mathematically, it is defined as follows:

$$\% \text{ Cost Saving} = \frac{\text{Traditional Contract Cost} - \text{Performance Based Contract Cost}}{\text{Traditional Contract Cost}} * 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where, n is the total number of contracts in a country. The mean cost saving; standard deviation; and the minimum, and maximum cost saving of worldwide, 'North and South America', Europe, 'Africa and Asia', and 'rest of the world' were calculated in this study. It showed that the maximum cost saving was 54.94 percent, and maximum mean cost saving was 19.06 percent.

The authors conducted exploratory spatial data analysis (ESDA) to identify spatial dependence patterns and spatial heterogeneity. The cost savings of the countries were plotted in the Moran scatter plot, a tool for visual exploration of spatial auto-correlation. The four quadrants of the scatter plot show four local spatial variables of a country as well as its surrounding countries. The first quadrant, High-High

(HH), refers a country with a high average cost saving that is surrounded by high average cost savings countries. The second quadrant is Low-High (LH), third quadrant is Low-Low (LL), and fourth is High-Low (HL). The author categorized the countries into two classes, high-cost-saving (HCS) and low-cost-saving (LCS) countries. The HCS are mostly in Europe and America, whereas LCS countries are generally in Africa and Asia. In both the HCS and LCS countries, the majority of the countries fall in the first and third quadrant (HH and LL). That means that if a country's surroundings are high-cost-saving countries, the country itself would have high cost saving, and if a country is surrounded by the low-cost-saving countries, then the country itself will have low cost savings. In another words, the average cost saving spatial variable is significantly positively correlated to the countries. There are some countries whose cost saving is high despite of having low-cost-saving countries surrounding them, and there are some countries whose cost saving is low despite of having high-cost-saving countries surrounding it.

The statistical test showed that cost savings in a country was insignificant and positively correlated with the duration and size of contracts. It also was found that the cost saving in a country was positively correlated with the contract size of the surrounding countries.

2.3.8 Performance-Based Contracting for Road Maintenance in Indiana

McCullouch et al. (2009) studied the feasibility of PBC as an option to maintaining a huge road network of 1,940 lane miles in Indiana cost effectively. This study synthesized PBC programs; evaluated cost data; interviewed and analyzed PBC experienced DOTs officials; defined the PBC system requirements for developing, contracting, monitoring, and managing a contract; defined and analyzed the risk factors; described the maintenance options and how other states calculated overhead costs; and described Level Of Service (LOS) programs used by other states.

The study collected data from 449 contracts of from national and international agencies from 1996 to 2007, and conducted interviews. One of the major objectives of this study was to determine the cost saving calculation when using PBC over other methods. However, the cost calculations were not documented; instead, lane mile costs were determined and compared. The authors suggested four reasons for using PBC for road maintenance: reduce maintenance cost; enforce quality standards; provide transparency; and improve overall road conditions. Regarding performance standards and inspection methodology, the study synthesized that different countries have different performance standards to be met by contractor and inspection frequency. The author suggested six lessons from evaluating the PBC approach: PBC contracts were influenced by political interests; they were not cost effective for geographic contracts; most PBC contracts were focused on specific facilities, such as rest areas or bridge maintenance; PBC contracts created an environment that promoted the use of innovative methods to conduct tasks; they did not include snow and ice removal activities; and PBC programs required the development of new agency. This study also suggested that for establishing a PBC in INDOT, the major components were a PBC team, a PBC administrator, and an LOS program.

The author compared the costs of in-house and PBC contract in terms of lane/mile within four states: INDOT, NCDOT, FDOT, and VDOT. The cost comparison shows that the cost of PBC is higher than in-house; however, it is neither clear that they were compared on an equal basis nor that a life-cycle cost analysis was considered. The author collected the performance measures, LOS, and ratings prepared by various transportation agencies. It also collected 48 performance criteria for road asset maintenance that were prepared for VDOT.

2.3.9 A Conceptual Framework for Performance-Based Road Maintenance

Garza et al. (2009) developed a framework to serve as a guideline for effectively evaluate Performance-Based Road Maintenance Contracts (PBRMC). Based on the literature review, five key components of PBRMC—LOS, Timeliness of Response (TOR), Cost Efficiency (CE), Safety Procedures (SP), and Quality of Service (QOS) were discussed in this study.

The authors developed a methodology to evaluate the LOS. Performance criteria and targets were defined and developed to measure the contractor's work performance because the payment is tied with the output quality. The TOR depends upon the asset category. For each asset, to evaluate TOR, the information of service requested time, arrival time, work set up finished time, details of work, and work completion time are gathered by a responsible party. The contractor's work performance regarding TOR is evaluated comparing with required timeliness. To evaluate the SP in highway maintenance, first, a safety committee should be formed to define contractor's safety plan, performance safety measurement, criteria to evaluate, and establish safety goals. The methodology developed to evaluate the QOS in PBRMC. Using surveys, a data collection of the road users' are collected to assess their views upon the quality of the work performed by the contractor. For CE, the authors set two goals in assessing the cost effectiveness of PBRMC 1) determining the cost difference of maintenance work using PBRMC and using private contractor or In-House resources 2) to assess the impact on LOS, if the same amount of cost that was expended in PBRMC, is expended on the maintenance work using the traditional method.

2.3.10 A Framework for Monitoring Performance-Based Road Maintenance Contracts

Pinero (2003) developed a conceptual framework to monitor the effectiveness and efficiency of Performance-Based Road Maintenance (PBRM) contracts. The author also identified a statistically valid procedure to evaluate PBRM, and suggested the lessons learned. Based on literature reviews, the author considered five key components of the framework– level of Service (LOS), Cost Efficiency (CE), Timeliness of Response (TOR), Safety Procedures (SP), and Quality of Service (QOS).

Pinero also developed frameworks to evaluate each of the five components. The parameters of the methodology – input parameters, data collection, data analysis, and reporting – were different for each of the components. The author suggested using the R.S. Means Collection of Cost Indices, Engineering News Record (ENR), Construction Cost Indices, Federal Highway Maintenance and Cost Indices, and In-House records for the location adjustment of the cost data.

2.3.11 Cost Saving Analysis of Performance-Based Contracts for Highway Maintenance Operations

Anastasopoulos et al. (2010b) presented a methodology to estimate the probability and dollar amount of cost savings by using the PBC contracts instead of traditional road maintenance. Road maintenance contracting data were collected from around the world. The authors also developed a model to compare several contracting methods anticipated to help the transportation agencies in making the decision on whether to choose PBC or other contracting methods for the road maintenance during the pre-planning phase. Mathematically, the authors defined cost saving using PBC contracting over the In-House maintenance as explained in Equation 2.

$$Cost\ Saving = \frac{\text{In−House cost− PBC cost}}{\text{In−House cost}} * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Altogether, 337 contract data were collected from the various countries of the world between 1996 and 2007. Descriptive statistics were conducted for all contracts in order to determine cost savings. A number of independent variables were created, such as contract type, warranty project, contract duration (in years), and a dependent variable of cost saving. One of the results indicated that in PBC contracts, the mean cost saving and standard deviation were 12% and 9%, respectively.

In addition, the authors developed five models for analysis. The first model, a 'mixed logit model,' investigates the main factors affecting the estimation of cost saving. The results showed that if there were three or more activities or else large contract sizes, there would be a 74% lower probability of loss and a 26.9% probability of cost saving. Another result showed a 1% increase in the contract duration results, a 1.44% higher probability of having cost savings, and 5.81% lower probability of experiencing loss with the contract. The second model, the 'tobit model,' was developed for those contracts that incur zero or positive cost savings according to Equation 2. The third model for PBC contracts, a 'binary probit model,' was developed to recognize the factors that cause the probability of cost savings or no cost savings, and a regression module was applied to calculate the dollar value of cost saving or loss. The results also indicated that the PBC contracts were better than warranties with regard to the probability of cost saving.

The authors also suggested the conditions to be used the In-House maintenance method. They were low cost contracts, few activities, bridge and tunnel contracts, shoulder maintenance, emergency maintenance, short duration, medium length of the road, landscape contracts, and litter pick up. Similarly, the author suggested PBC contracting for the following conditions: high competition contracts, long extension contracts, huge projects like 400 lane-miles road contracts, illumination maintenance contracts, and consisting many activities contracts.

2.3.12 Maintaining roads: Experience with output-based contracts in Argentina

Liautaud (2001) illustrated the Argentina road maintaining experience that used output-based specification. The Argentine government shifted from the traditional input-based contract to the output-based contracts. The four purposes of shifting were to cut the administrative cost associated with the input-based contracts, to encourage innovation and risk transfer to the contractors, to develop more stable funding for road maintenance, and to meet road users' need in a better way. The Argentine government and the World Bank funded to carry out the output-based road maintenance contracts.

First of all, a nationwide road inventory survey was conducted to prepare a base line of the existing road-network that comprised estimated of traffic volume, required maintenance and rehabilitation road lengths, and the shape and size of the contracting amount. The roads were categorized into two groups as the road with traffic exceeding 3,000 vehicles per day were considered as concession-able and in between 300-3,000 vehicles was considered eligible for output based contracting. This contract was initiated in 1995 for 3,600 kilometers routine maintenance. After three year of the contract commencement, the output-based road contracts were reviewed and found that they were performing satisfactorily.

The payment to the contractor was tied with the contractor's performance, and was on the basis of per kilometer per month. Unless the performance was satisfactory per specification, daily penalties would be charged for that period until the work performance was carried out by the contractor. The agency issued several non-compliance certificates to the contractor; however, in overall, this contract gave satisfactory outcomes and renewed for more four years.

In the early round of the rehabilitation and maintenance contract, an initial five percent of the total contract amount was issued to the contractor to start the work. Then, two 10 percent payments were issued. The left over contract amount was split into the equal monthly installments over four years. In the second round, the payments were issued based on the contractor's performance in LOS. The combined rehabilitation and maintenance of the paved roads was called CREMA. As the monthly payments depend upon the performance of the contractor, the work was evaluated at on-site inspection every months. The inspections were conducted by the government engineers in the presence of the contractor. The performance indicators made to measure the road services were: the roughness, rut depth, cracking, and raveling.

The results and benefits of first phase contracts were: 1) the supervising cost of government was reduced, 2) the possibility of cost overruns were nil, 3) the contractor was responsible for all the contract management so there was no reason to delay, 4) the performance indicators were simple and easy to apply and monitor, 5) the contractor was fully responsible for maintaining the roads for a long time so there was less risk for dissatisfactory work performance, 6) the contract allowed innovation, 7) the payment was dependent upon the output of the task, 8) the CREMA program reduced the road users' cost.

2.3.13 Contracting Strategies for Road Maintenance in Texas

Menches et al. (2010) developed a 'decision tree' for the selection of an appropriate contracting method. Identified were five criteria for the selection of contract specification: 1) the level of control the DOT wanted to have in the contract; 2) trust in the contractor; 3) the qualification of the contractor; 4) political influence; and 5) the contractors' participation in the bidding process. Prepared was a contracting strategy selection guide for the designation of a suitable road maintenance contract.

Eleven case studies were examined, and identified lessons learned from the termination of PBCs in the Texas Department of Transportation (TxDOT). They were both parties should have fully understood the contract, the condition of the road should have been maintainable; the evaluation system should have been objective; the inspectors should have had experience in PBC; a best value method should be used in the selection of contractors; DOT should have started PBC with a small individual activity or a small bundled set of activities as a pilot program.

2.3.14 Performance-based Contracting for the Preservation and Improvement of Road Assets

Stankevich et al. (2009) differentiated PBC from traditional contracting. The PBC contracting was introduced in the year 1988. In this method, the contractor was paid based on work performance; and the agency specified neither any methods nor materials to be used by the contractor. There were two types of PBC: the Pure PBC (also called PBC) and the Hybrid PBC. The PBC contracts were fully outcome-based. On the other hand, the Hybrid PBC contracting was the combination of the Pure PBC and prescriptive-based contracting. In that contract, some activities were paid based on the PBC method, and what remained was paid based on the prescriptive based method.

It was discussed, the differences between PBC contracting and prescriptive-based contracting: first, in PBC contracting, the contractor was not held accountable for "what to do," "when to do," and "how to do." Second, the contractor bared the full risks of the contract in terms of management. Third, in the contract selection process, PBC normally used the best-value method, whereas the prescriptive-based method mostly used the lowest-bid method. Fourth, PBC used a prequalification process to select a technically qualified contractor. Finally, in PBC, payments were issued to the contractor on monthly installment basis, under a compliance with quality standards set for a specified service.

2.3.15 History and Development of Performance-Based Contracts

Pakkala (2005) described development of contracts from the 1960s to 2005. In the 1990s, the number of contracts increased, three-year routine maintenance contracts appeared, and long-term PBC contracts were introduced. There were various types of contracts – lump-sum contracts, unit-price contracts, hybrid contracts, and a combination of these three methods, and the selection criteria of the contracts were diverse among countries. Sweden and Norway did not select low-bid contracts; on the other hand, England, Australia, New Zealand, Finland, the USA, Canada, Holland, and Estonia selected best-value contracts. The author discussed two issues regarding the selection criteria: quality control plans and measuring ability of the contractor to perform the work.

In a comparison of maintenance contracts among 12 different regions of Canada, the USA, and other countries, the duration of the PBC contracts varied from 3 to 10 years; further, their mean contract duration was 6.8 years. The criteria for contractor selection mostly, but not fully, depended on the price. For example, Norway selected all contractors on the basis of the price, and England selected 30% on the basis of price. In a study of the scope of the contracts, four countries – Australia, Tasmania, England, and New Zealand – included all maintenance activities in a contract. The other eight countries included all road maintenance activities except resurfacing and rehabilitation work.

For performance measures (indicators) of a pavement, five measures were considered. They are the international roughness index (IRI), skid resistance, rutting, deflection, and texture and cracking. The LOS of line markings, drainage, vegetation and trash, winter maintenance, lighting, signs and signals, cleaning, and cracks and potholes were measured by visual inspection.

Regarding outsourcing the contracts, Norway, Switzerland, and other European countries had an increasing trend. The contract duration of PBC in these countries began from three years in the first round, and then moved to seven years in the second round. This study suggested some requirements for the PBC contracts: good baseline inventory survey of the road network, long-term funding for the maintenance; good tendering practices; common standards and performance measures; and good partnering between the agency and the contractor.

2.3.16 Performance-Based Contracting for Maintenance

The NCHRP (2009) conducted surveys with state DOTs, the Washington D.C. Department of Public Works (DCDPW), 10 Canadian Provincial transportation agencies, and a few private firms who had been engaged in PBC to identify the reasons for the use of PBC. The main reasons for the use of PBC were improved LOS, reduce agency cost, focus on outcomes, predictable maintenance budgets, transfer of risk to the contractor, and allow the contractor to develop innovative methods. The survey also identified the important factors as to why the PBCs were impeded in several countries. They were lack of government rules and regulations, lack of contractor experience, lack of training to reduce the impact of negative experience on PBMC, lack of legal authority to all parties, occasional loss of los in the first year, the contractors' capabilities were not sufficient, inability of competition among the contractors, warranty requirements, incorrect/incomplete baseline inventory data, fear that the life-cycle cost will increase, the need for secure funding for a long period, laying off dot staff, and the contractors' ability for emergency response to such activities as snow removal and traffic control devices. In addition to this, in a question as to why agencies did not perform PBMC, 52% responded that they had in-house resources and expertise to do most of the maintenance work, and 48% responded that they did not have PBMC experience at all. One of the main reasons behind using PBMC by the transportation agencies was that they do not have enough labor, and the management personnel accepted PBMC as an effective response to downsizing.

This study defined nine types of PBC contracts. The first one was a single activity, for example, striping. The second type was a single asset: it involves several activities under a single asset, for example, bridge maintenance. The third type was a set of related activities; it involves a set of maintenance activities in a location, for example, rest area maintenance. The fourth type was corridor, also termed as fence-to-fence contract. The fifth kind of contract was area-wide. In this type, an activity and/or an asset within an arena (district, city, county, or state) was offered for a contract. The sixth type of contract was a hybrid contract. It was a combination of two contracts. The final three types of contracts were agency-to-agency, warranty-based, and multi-phase contracts. Using the PBC contracts, this study examined the cost savings, which was between 10% and 40%; however, the calculations were not properly documented.

2.3.17 Performance Measures for Performance-Based Contracts

Zietsman (2004) studied the advantages and disadvantages, and points to be considered when selecting a PBMC method. The advantages are cost reduction, quality improvement of the road, risk reduction of the agency, an increase in innovation by the contractor, and an increase in productivity. In the experience in

West Australia, Virginia, and New Zealand, the author calculated a minimum cost savings of 15% and a maximum of 40% when using PBMC. Five disadvantages of the PBMC were the effect on employment, inability to deal with change, loss of flexibility, the impact on smaller contractors, and reduced competency in the agency. The author suggested that the following points be considered when planning to use PBMC contracting: skilled inspectors and contractors are needed, firms with an experience in a related field are better performers, start with routine maintenance, require permits for a transition period, and set up performance measures prior to advertising bids.

The author explained how ratings were calculated in an evaluation of a roadway. To evaluate a roadway four features were considered – potholes, bumps, joints, and turnouts. First of all, the road section was divided into a number of 0.1-mile samples, from which 30 samples were randomly selected to evaluate in detail. Then for every feature were evaluated in a scale of 1 to 5 points. For potholes, 5 points were given for no-potholes, 4 points for one-pothole, 3 points for two potholes, 2 points for three potholes, and 1 point for more than 4 potholes in a 0.1-mile sample. Then, average point or rating was calculated by taking the average of the samples, 3.7 was the average rating of the potholes in the roadway in the sample calculation below. To evaluate the roadway, percentage weight were defined as shown below. The rating of the potholes and scoring were calculated as shown below. The score was calculated as a product of rating and percentage weight. After that total score was calculated as the average value of the scores of the four features. Finally, MRP rating was calculated.

Features	Rating	Weight, %	Score
Potholes	3.7	40	1.48
Bumps	4.1	20	0.82
Joints	3.6	30	1.08
Turnouts	4.6	10	0.46
Total Score			**3.84**

MRP Rating=3.84/5.0=77% ………………………………………………………… (4)

In conclusion of the roadway evaluation, the calculated MRP rating of 77% was less than 80%. The 80% was the minimum threshold value to be met by the contractor, so the PBMC contractor did not comply with the performance standards.

2.3.18 Quality Assurance for Performance-Based Maintenance in Texas

Gharaibeh et al. (2011) categorized the roadside maintenance practices currently in place; developed performance standards, developed a condition assessment method, and also tested and refined by field trials in TxDOT's districts. An online survey was conducted with state DOTs to collect information regarding types of maintenance methods that were in use. The respondents showed the use of performance-based specifications and maintenance quality assurance (MQA) programs. Based on responses from 13 state DOTs and a literature review, initial performance standards and timeliness of response were recognized.

Moreover, the study developed pay-adjustment formulas for PBC. Pay adjustment, a function developed to decide whether the contractor was given incentive or disincentive. If the project LOS was equal to the target LOS, the incentive/disincentive to the contractor would be zero. When the project LOS score was less than the target LOS, the contractor would be charged a negative payment; if more, then the contractor would be positively rewarded. The best-value method, which was used in the PBC, selects not only technically superior contractors, but also low bidders. In contrast to this method, the conventional low-bid method selected the lowest bidder but neglected technical capacity.

2.3.19 Bidding Documents for Performance-Based Contract

The World Bank (2002) prepared a trial-bidding document for Performance-Based Contracts for Management and Maintenance of Roads (PBMMR). The bidding document was based on the pre-qualification process. The document encouraged the use of the prequalification process to screen the qualified bidders. A letter of invitation would be sent to the prequalified bidders for further bidding processes.

The document also included sample performance specifications; including service quality criteria, methods of inspection of service quality levels, timeliness, and a pay reduction method. It also included specifications for payment reductions and liquidated damages. The specifications contained both unpaved and paved roads. The document mentioned that the timeliness of some activities could be influenced by weather conditions. The road inspections of service quality levels for paved and unpaved roads were quite similar; for either kind, the inspections would be carried out as directed by the project manager.

Pay reductions would be applied for non-compliance of service-quality level requirements. The disincentive applied in the document is a percentage of the monthly lump sum amount of the contractor's pay. In an example for an unpaved road, if the contractor could not meet 'Road Usability' criterion or if the road is interrupted for traffic, 1% of the monthly lump sum amount of entire road or an affected road section would be reduced. The pay reductions for all the criteria were set as a percentage of the contractor's monthly payment.

2.3.20 Framework of Performance-Based Contracting

SAIC (2006) developed a framework and methodology to measure performance goals of typical performance-based reconstruction/ rehabilitation works, which can be used by state DOTs for the PBC contracts. This framework was developed working with subject experts at FHWA, state DOTs, and industry personnel. In PBC projects, defining a set of performance goals is one of the major tasks. The authors first categorized the performance goals into two types— pass or fail and multi-level performance measures. The pass or fail type of performance goals were easy to define, and the performance goals were assessed as either 'pass' or 'fail'. However, the pass or fail method does not provide much information about performance. On the other hand, the multi-level performance measure includes five levels of performance measurements, ranging from 'excellent', 'very good', 'good', 'poor', and 'very poor'. As this method had various levels to assess the performance of an activity, considerable information regarding the performance could be collected.

In addition, the authors developed a performance measurement menu to measure the performance of the PBC contractor. The menu defined the criteria for the five-level performance measurement for various elements. The authors mentioned four options for measuring the contractor's performance. They were continuous measurement; cyclic—daily, weekly, monthly, etc; start and end of the project, at project targets; and long-term measurement. To evaluate the performance of the contractor, the authors recommended using an unbiased or independent evaluator. The evaluators could be personnel from the Federal Highway Administration (FHWA) or any private consultant who had experience with similar works.

After the performance is measured, contractor's performance results are analyzed. The results are tied with incentives or disincentives to the contractor. After performance measurement criteria are developed, requests for proposals (RFPs) and an Invitation for Bid (IFB) are prepared and issued.

2.3.21 Performance-Based Road Contracts in Chad

Ellevset (2001) studied the characteristics of a PBC road maintenance project in Chad, Africa. PBC consisted of specific characteristics, and differed from traditional contracts in three aspects: contract focus, the payment model, and the improvement of a LOS. One of the main goals of PBC was to improve LOS. LOS was defined based on usability of road section, travel speed, road surface conditions, and roadside assistance.

The LOS of unpaved roads was measured against three parameters: general road conditions, users' comfort and safety, and durability. The general parameter consisted of whether the road was open to traffic, and the average speed of vehicles. The users' comfort and safety included road surface corrugation, rut depth, other surface degradations, usable road width, cleanliness of surface, and the height of tree branches above the road. The durability parameter was related to the crown height of the road, potholes present, cracking, cleanliness of road, rutting, loose pavement edges, pavement and shoulder height, and shoulder conditions.

The study found that in Chad PBC projects, the contractor tried to exploit the weakness of consultant supervision, and the selected contractor was not fully capable for the specified work. Moreover the level of LOS the contractor had to achieve was also kept very high. The study also identified six lessons learned from these projects - only 'maintainable' roads should be included in PBC; the LOS must be clearly defined in bid document; equitable distribution of risks between owner and contractor was necessary; performance criteria should have been simple; the contractors should have been given adequate training; the contractors should have been prequalified.

2.3.22 Performance Based Contracting and Improving the Current Contracting Process

Berkland and Bell (2007) examined the possibility of moving from MBC to PBC in maintaining South Carolina DOT (SCDOT) roads. To improve the current practice of using performance-based specification, SCDOT organized brainstorming workshops with district offices. The meetings concluded four major barriers in implementing PBC. The barriers discovered were lack of controllability, lack of budget, poor contractors' performance, and strong concerns with regards to job security. All the districts' participants agreed with a contractor pre-qualification process. It was recommended that annual training be implemented to all the staff so that all district offices would have a common understanding of PBC.

A questionnaire survey was conducted with private contractors that had worked with SCDOT, with regards to shifting from MBC to PBC. The survey results showed that the contractors agreed that PBC cost more than MBC. It was agreed that the contractors needed additional training and the PBC could be implemented.

2.4 Cost Comparison Studies

The literatures related to the road maintenance with various types of specifications are summarized in Table 2.4.

Table 2.4. Summary of Literature related to Cost Comparison among In-House, MBC, and PBC Methods

No.	Reference	State, Country	Major Findings
1	Halcrow (2011)	Nevada, U.S.A.	The author compared average NDOT In-House costs of road maintenance for various cities of Nevada with costs from other states. The study found that some NDOT costs were less than DOTs of other states.
2	Martin (1993)	U.S.A.	The author prepared the cost comparison methodology to compare the cost of SF and private contracting services. The cost components to be included in the cost calculation were also identified.
3	NCHRP (2011)	U.S.A.	The study determined a process to calculate the total cost of highway maintenance. The total cost is a sum of line cost, program support cost, and enterprise support cost. The share of both support costs were calculated based on the ratio of the amount of line activity costs over the total line activity cost.

Detailed Literature Review

2.4.1 Cost and Benefit Study Associated with Outsourcing Roadway Maintenance Activities

Halcrow (2011) conducted a 'cost and benefit' study related to out-sourcing road maintenance activities in Nevada. Data was collected on road maintenance costs from Nevada DOT (NDOT), Texas DOT (TxDOT), and Florida DOT (FDOT), and from several private contractors. In order to compare costs among agencies and/or with contractors, the direct and the indirect cost of an activity was calculated. The direct cost was the expenditure of materials, labor, and equipment that are directly associated with an activity. The indirect costs included the overhead charges by the DOT, the division, and the district, and the cost for maintenance station management. The actual cost of the DOT staff was calculated as the percentage of time allocated to specific maintenance work. Other indirect costs included the costs of advertisement and quality control inspection.

As minimal data was available from NDOT in order to compare the in-house maintenance costs with that of private contractors, cost data from other states was collected. Total costs of an activity were calculated by the addition of direct and indirect costs. Activities were compared that had the highest expenditures for eight NDOT projects in the year 2009 with costs for projects in TxDOT, and FDOT. The comparison displayed the average costs in Nevada for chip seal, debris removal, crack filling, and fog seal were higher than that of TxDOT. The cost of cut & fill in NDOT was lower than that of FDOT. However, there was no documentation provided for the costs data collection. Furthermore, it was not explained whether the cost was adjusted for time and location.

2.4.2 Cost Comparison Methodology

Martin (1993) conducted a study to determine the true costs of in-house and contracted services. For in-house services, direct costs were defined as fully dedicated costs for a target service; indirect costs were those that benefited from more than one target services. The indirect costs for personnel should have been proportionally allocated to target services in the ones involved. The total cost for in-house services was the sum of the direct costs and a proportional share of the indirect costs.

Described were three types of indirect costs associated with private contracts. They were contract administration costs, one-time conversion costs, and new revenue. A 'contract administration cost' referred to all the expenditures that occurred during the contract start to the contract end. 'One-time conversion cost' were costs incurred when converting a target service from in-house to a contract service delivery and were required to be amortized over an effective duration. For example, the salary of workers was a 'one-time conversion cost' because the workers could not be removed immediately due to the contract clauses. 'New Revenue' was when services are contracted out and an agency does not need to use some of the resources or equipment; the owner would sell out these resources or equipment. The total cost incurred in a private contract was the sum of the 'contract administration cost' and the 'one-time conversion cost' minus 'new revenue.'

2.4.3 Determining Highway Maintenance Costs

The NCHRP (2011) developed a process to calculate the total cost of a highway maintenance activity. Total cost consisted of the line activity cost, the program support cost, and the enterprise support cost. Line activity costs were direct costs. Program support costs were those costs that did not deliver any specific work product of construction or maintenance, but did support one or more line activities, for instance district maintenance staff, office stationery, and utilities. Other support costs that assisted the maintenance program were enterprise support costs; for example, head office administration, information technology, planning and research, and legal advice. NCHRP used five processes to determine the respective shares of a support cost to the direct costs. These processes were: 1) collect and separate maintenance program costs; 2) determine a share of support program costs to the line activities; 3) collect and separate enterprise support costs; 4) determine a share of enterprise support costs to the line activities; 5) add line activities, a share of support program, and a share of enterprise support costs to determine full cost.

A percentage share of both the support program activity, and enterprise-support activity costs to a line activity was calculated based on the ratio of the amount of line activity costs over the total line activity cost.

2.5 Delphi Studies

The literatures related to the road maintenance with various types of specifications are summarized in Table 2.5.

Table 2.5. Summary of Literature related to Cost Comparison among In-House, MBC, and PBC Methods

S. N.	Reference	State, Country	Major Findings
1	Migliaccio (2007)	Texas	The author developed a framework for transportation agencies to implement change in the project delivery strategy. The framework was developed based on the information from past literature review, case studies, and interview with subject experts. Then, it was validated by conducting a two round Delphi study.
2	Linstone and Turoff (2002)	U.S.A.	The authors explained Delphi method and its characteristics. The authors also synthesized numerous studies, which used Delphi method.
3	Delbecq (1975)	U.S.A.	The author discussed about three group techniques, which are useful for group judgments. They were Nominal Group Technique (NGT), Interactive group technique, and Delphi Technique. The author discussed the Delphi technique with a set of sample questionnaire.
4	Ozbek (2004)	Virginia	The author developed a warranty clause for PBC contracts. First, a draft template was prepared based on literature reviews, and then it was improved by conducting a survey with experts.
5	Williams et al. (2001)	U.S.A.	The authors conducted a study to identify the required improvements on the educational software. The authors used Delphi study to identify the required improvements and to bring consensus on the concerns.

Detailed Literature Review

2.5.1 Planning for Strategic Change in the Project Delivery Strategy

Migliaccio (2007) developed a framework with some definitions and guidelines for transportation agencies to guide when they change the project delivery methods. The framework was developed based upon information from research study of the SH-130 project and four case studies. That framework was validated by a Delphi study.

The Delphi study had two rounds of survey. First, 90 potential experts were invited who had experience on transportation projects using DB method. Out of 90 experts, 35 (39%) responded. In the first round Delphi study, the 35 Delphi experts were asked to evaluate the overall framework, to validate the framework components, to validate the framework definitions, and to provide suggestions. The experts were asked to rate on a scale of 1 to 7. Out of 35 members invited, 26 responded for the first round survey. For validation, the framework was classified into two types – type 1, the overall framework architecture and type 2, the detail guidelines. For the validations of type 1 and type 2, they had to meet two criteria: 1) group validation or how panel members scored the items and 2) panel consensus or agreement. Specifically, for the group validation of type 1, the average score of 7-likert scale should be more than equal to 5.0 or more than equal to 75% panel members should give a minimum score of 5.0. For type 2, the average score of 7-likert scale should be more than equal to 4.0 or more than equal to 75% panel members should give a minimum of 4.0. To evaluate the panel consensus, interrater reliability and average deviation were determined. The author considered the panel consensus was established if the average deviation was below a value 7/6 (1.167) and the interrater reliability was greater than equal to 0.60. The second round Delphi questionnaire was distributed to those 26 panel members who responded the first round survey. Out of 26 experts, 21 responded the second round survey. In the second round, the panel members were asked to rank the items.

2.5.2 The Delphi Method

Linstone and Turoff (2002) explained Delphi method, its techniques, and its applications in various fields. The authors defined the Delphi method as a structured group communication, in which the panel members provide their views. In the Delphi method, the monitor develops questionnaire, summarizes the responses, and communicates with panel members in multiple rounds. The monitor also keeps anonymity of the responses received from the panel members. One of the characteristics of the Delphi method is the panel members do not have to physically get together to communicate. The authors categorized Delphi communications into two processes. In the first type, the monitor team designs the questionnaire and distributes to the respondents. Usually, the respondents use paper-and-pencil to provide their views. Based upon the respondents' view, the monitor team develops new questionnaire, and again send to the respondents. This method was also said conventional Delphi. In the second type of Delphi process, the questionnaire is distributed and collected their views using a computer program; so monitor team can summarize the results on real time. The authors synthesized numerous studies of the Delphi method in various fields – medical, business, academia, drug abuse, etc.

The authors synthesized a Delphi method of sources of pollution for Grand Traverse Bay in the next two decades. In that study, first the Delphi panel was formed, and then three rounds of survey were conducted. In the first round, based on literature review, a monitor team developed an open discussion questionnaire survey with some subjects (e.g. sources of pollution, pollutants). In the survey, the panel members were asked to add more subjects thought to be important. The respondents added 17 sources of pollution and 18 pollutants. Based on the subjects collected in the first round, the monitor team developed the second round survey listing all the subjects, and then sent to the panel members to identify the important ones. Conducting statistical test with the responses of the second round, 10 important subjects were identified, which were listed for the third round survey and again sent to the panel members.

2.5.3 Group Techniques for Program Planning: A Guide to Nominal Group and Delphi Processes

Delbecq (1975) discussed about three group techniques, which are useful for group judgments. They were Nominal Group Technique (NGT), Interactive group technique, and Delphi Technique. With NGT, the individuals physically present in a meeting and share their ideas with individuals with writing on a piece of paper but they do not speak each other. At the end of the meeting, the individuals present their written idea in the meeting in round-robin fashion, and the facilitator prepares a list idea. In the next round of the meeting, discussion and voting on the ideas takes place, and, each individual provide their rating or ranking on each of the idea points to identify the important ones. The interactive group technique is very similar to the NGT; however, the individuals openly discuss or share their idea with individuals.

With Delphi technique, the individuals do not have to physically get together for their communications; a facilitator communicates with individuals with multiple rounds of surveys. Therefore, this technique keeps anonymity of the respondents. The respondents are subject experts in their field, and the number of experts in the Delphi technique usually varies from 10-15 to several hundred. With Delphi technique, usually, the first round survey consists of an open-ended or broad-type questions to collect the ideas from experts. The collected responses are grouped, and then a list of distinguished responses is prepared for each question. The second round questions were developed based on the responses of the first round survey. In the second round, the respondents are asked to rate the subjects to identify the important ones. At the end of the second round, analysis of the responses was conducted to identify important subjects, and if required, following rounds of survey were also developed and distributed.

2.5.4 Development of Performance Warranties for Performance Based Road Maintenance Contracts

In 1996, the first PBC maintenance contract was introduced in USA by Virginia DOT (VDOT) (Ozbek 2004). VDOT awarded that contract to the VMS contractor with contract duration of 5.5 years, in which warranty was not included. In this study, the author developed a warranty clause for future PBC maintenance contracts for VDOT, which offers contractor's liability for the work performed after immediate end of the contract. First, the author developed a draft copy of warranty clause for the 'Paved Ditches'. To validate the warranty clause template, the author formed an expert panel, and a survey was conducted with them. The expert panel individuals were taken from academia, VDOT, and contractors who were working in the field of warranty for contracts. In the questionnaire survey, the author asked the panel members to provide comments on the draft warranty template. At the end, the comments received were incorporated and modified the draft template to develop the final version of warranty clause template.

2.5.5 Teacher Beliefs about Educational Software Now and in the Future: A Delphi Study

Williams et al. (2004) conducted a study to identify views of school-educational-software instructors and school-district-technology experts on the overall uses of the software for their curriculum. The authors used Delphi study to identify the instructors' concerns. The Delphi study had two rounds of survey, and both of the rounds had five questions – the deficits with the body of software, the adaptations adopted by the teachers, the suggestions of the teachers to improve the body of software, the changes need to meet classroom requirement, and the future of educational software. The first round survey had open ended questions, and specific software instructors and technology experts were selected for the survey using *stratified sampling method*. All together, 69 possible participants were invited for the first round survey, out of which 58 (84%) of them responded.

The second round survey was developed with the responses collected from the first round; however, the authors did not listed all the distinguished subjects in the second round survey questions, but only listed the seven high frequency subjects. Out of the seven subjects, the respondents were asked to rate only five subjects. They were also asked the reasons for choosing the five subjects. In the second round, 96% completed the survey. Descriptive analysis of mean scores and standard deviations were used to analyze the response data. The authors identified top ranked items; however, they did not explain the detail basis of choosing the top rank items.

Chapter 3: Research Methodology

3.1 Overview of Research Methodology

Figure 3.1 shows an overall flowchart of methodology used for this dissertation. After the scope and objectives of the study were defined, literature reviews were conducted. This study conducted a national survey with state DOTs to collect best practices regarding road maintenance. After that, a comparison of cost and quality of chip seal and striping was conducted. Finally a framework to perform PBC in chip seal and striping was developed using Delphi study.

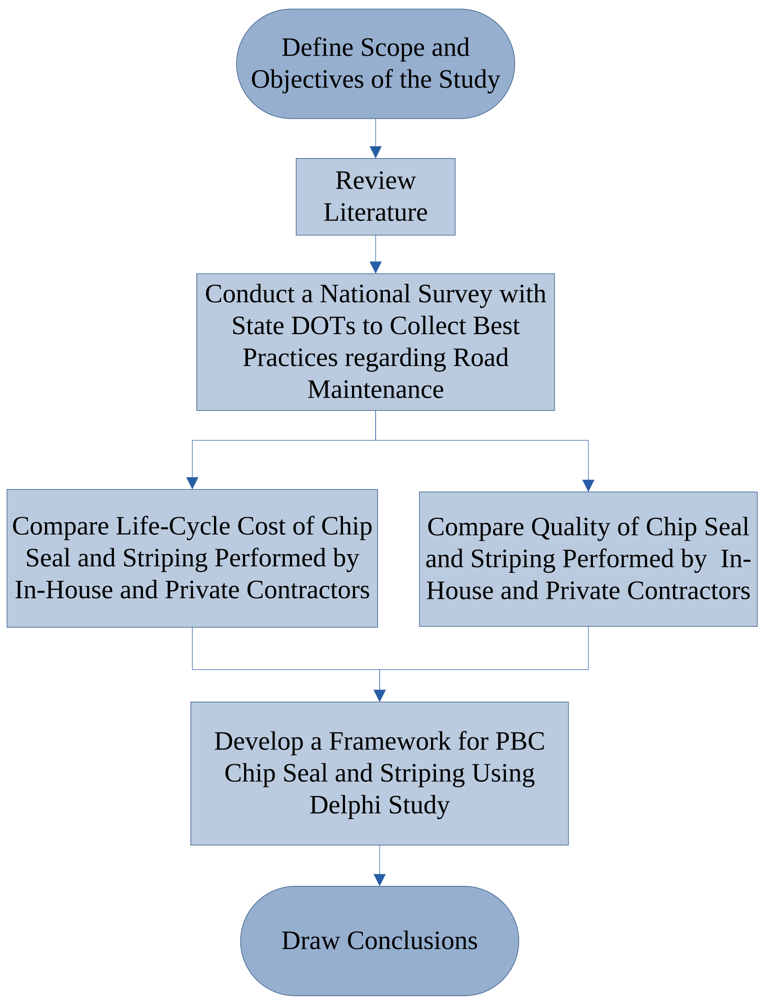


Figure 3.1 Overview of the Research Methodology

3.2 National Survey with State DOTs

After a significant number of literature were reviewed, a national survey was conducted with state DOTs. Three main objectives of this national survey were to collect in-depth information regarding factors affecting the selection of road maintenance methods, satisfaction levels of DOT personnel with these road maintenance methods, and lessons learned from using these methods. To collect this information, a questionnaire survey was distributed to 49 state DOTs' maintenance divisions with an email attachment. Email reminders were sent to the respondents who did not respond the survey in a month. The survey is presented in Appendix A.

3.3 Cost Comparison of In-House and Private Contractors' Work

Cost data of chip seal and striping activities performed by In-house and private contractors from FY 1990 to 2014 were collected from the NDOT Maintenance and Asset Management Division, Carson City, Nevada. The cost data of chip seal and striping works performed In-house were downloaded from the Maintenance Management Reporting System (MMS), and cost data regarding private contractors who performed projects were collected from the same division as well as from NDOT website. Then, unit maintenance costs per year were determined and compared using the life-cycle cost analysis method.

To perform cost comparison, the direct and indirect costs of chip seal and striping were determined. Direct Costs were all the costs that were directly associated with a line activity. For example, the direct costs of In-house performed works were labor cost, material cost, and equipment cost. In the case of outsourced works, direct cost is the cost of the contract amount. Indirect costs are those costs, which are not directly associated with a single maintenance activity, for example, salary of state DOT personnel who were partially involved in several maintenance activities. Regarding the In-House performed cost data, this consisted of labor cost, material cost, and equipment cost. In addition, there was a significant portion of the NDOT personnel who worked for planning, estimating, and monitoring for chip seal and striping works; therefore, the indirect cost of NDOT personnel as a percentage share was also determined to add with the direct cost in order to calculate the total cost of chip seal and striping works performed by the In-House work force. Mathematically, the total maintenance cost can be calculated as

$$Total\ Maintenance\ Cost = Direct\ Cost + Indirect\ Cost \tag{3.1}$$

Regarding the Out-Sourced chip seal and striping works, there was also an involvement of the NDOT personnel for contracting work; however, they were not involved as much as in the In-House performed work. Therefore, the involvement of the NDOT personnel was challenging to calculate and so it was neglected in this study. In other words, for Out-Sourced chip seal and striping works, the indirect cost was not added even though the involvement of NDOT personnel existed to some extent.

To calculate the indirect costs, the salary of the NDOT personnel was collected from the NDOT website for 2009 and after. To calculate the salary expenses of the maintenance division personnel, first, the percentage of the maintenance budget with the total budget of NDOT was determined. For 2009, the sample calculation of percentage of maintenance budget with total budget was:

Total Maintenance and Construction Budget = \$605.80 M

Total Maintenance Division Budget = \$119.80 M

% of Maintenance Budget with Total Budget $= \frac{\text{Total Maintenance Budget}}{\text{Total Maintenance+Construction Budget}} * 100\%$

$= \frac{\$119.80\text{ M}}{\$605.80\text{ M}} * 100\%$

= 19.80%

For 2010 to 2013, similar calculations were carried out to determine the percentage of maintenance budget within total budget. Table 3.1 shows the calculated average percentage of maintenance budget within total budget was calculated as 16.57%. This percentage indicated that from 2009 to 2013, on average, 16.57% of the total budget was expended on maintenance of road activities.

Table 3.1. Administrative Costs for NDOT's Maintenance Division

Year	Administrative Cost ($M)	Maintenance Division Budget ($M)	New Construction Budget ($M)	Total Maintenance & Const. Budget ($M)	Indirect Cost of Maintenance Division (%)
2009	134.70	119.80	486.00	605.80	19.80
2010	127.90	136.40	594.30	730.70	18.70
2011	125.80	111.70	651.40	763.10	14.60
2012	120.40	132.90	748.10	881.00	15.10
2013	123.80	113.80	661.00	774.80	14.70
Avg.	**126.52**	**122.92**	**628.16**	**751.08**	**16.57**

The percentage share of salary expenses of the maintenance division was calculated using the average percentage of the maintenance budget, which was 16.57%. Therefore, the indirect cost spent on maintaining the road activities was determined as follows:

Average administrative cost of NDOT = $126.52 M

Average salary for maintenance division = $126.52 M x 16.57%

= $20.96 M (average indirect cost)

Percentage of Indirect Cost of Maintenance Division

$$= \frac{\text{Average Indirect Cost}}{\text{Average Maintenance Division Budget}} * 100\%$$

$$= \frac{\$20.92\text{ M}}{\$122.92\text{ M}} * 100\%$$

= 17.06% of Maintenance Budget

The cost comparison was conducted by using Life-Cycle Maintenance Cost (LCMC) per year for chip seal and striping. The process of calculating the LCMC is described in the sub-section 3.3.1. The unit maintenance cost was determined by dividing the total maintenance cost by the quantity performed. For In-house works, the quantities performed were also taken from the MMS data, whereas for contractor performed works, it was taken from the contract document. Since the works were performed in various years, they were adjusted to the 2014 base cost using *Highway cost index*. Moreover, Annual Average Daily Traffic (AADT) was different for road sections and might have effected the life of chip seal works.

Therefore, the 2012 AADT of the road sections (NDOT 2012) was also considered by determining unit cost per 1,000 AADT for comparison.

3.3.1 Determination of Life-Cycle Maintenance Costs

Life-cycle cost analysis is used to evaluate the most cost-effective method. In this dissertation, the LCMC was calculated for chip seal and striping. Here, the unit maintenance cost and average frequency (number of times chip seal and striping was performed) of maintenance were used to calculate the LCMC of the maintenance activities. Figure 3-2 shows the steps to calculate the LCMC of chip seal and striping works, which are as follows:

1. The cost data of chip seal and striping works performed by In-House and private contractors were collected from 1990 to 2013, and then analyzed to determine the direct cost of the road sections chip sealed and striped in each year;
2. Indirect costs were calculated as 17.06% of maintenance budget or direct cost;
3. Total costs of chip seal and striping of the road sections were calculated. For In-House performed works, the total cost was the sum of direct and indirect costs. For Out-Sourced works, the total cost was the amount of the contract amount;
4. Then, a unit cost was calculated by dividing the total cost by the quantity of work performed. For chip seals, a standard thickness of 3/8 inch was considered; however, if the works performed were 7/8 inch, the extra thickness was converted into an equivalent thickness of 3/8 inch;
5. Since the works performed were of various years, the unit costs were adjusted to a 2014 base cost using the *Highway cost index*;
6. The average frequency of maintenance for each of the road sections was determined;
7. The unit cost spent per year was calculated by dividing the unit cost with the frequency of the work performed;
8. The average unit cost per year per 1,000 AADT of chip seal was calculated by dividing the unit cost per year by the average AADT (in 1,000) of the road section.

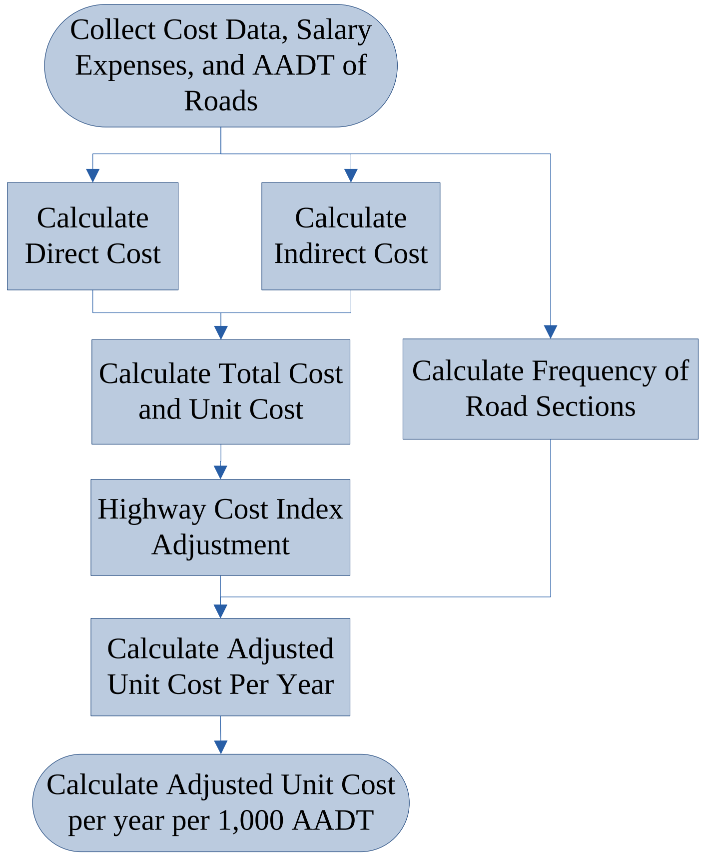


Figure 3.2 Determination of Life-Cycle Maintenance Cost

3.4 Quality Assessment of Activities Performed by In-House and Private Contractors

To evaluate the quality delivered by In-house and private contractors for chip seal and striping works, an on-site quality evaluation was carried out. To validate the on-site quality evaluation work, three surveys were conducted with local road users, NDOT maintenance division personnel, and Nevada contractors. The process is described in detail in the following sub-sections.

3.4.1 Process for On-Site Quality Evaluation of Maintenance Activities

To compare quality of chip seal and striping delivered by the three road maintenance methods, first performance measures were developed for the activities. For chip seal, five performance measures were developed. They are presence of pot holes, loss of aggregates, presence of cracks on the surface, presence of rutting, and uniform distribution of aggregates on the surface. The road sections were evaluated based on the performance measures during on-site evaluation. Each of the measures were evaluated on a scale of 1 to 5, '5' being 'very satisfied' and '1' being 'very dissatisfied.' The detail of the performance measures are shown in Appendix B.

For striping, three performance measures were developed. They were ensuring road striping is visible during the day, ensuring road striping is visible during the night, and ensuring road striping is straight and continuous. The performance measures were rated on the same scale of 1 to 5. The details of the performance measures are shown in Appendix B. The performance ratings were based on objective visual based criteria, which are shown in Figure 3-3.

To conduct on-site evaluation, a minimum of four road sections for each of the activities performed by In-house and private contractors were selected. Regarding striping under PBC method, only one contract was evaluated because there was only one PBC contract with NDOT. To select the road sections, the following factors were considered:

1. Same year of maintenance activity conducted,
2. Similar Average Annual Daily Traffic (AADT) of the road sections,
3. Similar topography and weather conditions, and
4. Length of road sections is in-between 3 and 40 miles

Considering the above four factors, a minimum of 30 samples were selected from each of the road section using the *Random Stratified Sampling Method*. If the road section was 8 miles long, that road section was divided into 80 samples of 0.10 mile long. For several road sections, more than 30 samples were evaluated because during the on-site evaluation, it was found that the actual length of road sections were longer than previously estimated. Table 3.2 shows the details of the road sections evaluated.

Table 3.2. Road Sections Selected for On-Site Quality Evaluations

S.N.	Maintenance Activities	Name of the Selected Road Sections		
		In-House	MBC	PBC
1	Chip Seal	2 Section of US 93, US 06, SR 266	2 Sections of US 93, SR 121, SR 305, SR447, SR 225	-
2	Striping	2 Sections of US 95 SR 163 SR 160	2 Section of US 93 US 93 2 Sections of US 95	US 95

3.4.2 Rating Surveys for Quality Satisfaction of Maintenance Activities

This sub-section details the process adopted for three surveys, which were conducted to assess overall satisfaction levels with the quality of chip seal and striping works performed by In-House and private contractors. These surveys were conducted with local road users of the sections where the on-site investigation was carried out, with NDOT maintenance division personnel, and with Nevada contractors' personnel. In addition to these, in the national survey of the state DOT mentioned before, a question was asked to the state DOTs personnel regarding their satisfaction levels with the works performed by In-House and the private contractors. The detail of the surveys is discussed in the following sub-sections.

3.4.2.1 Surveying Users of Selected Road Sections

To assess the overall quality of specific road sections, which were selected for on-site investigations, a short survey was conducted with local road users during the site visit. This survey dealt with the output quality of the works and safety measures provided during maintenance works; the criteria were evaluated on a scale of 1 to 5, "1" being very dissatisfied and "5" being very satisfied. The detail of the survey is provided in Appendix C. The main aim of this survey was to collect the satisfaction levels of the overall quality of the chip seals and striping with the local road users. A minimum of 30 road users' responses were collected for each of the road sections; however, at some particular road sections, where the traffic volume was very low (below 300 AADT), the number of respondents were less than 30. To collect the road users' satisfaction levels, the following five methods were used:

1. Stopping the vehicles to request the users to participate in the survey,
2. Standing at the gas station that was within the road section or at the nearest one,
3. Visiting local office and business centers to request participation in the survey,
4. Dropping the local users mailboxes to drop empty pre-paid envelops, and
5. Distributing empty pre-paid envelopes to the users on hand.

3.4.2.2 Quality Satisfaction Rating Survey with NDOT Personnel

To assess overall quality of chip seal and striping works performed by In-house and private contractors, an online survey (Qualtrics) was conducted with NDOT maintenance division personnel who oversee the works performed by both parties. This survey was different from the previous road users' survey because it dealt with the overall quality of the works performed by In-house and private contractors in all of Nevada, rather than specifying for a specific road section. This survey dealt with the output quality, safety measures provided during maintenance works, quality of materials and workmanship used for chip seals and striping works; each of the criteria were evaluated on the same scale of 1 to 5. The questionnaire of this survey is provided in Appendix D.

3.4.2.3 Quality Satisfaction Rating Survey with Private Contractors

The previous survey sent to the NDOT personnel was also distributed to the Nevada contractors' personnel, to assess the overall quality of works performed by In-house and private contractors. This survey was sent to only those contractors who had conducted chip seals and striping works with NDOT in the past. This survey also used an online survey tool, named Qualtrics. The questionnaire of the survey is provided in Appendix E.

3.4.2.4 State DOT Survey

A national survey was also conducted with 49 state DOTs. One of the objectives of this survey was to collect information regarding the satisfaction levels of state DOTs regarding the overall quality delivered for maintenance works using In-House and private contractors. Email invitations were sent to the state DOT maintenance division engineers to collect the information. The questionnaire of the survey is provided in Appendix A.

3.5 Delphi Study

After the cost and quality comparison works, in order to develop a framework to perform performance-based chip seal and striping contracts, a Delphi study was conducted. The Delphi study identified important issues regarding the implementation of performance-based chip seal and striping. Before starting the Delphi study, the qualifications of the Delphi panel members were defined. The minimum qualification of the panel members were defined as follows:

1. The individuals must have at least 5 years of experience on transportation industry sector,
2. The individuals must be involved in PBC chip seal or PBC striping projects for at least two years, or involved in contracting for chip seal or striping for a minimum of two years with theoretical knowledge on performance-based specifications,
3. If individuals are from state DOTs, they should be working as an engineer or a manager position; or if the individuals are from university, they must have conducted researches on performance based contracting; or if the individuals are from contractor side, they must be working as an engineer or manager.

After the qualification of the panel members were defined, a list of probable individuals was prepared. The individuals were from state DOTs, academicians, and other transportation agencies, such as World Bank. All together, 62 individuals were identified and invited for the first round survey. Figure 3.3 shows the details of each of the rounds, which were explained in the following sub-sections.

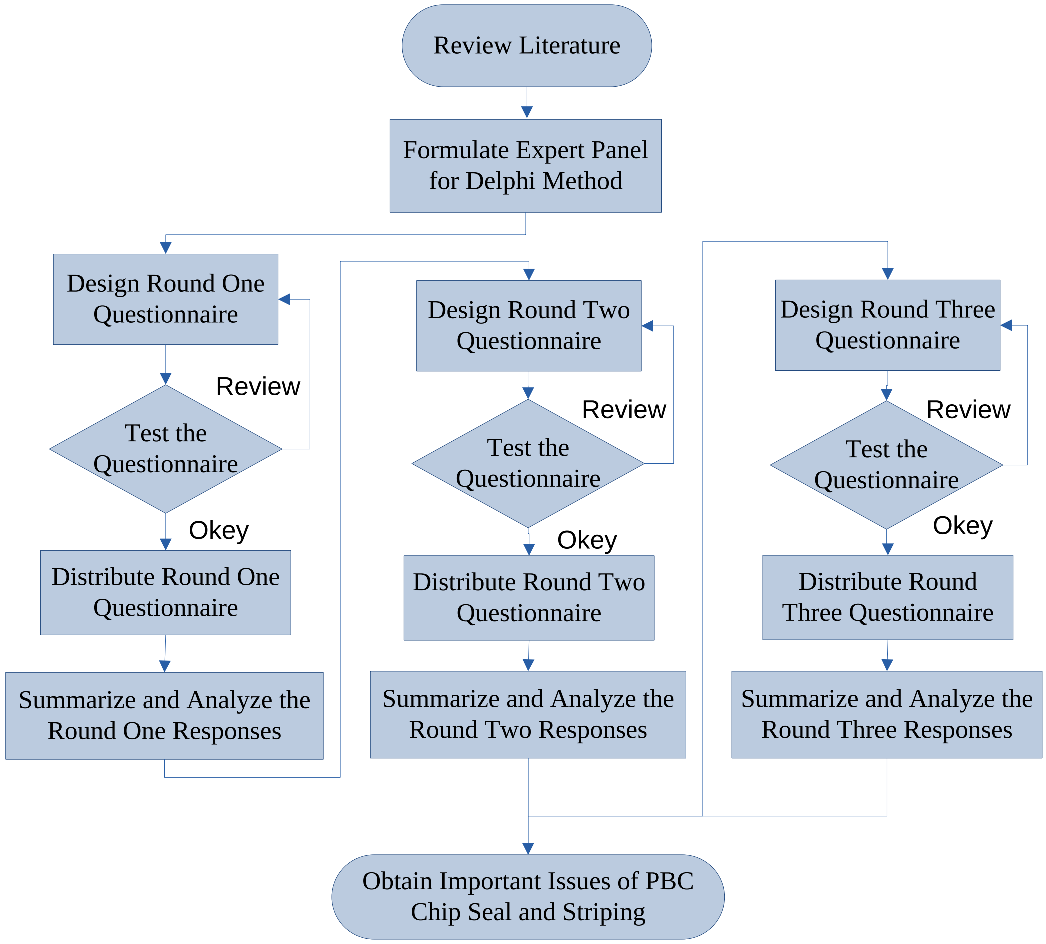


Figure 3.3 Flowchart of the methodology of the Delphi study

3.5.1 Delphi Study Round One

In the first round, open-ended-question-phone interviews were conducted. Sixty-two individuals were invited who had a minimum qualification explained as per section '3.5 Delphi Study.' Out of 62 individuals, 42 (67%) accepted to participate in this Delphi study; therefore, a 42 member Delphi panel was formed. When the invitations were distributed to the panel members, it was explained that what the Delphi study is, approximate time to complete each of the three rounds, and the objectives of the Delphi study. The first round interview invitations were distributed to the individuals by email in the first week of May 2015 and asked them to schedule for a phone interview. After one month of the invitations distributed, reminder emails were sent to the individuals who did not respond. From July second week, follow up calls were made to request them to participate in the study. For each of the panel member, when phone interview was scheduled, interview questions were sent to the panel members for their better preparation.

There were three sections in the phone interview. The first section was regarding the panel members' background information; the second section was regarding the chip seal; and the third section was regarding the striping. The approximate time for the phone interview was 36 minutes, and the first round phone interview was ended at the end of September 2015. In October, to analyze the responses, first of all, all the responses were digitized in a excel sheet. Since the phone interview was open-ended question, for each of the questions, a wide range of responses was collected. A maximum of 180 responses were collected for a question. Grouping the 180 responses, a distinguished 14 responses were listed out. The phone interview questions were presented in Appendix F.

3.5.2 Delphi Study Round Two

In the first week of November, the second round web-based Qualtrics survey was developed and distributed to the 42 panel members, who responded the first round phone interview. In this survey, the panel members were asked to rate the subjects (distinguished responses) of each of the questions on a scale of 1 to 5, "5" being very important and "1" being very unimportant. A total of 31 questions were asked, and the estimated time to complete the survey was 15 minutes. After two weeks of the survey distribution, follow up calls were made to friendly remind the panel members to complete the survey. Out of 42, 40 (95%) panel members completed the survey by December 15.

The survey response data were of ordinal scale (dissatisfied, neutral, satisfied). To test the panel consensus of such data type, IntraClass Correlation Coefficient (ICC) test was conducted in Statistical Package for the Social Sciences (SPSS) software. Mathematically, the IntraClass Correlation Coefficient is defined as (Zaiontz 2015)

$$ICC\ Value = \frac{\text{variability of different ratings of the same subject}}{\text{total variation across total ratings and subjects}}$$

Generally, the ICC value ranges from 0.0 to 1.0, where 0.0 refers "no consensus" and 1.0 refers "perfect consensus." According to Montgomery et al. (2002), if the ICC value ranged from 0.00 to 0.40, "fair consensus"; ranged from 0.41 to 0.60, "moderate consensus"; 0.61 to 0.80, "strong consensus"; and ranged from 0.81 to 1.00, "almost perfect consensus." If the dataset is small, the ICC value sometimes may be negative, which refers "no reliability" (Fleiss 1975). For this dissertation, for the panel consensus, the following values were considered as—less than equal to 0.00, "no consensus;" 0.01 to 0.69, "fair consensus;" 0.70 to 0.79, "moderate consensus;" 0.80 to 0.89, "strong consensus;" 0.90 to 0.99, "almost perfect consensus;" and 1.00, "perfect consensus." In this dissertation, for each of the questions, if panel consensus was moderate or above, it was considered that panel consensus was established. If panel consensus was established, the important subjects were the top five subjects of which average rating scores were above 3.5 (3 was for Neutral and 4 was for Satisfied). If panel consensus was not established, a maximum of five highly rated subjects were selected as subjects for the third round survey. For some questions, for which only one subject was required to identify, if panel consensus was established, the highest rated subject was considered as the most important subject. If the panel consensus was not established, a maximum of five highly rated subjects were selected for the third round survey. The second round survey questions were presented in Appendix G.

3.5.3 Delphi Study Round Three

The third round survey was developed with questions, for which panel consensus was not achieved in the second round. In this round, the same subjects were listed and asked the panel members to rank them by drag and drop on a scale of 1 to 5, where 1 being 'very adequate time period' and 5 being 'very inadequate time period.' This survey was distributed to those 40 panel members who completed the second round survey. The survey was also distributed through Qualtrics, and was presented in Appendix H.

Chapter 4: Results and Discussions

The main objective of this dissertation was to develop frameworks for performance-based chip seal and striping contracts. A national survey with state DOTs were conducted to identify the best practices used for the chip seal and striping contracts. Then cost data was collected from NDOT to conduct life-cycle maintenance cost comparison of chip seal and striping works performed by In-House and Out-Sourcing methods. Then the author visited sites to collect data related to these maintenance activities' qualities for comparison purpose. Based upon these analysis frameworks for performance- based chip seal and striping contracts were prepared using a Delphi study. The results of each of the tasks were presented in the following sub-sections.

4.1 National Survey Results of State DOTs

A national survey was conducted with state DOTs to collect detail information regarding the uses of road maintenance methods. The main objectives of the national survey were to identify factors affecting the selection of the road maintenance contracting methods, and to collect the respondents' satisfaction levels with these methods. The state DOT maintenance division engineers were also asked to share their lessons learned with the use of these maintenance methods. The survey was distributed to 49 state DOTs maintenance division engineers except NDOT through email attachments. Out of 49, 34 state DOTs responded with 69% response rate.

The state DOTs maintenance engineers were asked about the types of road maintenance contracting methods they used to maintain the roads. The results showed that all the respondents (34 states) used In-House, 32 states used MBC, and 14 states (including Nevada) used PBC methods to maintain the road activities. Figure 4.1 shows the states with the types of maintenance contracts used: red indicates those states that used In-House, MBC, and PBC methods, green indicates states that used In-

House and MBC methods; gray indicates states that used only In-House, and white indicates that states that did not respond the survey.

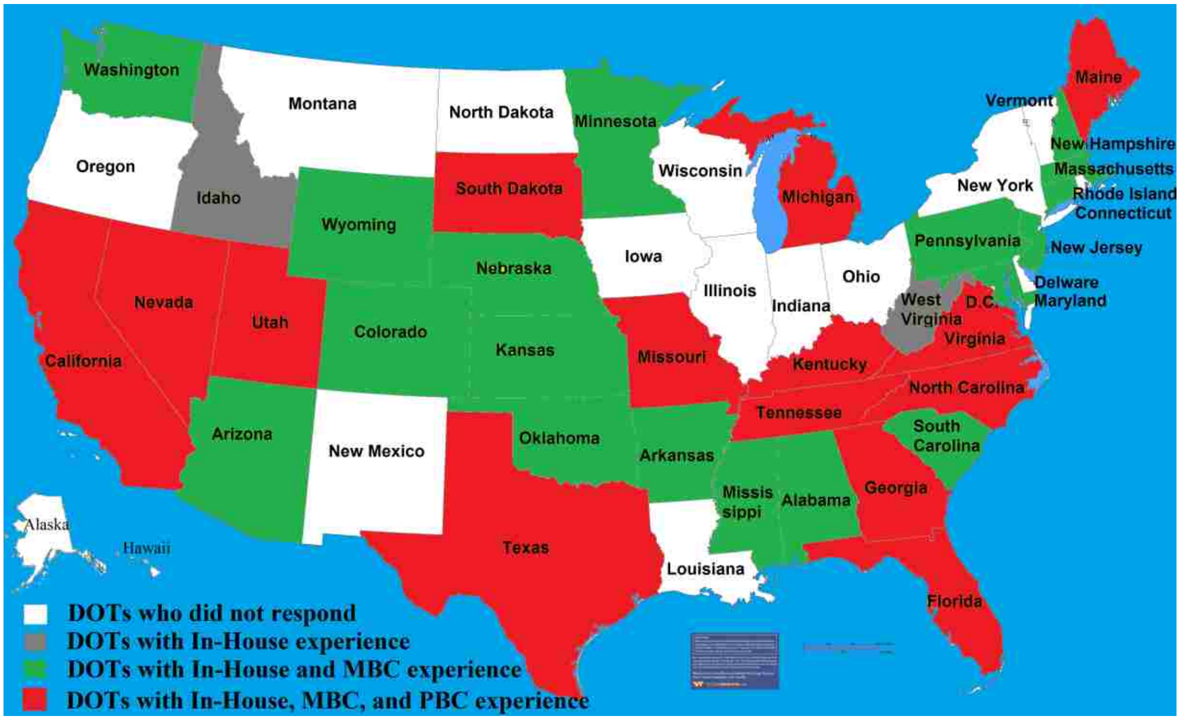


Figure 4.1 Responded States with In-House, MBC, and PBC Experience

4.1.1 Factors Affecting the Selection of Maintenance Methods

The respondents were asked to rate the factors affecting the selection of In-house and Out-Sourcing under MBC and PBC methods on a scale of 1 to 5, '1' being 'very dissatisfied' and '5' being 'very satisfied.' Since the data were in ordinal scale, the non-parametric Mann Whitney U Test was conducted to identify the top rank factors. Table 4.1 shows the ranks, factors, sample size, mean rank, and p-value of the Mann Whitney U Test. The result showed that the top three factors for the selection of the In-House method were 'Availability of DOT staff,' 'DOT staff have specific skill for jobs,' and 'Budget constraint.' The test results also showed that the number one ranked factors was significant different from other factors except second ranked factor. The test results indicated that the state DOTs will use In-House method to maintain their road if they had enough budget and enough staff with required skills. The finding of this research is similar to the NCHRP (2003) study, which identified that unavailability of DOT staff with required skill was one of the important factors for Out-Sourcing the maintenance works.

Table 4.1. Ranking of Factors Affecting the Selection of the In-House using Mann-Whitney U Test

Rank	Factors affecting the selection of in-house method	N	Mean rank	P-value
1	Availability of DOT staff	31	35.02	0.09
2	DOT staff have specific skill for jobs	31	27.98	
1	Availability of DOT staff	31	34.31	0.05
3	Budget constraint	29	26.43	
1	Availability of DOT staff	31	34.76	0.02*
4	To complete task on budget	28	24.73	
1	Availability of DOT staff	31	36.76	<0.01*
5	Quality of work	29	23.81	
1	Availability of DOT staff	31	38.61	<0.01*
6	Time constraint	30	23.13	
1	Availability of DOT staff	31	38.31	<0.01*
7	To complete task on schedule	28	20.80	

Note: * = Significant at alpha level 0.05.

The factors affecting the selection of MBC method were tested using Mann Whitney U Test to identify the significant difference in the rankings. Table 4.2 shows the results of this test. It shows that the top three factors for the selection of the Out-Sourcing under MBC method were ‘Unavailability of DOT staff,’ ‘DOT staff do not have specific skill for jobs,’ and ‘To complete task on schedule.’ The top ranked factor is significantly different than the rest of the factors. The state DOTs outsourced the maintenance works to the contractors if they do not have enough staff with required skills. Also they expect the private contractors to complete the maintenance works on time.

Table 4.2. Ranking of Factors Affecting the Selection of the MBC Method using Mann Whitney U Test

Rank	Factors affecting the selection of MBC method	N	Mean rank	P-value
1	Unavailability of DOT staff	30	36.35	0.01*
2	DOT staff do not have specific skill for jobs	31	25.82	
1	Unavailability of DOT staff	30	31.03	<0.01*
3	To complete task on schedule	28	35.50	
1	Unavailability of DOT staff	30	35.15	<0.01*
4	To complete task on budget	27	22.17	
1	Unavailability of DOT staff	30	38.02	<0.01*
5	Time constraint	28	20.38	
1	Unavailability of DOT staff	30	36.72	<0.01*
6	Quality of work	28	21.77	
1	Unavailability of DOT staff	30	37.92	<0.01*
7	Budget availability	27	19.09	

Note: * = Significant at alpha level 0.05.

Table 4.3 shows the result of the Mann Whitney U Test for the factors affecting the selection of PBC method. It shows that the top three factors were 'Unavailability of DOT staff,' 'DOT staff do not have specific skill for jobs,' and 'Innovation.' The results also showed that the first ranked factor is not significantly different from the rest of the factors. In this method, the state DOTs expect some innovation on the work, because PBC is used for some innovative ideas to be generated from the private contractors during the maintenance works.

Table 4.3. Ranking of Factors Affecting the Selection of the PBC Method using Mann Whitney U Test

Rank	Factors affecting the selection of PBC method	N	Mean rank	p-value
1	Unavailability of DOT staff	9	9.72	0.54
2	DOT staff do not have specific skill for jobs	8	8.19	
1	Unavailability of DOT staff	9	9.50	0.35
3	Innovation	7	7.21	
1	Unavailability of DOT staff	9	10.89	0.30
4	Contractors' capability to perform works	9	8.11	
1	Unavailability of DOT staff	9	11.28	0.16
5	To save money (considering life-cycle cost)	9	7.72	
1	Unavailability of DOT staff	9	11.50	0.11
6	To save time	9	7.50	
1	Unavailability of DOT staff	9	10.78	0.14
7	Types of maintenance activity	8	7.00	

4.1.2 Satisfaction Levels with the use of Maintenance Methods

In another question, the respondents were asked to provide their satisfaction levels on the benefits (overall experience, schedule advantage, cost advantage, quality delivered, and risk transfer) received from these three contracting methods. The respondents rated their satisfaction levels on the same scale of 1 to 5. Thirty-three responses were received for In-House method, twenty-nine responses were received for MBC method, and nine responses were received for PBC method for this question. The Mann Whitney U Test was conducted to identify the significant difference between the satisfaction levels of these three contracting methods. Table 4.4 shows that the state DOTs were significantly more satisfied with In – House methods regarding four benefits, namely overall experience, schedule advantage, cost advantage, quality delivered, than MBC and PBC methods. However, the differences of satisfaction level between the MBC and PBC methods were not significant at alpha level 0.05. Regarding the satisfaction levels with quality delivered, the respondents were significantly least satisfied with the work performed by PBC as compared to In-House method; this was clearly counter-intuitive because PBC contracts have predetermined significantly higher performance standards that need to be achieved in order to the contractor get paid. Regarding the risk transfer to the contractor, the respondents were significantly more satisfied with using the PBC method as compared to the MBC method. This finding shows that PBC has to transfer significantly higher risk to the private contractors in compared to MBC method.

Table 4.4. Results of the Mann-Whitney U-Test of Rating of the Benefits of Three Methods

S.N.	Benefits	Contracting methods	N	Mean rank	P-value
1	Overall experience	In-house	33	37.19	<0.01*
		MBC	29	21.48	
		MBC	29	18.63	0.89
		PBC	9	18.11	
		In-house	33	22.75	0.05*
		PBC	9	14.78	
2	Schedule advantage	In-house	33	40.27	<0.01*
		MBC	29	21.52	
		MBC	29	19.55	0.53
		PBC	9	17.00	
		In-house	33	23.88	<0.01*
		PBC	9	9.13	
3	Cost effectiveness	In-house	33	38.17	<0.01*
		MBC	29	23.91	
		MBC	29	19.16	0.86
		PBC	9	18.44	
		In-house	33	22.74	0.03*
		PBC	9	13.81	
4	Quality delivered	In-house	33	35.86	0.02*
		MBC	29	26.53	
		MBC	29	20.12	0.18
		PBC	9	14.94	
		In-house	33	23.14	0.01*
		PBC	9	12.19	
5	Risk transfer	MBC	29	15.54	0.04*
		PBC	9	23.88	

Note: * = Significant at alpha level 0.05.

4.1.3 Lessons Learned from Using the Maintenance Methods

The respondents were also asked to share the lessons learned from the experience of using the In-House and out-sourcing under MBC and PBC methods. The high frequency top three lessons learned from using the In-House method were 1) the work should have been clear and easy to understand, 2) a department should have hired qualified personnel and/or a multi-skilled workforce, and 3) it was easier to react with unanticipated events. Similarly, the top three lessons learned from using the outsourcing under MBC method were 1) ensure specification and contract document were clearly written, 2) Inspectors and administrators clearly understood the contract, and 3) If the contract was PBC, the contract should have been long term and the scope should have been dynamic, so that the contract always followed the current policies set. Regarding the lessons learned from using the PBC method, since the PBC method has basically four phases at its implementation. The lessons learned were also typically asked for each of the phases. Therefore, the top three lessons learned for four phases—contract procure phase, initial baseline measurement phase, performance measurement phase, and payment phase were listed in Table 4.5.

Table 4.5. Lessons Learned from using Performance Based Method

S.N.	Description	Percent of Respondents
	Contract procurement phase (N=7)	
1	Hold Pre-bid meeting	43%
2	Develop detailed measures of all assets	29%
3	Set duration of contract as long as you are comfortable.	29%
	Initial baseline measurement phase (N=4)	
1	Make sure to have a good baseline	50%
2	Decide who performs baseline evaluations	50%
3	Contractors will do their own baseline to make sure you are accurate	25%
	Performance measurement phase (N=7)	
1	Performance measures should be clearly defined and an independent third party should conduct performance measurement	100%
2	Performance targets should align with your expectation and payment.	29%
3	Use pre-existing performance standards if possible and provide trainings regarding PBC	14%
	Payment phase (N=7)	
1	Certain measures should be timeliness and tied to scheduled payment	43%
2	Payment should be based on performance	29%
3	It is a good idea to front-load a contract with higher payments early, and then move to same amount each month.	14%

4.2 Life-Cycle Maintenance Cost Comparison

Life-Cycle Maintenance Cost (LCMC) of chip seal and striping works performed by In-House and Out-Sourcing methods were compared. The results of the LCMC comparison of chip seal and striping were presented in the following sub-sections.

4.2.1 Chip Seal

The LCMC cost of chip seal works performed by In-House and Out-Sourcing under MBC method were determined. To calculate LCMC of chip seals performed by In-House method, first, all chip seal maintenance costs spent since 1990 were gathered. The unit cost (cost per square yard) was calculated per section 3.3.1. Table 4.6 shows the sample calculation of the average unit cost of chip seal of SR XXX MI performed by In-House method.

Table 4.6. Details of Unit Cost Calculation for Chip Seal of SR XXX MI

Maintenance Year	Material Cost ($)	Labor Cost ($)	Equipment Cost ($)	Total Direct Cost ($)	Total Direct Cost (2014) ($)	Indirect Cost, 17.06% ($)	Total Cost of Chip Seal ($)	Unit Cost ($/SY)
2001	142,547	22,885	28,509	193,941	201,642	34,400	236,042	0.43
2009	313,199	59,154	206,870	582,223	589,972	100,649	690,621	1.33
2011	481,565	39,384	105,185	626,134	648,780	110,682	759,462	2.33
Average Unit Cost								**1.33**

The average unit cost, the average frequency of maintenance works, the average unit cost per year were calculated as described in section 3.3.1. With the available chip seal maintenance cost data collected from NDOT, the average frequency of maintenance performed by In-House was calculated as 5.4 year – on average, In-House staff performed chip seals on the same section of a road on every 5.4 years. The sample calculation of determining average frequency of maintenance was presented in Appendix I. Assuming that life of chip seal might have been affected by AADT of the road section; the average unit cost per year per 1,000 AADT was also calculated.

The average unit cost, average unit cost per year, AADT, and average unit cost per year per 1,000 AADT of 49 road sections were calculated. Table 4.7 shows the average unit cost of chip seal, average unit cost per year, and average unit cost per year per 1,000 AADT of the road sections performed by the In-House were $1.20, $0.22, and $0.64 respectively. The sample calculation of average unit cost of US 06 NY and unit costs of 49 road sections is presented in Appendix J.

Table 4.7. Cost of Chip Seal Performed by In-House for 49 Road Sections

S.N.	Road Sections, County	Average Unit Cost ($)	Average Unit Cost/Yr. ($/Yr.)	AADT	Average Unit Cost/Yr./ 1,000 AADT ($)
1	SR XXX CH	1.49	0.28	2965	0.09
2	SR XXX HU	1.06	0.20	370	0.53
3	SR XXX CL	0.84	0.16	1050	0.15
4	SR XXX CL	1.00	0.18	2340	0.08
5	SR XXX EL	1.00	0.19	175	1.06
6	SR XXX EL	1.25	0.23	13,125	0.02
.	………….	….	…	….	….
.	………….	….	…	….	….
49	US XXX WA	1.21	0.22	17,589	0.01
	Average	**1.20**	**0.22**	**2740**	**0.64**

To calculate the average unit cost of chip seal performed by private contractors under MBC method were calculated following the steps as explained in section 3.3.1. In Nevada, there were 21 Out-Sourced chip seal projects; therefore, the average unit costs of 21 chip seal contracts were determined. In that 21 contracts, a total of 48 road sections were chip sealed. In these chip seal contracts, since the cost of striping were also included, the net chip seal cost of each projects were first calculated by deducting 12.3% as average cost of striping. The 12.3% of striping cost was calculated from three NDOT prepared estimated cost percentage share for bids. The detail calculation of the determination of average striping cost is shown in Appendix K. To calculate the average frequency of the chip seal works performed by the private contractors, similar steps were followed as for In-House method and found that the average frequency was 3.16 years. The sample calculation of determining average frequency of maintenance was presented in Appendix I. Table 4.8 shows the average unit cost, the average unit cost per year, the average AADT of the road sections included the contract, and average unit cost per year per 1,000 AADT of 21 chip seal contracts. The average unit cost, average unit cost per year, and average unit cost per year per 1,000 AADT of the chip seals performed by MBC method were $2.78, $0.80, and $0.48 respectively.

Table 4.8. Cost of Chip Seal Performed by Private Contractors for Various Road Sections

S.N.	Contract Number	Average Cost/SY ($)	Average Cost/SY/YR ($)	AADT	Average Cost/SY/YR/ 1000 AADT ($)
1	Contract 01	1.99	0.57	829	0.69
2	Contract 02	2.58	0.74	9650	0.08
3	Contract 03	2.25	0.64	4556	0.14
4	Contract 04	2.05	0.59	404	1.45
5	Contract 05	4.38	1.25	-	-
6	Contract 06	2.08	0.60	1886	0.32
7	Contract 07	2.44	0.70	2500	0.28
8	Contract 08	1.87	0.54	10,854	0.05
9	Contract 09	3.42	0.98	2550	0.38
10	Contract 10	2.19	0.63	1375	0.46
11	Contract 11	2.64	0.75	-	-
12	Contract 12	6.80	1.94	-	-
13	Contract 13	1.41	0.40	1024	0.39
14	Contract 14	5.33	1.52	5390	0.28
15	Contract 15	2.35	0.67	1125	0.60
16	Contract 16	3.00	0.86	2190	0.39
17	Contract 17	2.25	0.64	1279	0.50
18	Contract 18	1.32	0.38	450	0.84
19	Contract 19	2.79	0.80	1300	0.61
20	Contract 20	1.79	0.51	4510	0.11
21	Contract 21	3.53	1.01	950	1.06
	Average	**2.78**	**0.80**	**2785**	**0.48**

Table 4.9 compares the costs of chip sealing performed by In-House and MBC methods. The result shows that the average unit cost of chip seals and average unit cost of chip seals per year performed by In-House method were significantly cheaper than when performed by MBC method. However, when the average AADT of the road sections were considered, the average unit cost per year per 1,000 AADT performed by MBC method was slightly lower than that of performed by In-House method; nonetheless, the mean difference was not significant. This implies that NDOT Out-Sourced the chip seal works of those road sections, which had relatively higher AADT. The AADT of the road sections might have affected the life of the chip seal, which ultimately dropped the frequency of maintenance works performed by MBC method. Looking into the In-House and private contractor performed cost data, the In-House performed chip seal works includes only labor cost, material cost, and equipment cost. In the case of the MBC contractor performed chip seal works, the contract included the costs of traffic control, dust control, and pollution control, which was approximately ten percent of the net chip seal cost.

Therefore, for a fair comparison, if the additional three costs were taken out from the contractor performed contracts, the unit cost of MBC method would lower down by approximately ten percent of the costs presented in the Table 4.9; however, still the MBC contractor performed chip seal cost would be higher than when performed by In-House method. A cost analysis performed in Missouri DOT also showed that the chip seal works performed by Out-Sourcing method was also approximately two times higher than when performed by In-House method (Broeker 2012).

Table 4.9. ANOVA Test Results of In-House and Private Contractor Performed Chip Seals' Unit Cost

Costs of Chip Seals	Method of Maintenance	N	Mean	P-value
Average Unit Cost ($)	In-House	49	1.20	<0.01*
	MBC	21	2.78	
Average Unit Cost / Yr ($)	In-House	49	0.22	<0.01*
	MBC	21	0.88	
Average Unit Cost/Yr./ 1,000 AADT ($)	In-House	49	0.64	0.22
	MBC	21	0.48	

* Significant at alpha level 0.05

4.2.2 Striping

The LCMC cost and average frequency of striping for the In-House staff performed works for striping were calculated. The average frequency of striping works performed by In-House was found to be 1.30 years. Since the life of the striping do not depend on AADT of road section so far, the average unit cost per year was not normalized with AADT of the road sections. Table 4.10 shows the average unit cost (cost per line mile) and average unit cost per year of striping works performed by In-House method. The average unit cost and average unit cost per year of 29 striping works performed by the In-House method were $245.54 and $188.87 respectively.

Table 4.10. Cost of Striping of Road Sections When Performed by In-House Method

S.N.	Name of Roads	Average Cost/ L-Mile ($)	Average Cost/ L-Mile/Yr ($)
1	US XXX	330.73	254.41
2	US XXX	170.42	131.09
3	US XXX	193.49	148.84
4	US XXX	201.12	154.71
5	US XXX	209.60	161.23
6	US XXX	240.97	185.36
7	US XXX	175.46	134.97
8	US XXX	222.93	171.49
9	US XXX	175.04	134.65
10	US XXX	175.84	135.26
11	SR XXX	259.19	199.37
12	SR XXX	308.90	237.62
13	SR XXX	234.47	180.36
14	SR XXX	230.67	177.44
15	SR XXX	198.67	152.82
16	SR XXX	204.06	156.97
17	SR XXX	204.58	157.37
18	SR XXX	197.54	151.96
19	SR XXX	210.37	161.82
20	SR XXX	187.32	144.09
21	SR XXX	180.61	138.93
22	SR XXX	156.10	120.08
23	SR XXX	250.83	192.95
24	SR XXX	301.66	232.04
25	SR XXX	275.12	211.63
26	SR XXX	290.58	223.52
27	SR XXX	276.99	213.07
28	SR XXX	296.45	228.04
29	IR XXX	760.86	585.27
	Average	**245.54**	**188.87**

The unit cost of Out-Sourced striping contracts was calculated by dividing the striping cost (the average striping cost percentage as explained in the determination of LCMC of chip seal, 12.3%) by line mile (L-Mile) quantity of striping. There were twenty-one contracts performed under MBC method and one contract under PBC method. The average striping frequency of Out-Sourced striping works were calculated as 1.89 years. That means on average, striping works performed by MBC method was repainting on every 1.89 years on the same section of a road. Regarding the striping work performed by the PBC method, the contractor was fully responsible to maintain the striping lines (as explained in contract document) for 5 years. Therefore, for the PBC performed work, the frequency of the striping became 5 years. Table 4.11 shows the data analysis result of average unit cost per L-Mile and average unit cost per L-Mile per year of the 21 contracts. The average unit cost and average unit cost per L-Mile per year of striping performed under MBC and PBC methods were $1685.95, $892.08 and $8482.23, $1696.45 respectively.

Table 4.11. Average Unit Cost Calculation for Striping performed by MBC and PBC Methods

S.N.	Contract Number	Average Cost / L-Mile ($)	Average Cost / L-Mile / Yr ($)
Private Contractors Under MBC			
1	Contract 01	1651.70	873.92
2	Contract 02	1447.44	765.92
3	Contract 03	1221.17	646.84
4	Contract 04	1009.35	534.05
5	Contract 05	2462.93	1303.14
6	Contract 06	1173.12	620.70
7	Contract 07	1681.85	889.87
8	Contract 08	1674.69	886.08
9	Contract 09	2247.04	1188.91
10	Contract 10	1233.38	652.58
11	Contract 11	1561.24	826.05
12	Contract 12	3349.26	1772.09
13	Contract 13	982.50	519.84
14	Contract 14	2335.00	1235.45
15	Contract 15	1541.53	815.62
16	Contract 16	1761.05	931.77
17	Contract 17	1360.00	719.58
18	Contract 18	1727.17	913.85
19	Contract 19	1829.14	967.80
20	Contract 20	1171.12	619.64
21	Contract 21	1984.28	1049.88
	Average Cost	**1685.95**	**892.08**
Private Contractor Under PBC			
1	P036-12-050	8482.23	1696.45

Table 4.12 compares the average unit costs of striping performed by In-House and private contractors under MBC and PBC methods. The average unit cost and average unit cost per year of striping performed by the three methods were $245.54, $176.65 (for In-House); $1660.15, $787.39 (for MBC), and $8626.94, $1725.39 (for PBC) respectively. ANOVA test results showed that the average unit cost of striping performed by In-House was significantly much lower than that of performed by private contractors under MBC and PBC methods, followed by MBC and PBC methods. Looking into the cost data of the works performed by In-House and private contracts, the In-House performed striping works

includes only labor cost, material cost, and equipment cost. In the case of Out-Sourcing contracts under the MBC method, the contracts included the costs of traffic control, dust control, and pollution control. For fair comparison, if the additional three costs were taken out from the Out-Sourcing contracts, the unit cost of striping works performed by MBC method would lower down to half of the calculated cost presented in the Table 4.12.

Table 4.12. ANOVA Test Results of In-House, MBC, and PBCs' Striping Unit Cost

Costs of Striping	Method of Maintenance	N	Mean	P-value
Average Unit Cost/L-mi ($)	In-House	29	245.54	<0.01*
	MBC	21	1685.95	
	In-House	29	245.54	<0.01*
	PBC	1	8482.23	
	MBC	21	1685.95	<0.01*
	PBC	1	8482.23	
Average Unit Cost /Yr ($)	In-House	29	176.65	<0.01*
	MBC	21	892.08	
	In-House	29	176.65	<0.01*
	PBC	1	1696.45	
	MBC	21	892.08	<0.01*
	PBC	1	1696.45	

* Significant at alpha level 0.05

4.3 Quality Comparison of Chip Seal and Striping

This section presents results regarding on-site quality investigation of chip seal and striping. It consists two parts: researchers' evaluation and surveys conducted with Nevada local road users,' NDOT maintenance personnel, and Nevada contractors' personnel. They were described in the following sub-sections.

4.3.1 Researcher's On-Site Quality Evaluation

This sub-section shows the results obtained from the on-site quality evaluations conducted by the researcher for chip seal and striping. The works were presented in the following sub-sections.

4.3.1.1 Chip Seal

To evaluate chip seal qualities, a total of ten road sections were selected with criteria as explained in section 3.4.1. Out of ten, four-road sections (US XX LN, SR XXX ES, US XX EL, and US XX NY) chip sealed by In-House method and six road sections (SR XXX CH, US XX CL, US XX LN, SR XXX LA, SR XXX WA, and SR XXX EL) were chip sealed by MBC method with different contractors. There were no chip seal works performed by PBC method in Nevada. Table 4.13 shows the details of the ten road section evaluated during a site visit. The AADT data for 2012 were presented for each of the road sections.

Table 4.13. Road Section Details of Chip Seal Evaluation Work

Methods of Maintenance	Road Name	County	Mileage	AADT	Contract Date
In-House	US XX	LN	64-80	2,100	2012
	SR XXX	ES	0-25	250	2012
	US XX	EL	74-83	1,450	2011
	US XX	NY	2-26	625	2011
Private Contractors under MBC	SR XXX	CH	0-27	60	2014
	US XX	CL	52-68	2,250	2012
	US XX	LN	109-132	1,200	2012
	SR XXX	LA	69-97	1,650	2012
	SR XXX	WA	10-25	933	2013
	SR XXX	EL	112.9-127.5	633	2014

The quality of chip seal was evaluated using five criteria – presence of pot holes, loss of aggregate, presence of cracks on the surface, presence of rutting, and uniform distribution of aggregate on the surface. Using these criteria, the aforementioned ten road sections were evaluated to compare the chip seal works performed by the In-House versus Out-Sourcing under MBC method. The on-site evaluation data were analyzed using Analysis of Variance (ANOVA) to compare the mean difference of works performed by In-House and MBC methods. The result of the analysis is presented in Table 4.14. The result showed that the mean rating for two criteria—'loss of aggregate' and 'presence of cracks on the surface' when performed by In-House method were significantly high rated than when performed by

MBC method. This indicated that the chip seal works performed by In-House method had lower loss of aggregate and lower presence of cracks on the pavement as compared to the MBC performed chip seals. Regarding presence of rutting and uniform distribution of aggregate on the surface, there was numerical difference for the works performed by two parties. On average, the mean rating of chip seal performed by In-House were significantly high rated than when performed by private contractors under MBC method.

Table 4.14. Researchers' Evaluation of Chip Seal Performed by In-House and MBC Contractors

S.N.	Description	Maintenance Methods	N	Mean	Std. Dev.	P-Value
1	Presence of pot holes	In-House	120	5.00	0.00	N/A
		MBC	186	5.00	0.00	
2	Loss of aggregate	In-House	120	4.98	0.16	0.02*
		MBC	186	4.82	0.68	
3	Presence of cracks on the surface	In-House	120	4.62	0.55	<0.01*
		MBC	186	3.51	1.38	
4	Presence of rutting	In-House	120	4.97	0.18	0.70
		MBC	186	4.96	0.23	
5	Uniform distribution of aggregate on the surface	In-House	120	5.00	0.00	0.26
		MBC	186	4.97	0.31	
	Average	**In-House**	**120**	**4.91**	**0.12**	**<0.01***
		MBC	**186**	**4.65**	**0.10**	

* Significant at alpha level 0.05

Figure 4.2 shows the chip seal road surface maintained by In-House and Out-Sourcing under MBC methods. The first row of pictures has shown four road sections maintained by In-House method, and the second row four pictures maintained by private contractors under MBC method. Additional photographs have been shown in the Appendix L.

Figure 4.2 Photos of road sections with chip seal performed by In-House and MBC methods.

4.3.1.2 Striping

To evaluate the striping qualities, all together nine road sections were evaluated; four/four road sections were performed by In-House and MBC methods, and one road section was performed by PBC method were evaluated. There was only one road section performed by PBC method in Nevada that was evaluated for this study. Table 4.15 shows the details of the nine road section evaluated during a site visit.

Table 4.15. Road Section Details of Striping Evaluation Work

Methods of Maintenance	Name of Roads	County	Mile Post	AADT	Contract Date
In-House	US XX	CL	21-56	6,600	2012
	SR XXX	CL	0-9	6,250	2012
	SR XXX	CL	22-43	41,000	2013
	US XX	CL	97-132	3,300	2013
MBC	US XX	CL	52-68	2,250	2011
	US XX	CH	0-15	2,600	2011
	US XX	LN	109-132	1,200	2011
	US XX	MI	83-92	2,500	2011
PBC	US XX	CL	0-21	6,600	2012-2017

The quality of striping works were evaluated under three criteria–the striping on the road is visible during the day, the striping on the road is visible at night, and the striping on the road is continuous and was painted at right alignment. Using these three criteria, the abovementioned nine road sections were evaluated to compare the works performed by In-House, Out-Sourcing under MBC and PBC methods. Table 4.16 shows the mean ratings of the striping works performed by the three methods. ANOVA test was conducted to determine the mean differences of the striping qualities under these criteria. The result of the analysis is presented in Table 4.16. For the visibility during the day, the striping performed by PBC and MBC were significantly high rated when performed by In-House method than when performed by In-House method; however, the mean difference between PBC and MBC was not significant. For the visibility at night, the striping performed by PBC was significantly higher than when performed by In-House method and MBC; however, the mean difference between In-House and MBC was not significant. On average, the mean rating of striping performed by PBC method was significantly high rated than when performed by other two methods, followed by MBC method and In-House method. A study conducted in Mississippi DOT revealed that the deterioration rate of pavements performed by warranty provider contracts was slower than when performed by contractors who did not provided warranty (Yan et al. 2013).

Table 4.16. Results of Researchers' Evaluation of Striping Works

S.N.	Description	Maintenance Methods	N	Mean	Std. Dev.	P-Value
1	Striping visible during day	In-House	132	4.77	0.42	<0.01*
		MBC	122	5.00	0.00	
		In-House	132	4.77	0.00	<0.01*
		PBC	32	5.00	0.00	
		MBC	122	5.00	0.00	N/A
		PBC	32	5.00	0.00	
2	Striping visible during night	In-House	132	4.00	0.00	N/A
		MBC	122	4.00	0.00	
		In-House	132	4.00	0.00	<0.01*
		PBC	32	5.00	0.00	
		MBC	122	4.00	0.00	<0.01*
		PBC	32	5.00	0.00	
3	Striping line is continuous and at right alignment	In-House	132	4.91	0.31	<0.01*
		MBC	122	5.00	0.00	
		In-House	132	4.91	0.31	0.92
		PBC	32	4.90	0.30	
		MBC	122	5.00	0.00	<0.01*
		PBC	32	4.90	0.30	
	Average	**In-House**	**132**	**4.56**	**0.17**	**<0.01***
		MBC	**122**	**4.67**	**0.01**	
		In-House	**132**	**4.56**	**0.17**	**<0.01***
		PBC	**32**	**4.97**	**0.10**	
		MBC	**122**	**4.67**	**0.01**	**<0.01***
		PBC	**32**	**4.97**	**0.10**	

* Significant at alpha level 0.05

Figure 4.3 shows the pictures of striping lines maintained by In-House and Out-Sourcing under MBC and PBC methods. From the top left, the first three pictures (US 95 CL, SR 163 CL, and SR 160 CL) were of maintained by In-House; the second three pictures (US 95 CL, US 93 CL, and US 95 CH) were maintained by Out-Sourcing under MBC method; and the third three pictures (US 93 LN, US 95 CL, and US 95 CL) were maintained by Out-Sourcing under PBC method. The last three pictures (US 95CH, US 93 LN, and US 95 CL) were taken at night, which were maintained by In-House, Out-Sourcing under MBC and PBC methods respectively. Additional photographs are presented in the Appendix M.

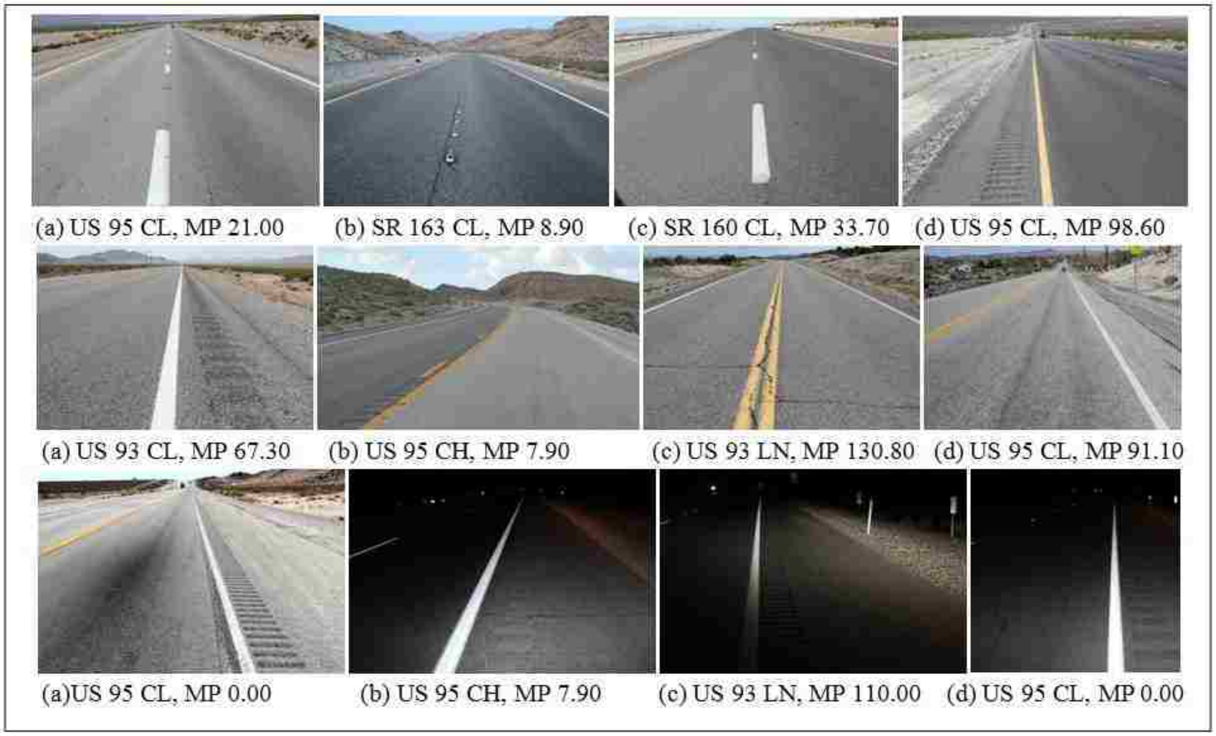


Figure 4.3. Photos of Striping Performed by In-House and Private Contractors under MBC and PBC Methods

4.3.2 Rating Surveys for Quality Satisfaction of Maintenance Activities

To validate the on-site quality evaluation of chip seal and striping works, three surveys were conducted to assess the quality of chip seal and striping. The surveys were conducted with local road users of selected road sections, NDOT personnel, and private contractor personnel. The details of the each of the survey are presented in the following sub-sections.

4.3.2.1 Survey with users of selected road sections

After maintenance work is done, the local road users of selected road sections (where on-site evaluations were conducted) were asked to provide their satisfaction levels on the quality of chip seal and striping works performed by In-House and private contractors. In this survey, the agency which performed the maintenance works was kept anonymous so that the local road users would not favor. The results of the survey were described in the following two sub-sections.

4.3.2.1.1 Chip Seal

A survey was conducted to assess the satisfaction levels of local road users on the chip seal quality performed by In-House and private contractors under MBC method. The survey was conducted for all ten road sections where on-site investigations were performed. To collect the satisfaction levels of the road users, three criteria were developed for the survey. They were 1) the surface of chip-sealed roads are smooth and have little loose aggregate, 2) the ride quality of the road is comfortable at posted speeds, and 3) proper traffic control was provided during construction. On this survey, the users were asked to rate the criteria on the scale of 1 to 5. An ANOVA test was conducted to the mean difference between the ratings provided for In-House and MBC performed works. Table 4.17 shows the result that the mean rating of chip seal performed by In-House were significantly higher than when performed by MBC.

Table 4.17. Results of Road Users' Evaluation of Chip Seal Works

S.N.	Description	Methods of Maintenance	N	Mean	Std. Dev.	P-Value
1	The surface of chip-sealed roads are smooth and have little loose aggregate	In-House	123	4.82	0.44	<0.01*
		MBC	87	4.56	0.73	
2	The ride quality of the road is comfortable at posted speeds	In-House	123	4.75	0.49	<0.01*
		MBC	87	4.29	0.90	
3	Proper traffic control was provided during construction	In-House	25	4.96	0.20	0.01*
		MBC	22	4.63	0.58	
	Average	**In-House**	**126**	**4.79**	**0.40**	**<0.01***
		MBC	**119**	**4.44**	**0.75**	

* Significant at alpha level 0.05

4.3.2.1.2 Striping

Similar to the chip seal, a survey was conducted to assess the satisfaction levels of local road users on striping quality performed by In-House and private contractors under MBC and PBC methods. This survey was also conducted for all nine road sections where on-site investigations were performed. To collect the local users' satisfaction levels, three criteria were used. They were 1) the striping on the road is visible during the day, 2) the striping on the road is visible during at night, and 3) provided proper traffic control or warning signs during striping. On this survey also, the users were asked to rate on the same scale of 1 to 5. An ANOVA test was conducted to see the mean difference among the ratings provided for In-House and private contractors under MBC and PBC methods. Table 4.18 shows the result that the mean rating of the striping visible during day, the work performed by PBC method was significantly high rated than when performed by In-House and MBC methods, followed by MBC and In-House methods. For the striping lines visible at night and on overall average of the three criteria, the mean rating of striping performed by private contractors under PBC method was significantly higher than when performed by In-House and private contractors under MBC method, followed by MBC and In-House methods; however, the mean difference between MBC and In-House was not significant.

Table 4.18. Results of Road Users' Evaluation of Striping Work

S.N.	Description	Methods of Maintenance	N	Mean	Std. Dev.	P-Value
1	The striping on the road is visible during the day	In-House	124	4.69	0.71	0.03*
		MBC	136	4.84	0.37	
		In-House	124	4.69	0.71	0.02*
		PBC	31	5.00	0.00	
		MBC	136	4.84	0.37	0.02*
		PBC	31	5.00	0.00	
2	The striping on the road is visible during at night	In-House	121	4.29	1.07	0.85
		MBC	120	4.27	0.73	
		In-House	121	4.29	1.07	0.03*
		PBC	31	4.71	0.46	
		MBC	120	4.27	0.73	<0.01*
		PBC	31	4.71	0.46	
3	Provided proper traffic control or warning signs during striping	In-House	64	4.64	0.74	0.02*
		MBC	66	4.88	0.37	
		In-House	64	4.64	0.74	0.10
		PBC	12	5.00	0.00	
		MBC	66	4.88	0.37	0.27
		PBC	12	5.00	0.00	
Average		**In-House**	**124**	**4.56**	**0.71**	**0.26**
		MBC	**136**	**4.64**	**0.43**	
		In-House	**124**	**4.56**	**0.71**	**0.02***
		PBC	**31**	**4.85**	**0.23**	
		MBC	**136**	**4.64**	**0.43**	**<0.01***
		PBC	**31**	**4.85**	**0.23**	

* Significant at alpha level 0.05

4.3.2.2 Quality Satisfaction Survey with NDOT personnel

Another survey was conducted with NDOT maintenance division personnel to assess their satisfaction levels on quality of chip seal and striping works performed by In-House and private contractors under MBC method. In this survey, the respondents were asked to provide their overall satisfaction levels on the performance of works performed by the In-House and MBC methods rather than asked for a specific road section. The results of the survey were described in the following two sub-sections.

4.3.2.2.1 Chip Seal

A survey was conducted to assess the overall satisfaction levels on the chip seal quality performed by In-House and private contractor under MBC method. This survey was conducted using online survey—Qualtrics. In this survey, unlike the survey with local road users, the NDOT maintenance division personnel were asked to give their overall perception towards satisfaction levels on works performed by In-House and MBC methods. To evaluate their satisfaction levels, five criteria were considered. They were 1) the surface of roads are smooth and have little loss of chips, 2) the ride quality of road is comfortable at posted speed, 3) provided proper traffic control during construction, 4) quality of materials used, and 5) quality of workmanship. On this survey, the division personnel were asked to rate on the same scale of 1 to 5. The ratings of the personnel for In-House and MBC maintained road sections were statistically compared using ANOVA. Table 4.19 presents the result that the NDOT personnel significantly high rated for the chip seals performed by In-House than when performed by MBC method for all five criteria.

Table 4.19. Results for Chip Seal Ratings Provided by NDOT Personnel

S.N.	Criteria	Maintenance Methods	N	Mean	Std. Dev.	P-Value
1	The surface of roads are smooth and have little loss of chips	In-House MBC	35 36	4.74 2.14	0.44 1.02	<0.01*
2	The ride quality of road is comfortable at posted speed	In-House MBC	35 36	4.71 2.92	0.46 0.94	<0.01*
3	Provided proper traffic control during construction	In-House MBC	35 36	4.89 2.75	0.32 1.16	<0.01*
4	Quality of materials used	In-House MBC	35 36	4.60 3.17	0.55 1.16	<0.01*
5	Quality of workmanship	In-House MBC	35 36	4.91 1.94	0.28 0.80	<0.01*
Average		**In-House** **MBC**	**35** **36**	**4.77** **2.58**	**0.33** **0.86**	**<0.01***

* Significant at alpha level 0.05

4.3.2.2.2 Striping

Similar to the chip seal in the previous sub-section, to assess the satisfaction levels on the striping quality performed by In-House and private contractors under MBC method, an online survey was conducted with NDOT maintenance division personnel. In this survey also, the NDOT maintenance division personnel were asked to give their overall perception towards satisfaction levels on works performed by In-House and MBC method. To assess the satisfaction levels, five criteria were considered. They were 1) the striping on the road is visible during the day, 2) the striping on the road is visible during at night, 3) provided proper traffic or warning signs control during striping, 4) quality of materials used, and 5) quality of workmanship. To collect the satisfaction levels with the division personnel, they were asked to rate the five criteria on the same scale of 1 to 5. The ratings of the divisional personnel for the striping works performed by In-House and MBC method were statistically compared using ANOVA. The result of this analysis is presented in Table 4.20. The result showed that the NDOT personnel significantly high rated for the striping works performed by In-House than when performed by private contractors for all five criteria.

Table 4.20. Results of Striping Ratings Provided by NDOT Personnel

S.N.	Criteria	Maintenance Methods	N	Mean	Std. Dev.	P-Value
1	The striping on the road is visible during the day	In-House	30	4.50	0.68	<0.01*
		MBC	30	3.83	0.95	
2	The striping on the road is visible during at night	In-House	30	4.20	0.85	0.02*
		MBC	29	3.66	0.94	
3	Provided proper traffic or warning signs control during striping	In-House	30	4.33	0.88	<0.01*
		MBC	29	3.28	0.96	
4	Quality of materials used	In-House	29	4.21	0.77	<0.01*
		MBC	30	3.43	1.00	
5	Quality of workmanship	In-House	30	4.37	0.89	<0.01*
		MBC	30	3.33	0.96	
Average		**In-House**	**30**	**4.33**	**0.75**	**<0.01***
		MBC	**30**	**3.49**	**0.89**	

* Significant at alpha level 0.05

4.3.2.3 Rating Survey for Quality Satisfaction with Private Contractors

As same to the previous survey with NDOT maintenance division personnel, another survey was conducted with the private contractors' personnel who had performed the chip seal and striping works with NDOT. They were also asked to provide their overall satisfaction levels on the chip seal and striping works performed by In-House and private contractors under MBC methods. The survey results were discussed in the following two sub-sections.

4.3.2.3.1 Chip seal

To assess the overall quality of chip seal, an online survey was also conducted with Nevada private contractors' personnel asking them to provide their satisfaction levels with the works performed by NDOT (In-House) and private contractors under MBC methods. In this survey, the private contractors' personnel were asked to give their overall perception rather than to give for a specific road section. For this survey also, the same five criteria were considered. They were 1) the surface of roads are smooth and have little loss of chips, 2) the ride quality of road is comfortable at posted speed, 3) provided proper traffic control during construction, 4) quality of materials used, and 5) quality of workmanship. The respondents rated on the same scale of 1 to 5. Since there were limited number of contractors who had performed the chip seal works with NDOT, the sample size was small (5 responses). An ANOVA test was conducted to see the mean difference between the ratings provided for the chip seal works performed by In-House and MBC methods. Table 4.21 presents the result of the responses that for provided proper traffic control during construction, the respondents significantly high rated for the works performed by the private contractors under MBC method than for the works performed by In-House method. For other four criteria as well as on average ratings of the five criteria, the mean rating differences of chip seals performed by In-House and private contractor were not significant.

Table 4.21. Results Chip Seal Ratings Provided by Private Contractors

S.N.	Criteria	Maintenance Methods	N	Mean	Std. Dev.	P-Value
1	The surface of roads are smooth and have little loss of chips	In-House	5	4.00	0.71	0.35
		MBC	5	4.40	0.55	
2	The ride quality of road is comfortable at posted speed	In-House	5	4.00	0.71	0.35
		MBC	5	4.40	0.55	
3	Provided proper traffic control during construction	In-House	5	3.20	0.84	0.01*
		MBC	4	4.75	0.50	
4	Quality of materials used	In-House	5	3.80	0.84	0.20
		MBC	4	4.50	0.58	
5	Quality of workmanship	In-House	5	4	0.71	0.34
		MBC	5	4.40	0.55	
Average		**In-House**	**5**	**3.80**	**0.53**	**0.09**
		MBC	**5**	**4.44**	**0.52**	

* Significant at alpha level 0.05

4.3.2.3.2 Striping

Similar to the chip seal, to assess the overall satisfaction levels of quality of striping work performed by In-House and private contractors under MBC methods, an online survey was conducted with the personnel of Nevada private contractors who had performed striping works with NDOT. In this survey also, the private contractor personnel were asked to give their overall perception towards satisfaction levels with works performed by NDOT (In-House) and private contractors under MBC methods. The same five criteria were considered to assess the striping quality. They were 1) pavement striping is visible during the day, 2) pavement striping is visible during wet weather and night, 3) provided proper traffic or warning signs control during striping, 4) quality of materials used, and 5) quality of workmanship. The respondents were asked to rate on the same scale of 1 to 5. Four responses were received on this survey. To see the mean difference of the ratings provided for the striping works performed by the NDOT and private contractors' personnel, an ANOVA test was conducted. The result of this analysis is presented in Table 4.22. The result showed that the mean rating difference of striping performed by In-House and private contractors were not significant for all five criteria.

Table 4.22. Results of Striping Ratings Provided by Private Contractors

S. N.	Criteria	Maintenance Methods	N	Mean	Std. Dev.	P-Value
1	Pavement striping is visible during the day	In-House	4	3.50	1.29	0.62
		MBC	4	4.00	1.41	
2	Pavement striping is visible during wet weather and night	In-House	4	3.50	1.29	0.62
		MBC	4	4.00	1.41	
3	Provided proper traffic or warning signs control during striping	In-House	4	4.00	0.81	0.17
		MBC	4	4.75	0.50	
4	Quality of materials used	In-House	4	4.00	0.82	0.17
		MBC	4	4.75	0.50	
5	Quality of workmanship	In-House	4	4.00	0.82	0.17
		MBC	4	4.75	0.50	
	Average	**In-House**	**4**	**3.80**	**0.91**	**0.34**
		MBC	**4**	**4.45**	**0.85**	

4.4 Delphi Study

To develop a framework to implement the PBC for chip seal and striping, a Delphi study was conducted. For the Delphi study, invitations were sent to 62 qualified state DOT maintenance engineers and academicians. Several state DOTs have more than one individual who were qualified to participate in this Delphi study, and so they were invited. Out of 62, 42 (68%) individuals accepted the invitation to become—the panel members of the Delphi study. Table 4.23 shows the detail result of the responses.

Table 4.23. Delphi Study Phone Interview Responses

Description	Number of Respondents	Percentage	Number of State DOTs
Number of responses	42	68%	26
Number of rejected	10	16%	9
Number of non-responses	10	16%	9
Total questionnaire sent	**62**	**100%**	**44**

The Delphi study consisted of three rounds of survey conducted with the panel members. The first round was an open-ended-question-phone interview. In this phase, interviews were conducted to collect probable subjects (issues) in implementation of the PBC chip seal and striping in various phases. The second round was the online survey with rating type questions, and the third round was also online survey with ranking type questions. The results of each of the round were presented in the following three sub-sections.

4.4.1 Delphi Study Round One

There were three sections in the Delphi study first round phone interview. The sections were 1) general information, 2) chip seal, and 3) striping. In the first section – general information, name of the respondents, name of the organization, current position, total years of experience, experience in In-House, MBC, and PBC methods, and the respondent's areas of expertise were asked. Table 4.24 shows summary of experience of the panel members. It shows that the panel members have experience with PBC ranged from two months (0.17 years) to ten years with an average experience of six years. The panel members' experience with In-House and MBC was longer than with PBC, that could be because the PBC is relatively newer method in the United States. The results of the second and third sections of the phone interview are presented in the following sub-sections. The interview questions are presented in Appendix N.

Table 4.24. Years of Experience of the Delphi Panel Members

Experience	Range of Years of Experience	Average Years of Experience	No. of Responses Who Have Experience on
Experience in Transportation Area	8-44	25	42 (100%)
Experience with In-House method	0-39	18	41 (98%)
Experience with MBC method	5-39	18	41 (98%)
Experience with PBC method	0.17-10	6	27 (64%)

4.4.1.1 Chip Seal

In the second section of the phone interview, the respondents were asked 13 questions regarding PBC chip seal. This section was divided into three phases—contract document preparation, contract procurement, and contract implementation. The results of these phases were presented in the following sub-sections.

4.4.1.1.1 Contract Document Preparation Phase

The Delphi panel members were asked four questions regarding contract document preparation phase. The first question was the factors affecting the selection of PBC for chip seal. A total of 36 panel members answered this question, and responses indicated that the most important (based on frequency) five factors were:

1. Increase Level of Service (LOS) (22 responses),
2. Transfer risk to the contractor (11),
3. Save life-cycle cost (11)
4. Create innovation (9), and
5. Provide longer warranty for the work done by the contractor (8).

Other factors received were Increase work efficiency (7), to overcome lack of skilled workers within state DOTs (6), durability (6), Outcome-Based Contract (5), consider capacity of contractors (5), due to political decision (3), easy to manage (2), provide higher road user satisfaction (1), statutes law (1), and to assurance of long-term funding (1). The national survey result of this study and NCHRP (2003) also revealed that state DOTs outsourced their maintenance works due to unavailability of skilled staff. The panel members were asked about the performance measures of PBC for chip seal contracts. A total of 29 responses were received for this question. Based on the frequency of responses, the top three performance measures were 1) smoothness or friction test, 2) loss of aggregate, and 3) bleeding. Figure 4.4 shows the summary of responses.

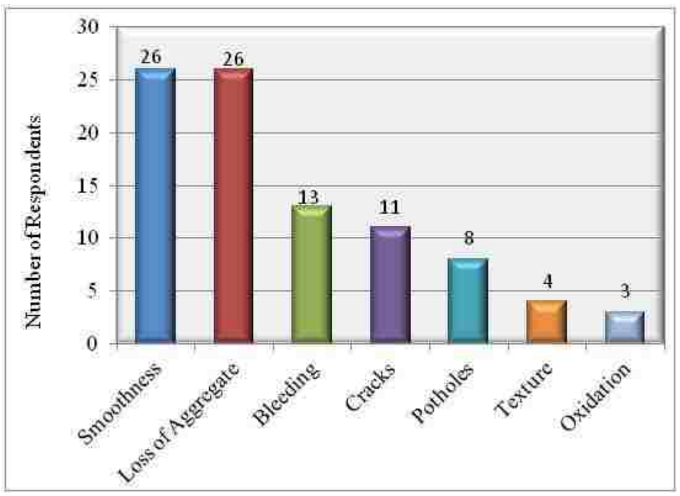


Figure 4.4 The Performance Measures of PBC Chip Seal

Then, the respondents were asked whether state DOTs should provide incentive/disincentives to the PBC chip seal contractor based on their performance. Thirty panel members answered this question, out of which, 23 respondents agreed on providing both incentives/disincentives, six agreed on providing only disincentives, and three were against on providing incentives and disincentives. The respondents who agreed on providing incentives and disincentives also stated that their ranges should be 1-10%. Some panel members also stated that disincentives should be comparatively more than incentives. The final question of this phase was whether the state-DOT-PBC-team personnel should be trained in the PBC chip seal before implementing the contract. Out of 40 respondents answered, 38 stated that they should be trained either In-House by bringing subject experts from other agency or the team should be sent to other agency if state DOT is implementing the PBC chip seal first time. Two respondents stated that no training was required for the PBC team.

4.4.1.1.2 Contract Procurement Phase

Regarding the contract procurement phase, three questions were asked. The first question was; who should be included on a PBC chip seal procurement team? Thirty-nine panel members answered this question. Almost all respondents stated that there should be a project manager or contract manager from maintenance division, a construction engineer, a material engineer, a district engineer, and a procurement/administration officer. The second question was; how long should be the contract duration of the PBC chip seal contract? The respondents indicated that the chip seal contract duration depends on various factors; however, it may vary from one to ten years. Specifically, 18 out of 34 respondents stated that the project duration should be in between three and five years. Figure 4.5 shows the summary of the responses. The third question was; what should be the contractor selection criteria for PBC chip seal? Out of 41 respondents, 26 stated that a PBC contractor should be selected using prequalification-based with low bid, and 15 stated that the best value procurement method should be used.

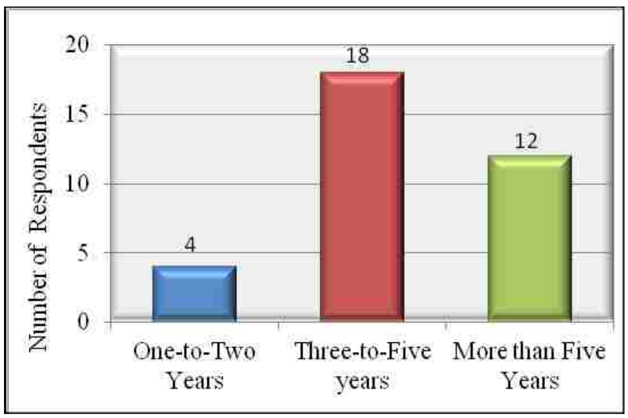


Figure 4.5 The Project Duration of PBC Chip Seal

4.4.1.1.3 Contract Implementation Phase

Regarding contract implementation phase, six questions were asked. The first question was related to the personnel to be included in the PBC implementation team? Out of 39 respondents, almost all stated that the implementation team members would be same as the procurement team members with swapping the procurement officer on the procurement team with inspectors. The second question was: how should the PBC chip seal contractor manage the traffic during the maintenance work? Out of 40 respondents answered, 16 stated that for low AADT (less than 3000) roads, the contractor may close one lane of road and detour the traffic with a pilot car; 15 stated that it depends on AADT of the road, work volume, and oil to be used for chip seal; some stated that the contractor should do the chip seal on interstate road work at night; some also stated that the department may ask proposal from the PBC contractor to manage the traffic during the maintenance work. The third question was how quickly (timeliness of response) the contractor has to fix the defects of the maintenance work during the warranty period? Out of 36 respondents, 20 stated that one to seven days, nine stated seven to 14 days, and four stated 14 to 30 days. The fourth question was who should perform the Quality Assurance (Q/A) work? Out of 40 panel members answered, 26 respondents stated that state DOT should perform the Q/A work. Figure 4.6 illustrates the summary of the responses.

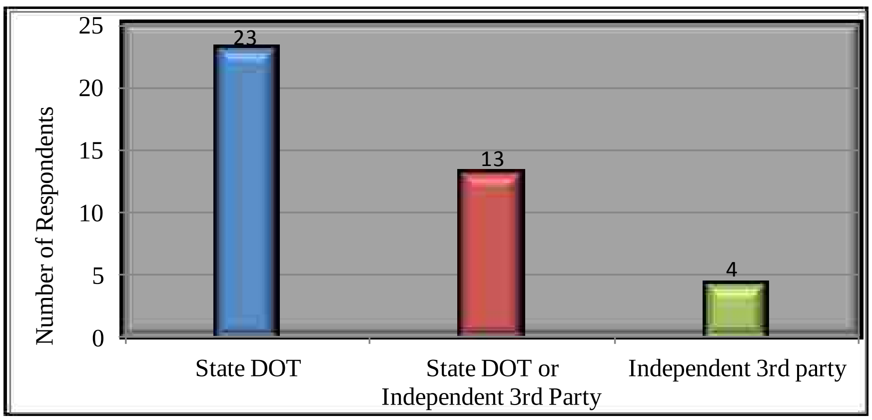


Figure 4.6 Parties to Conduct Quality Assurance of Chip Seal

Then, the respondents were asked about the monitoring frequency of chip seal work during the warranty period. Out of 33 respondents, 11 stated that agency should monitor the chip seal work annually, nine stated semi-annually, four stated quarterly, 11 stated monthly, and two stated randomly. Finally, the respondents were asked about a payment method to the PBC contractor. Out of 33 respondents provided their opinion, 25 stated the PBC chip seal contractor should be paid at initial acceptance and that amount depends on various factors (project size, cost of material and equipment), five respondents stated that initial payment should not be issued, and three stated initial payment should not be issued but more payment should be issued after the first chip seal placement is completed. After that, almost all the respondents stated that the remaining contract amount should be paid equally on a monthly basis.

4.4.1.2 Striping

In the third section of the phone interview, the respondents were asked 13 questions regarding PBC striping. The striping questions were very similar to the chip seal questions. This section was also divided into three phases—contract document preparation, contract procurement phase, and contract implementation phase. The results of these phases are presented in the following three sub-sections.

4.4.1.2.1 Contract Document Preparation Phase

The Delphi panel members were asked four questions regarding contract document preparation phase. The first question was factors affecting the selection of PBC striping. Thirty-Five respondents provided their opinion for this question. The responses indicated that the high frequency five factors were

1. Increase LOS (23 responses),
2. Transfer risk to the contractor (14),
3. Save life-cycle cost (10),
4. Last longer (10), and
5. Increased work efficiency (5).

Other factors were easy to manage (5), result-oriented contract (4), provide longer warranty (4), create Innovation (3), overcome lack of skilled workers within state DOTs (3), consider capacity of contractor (3), due to political decision (2), provide higher road user satisfaction (1), state statutes (1), and assure long-term funding (1). The national survey and the survey by NCHRP (2003) also showed that state DOTs outsourced their maintenance works due to unavailability of skilled staff. In the second question, performance measures to be used in PBC striping contracts were asked. Thirty-Eight respondents answered this question. The performance measures were retro-reflectivity, striping width, striping alignment, and striping color. All the respondents stated retro-reflectivity was the most important measure. Figure 4.7 shows the summary of the responses

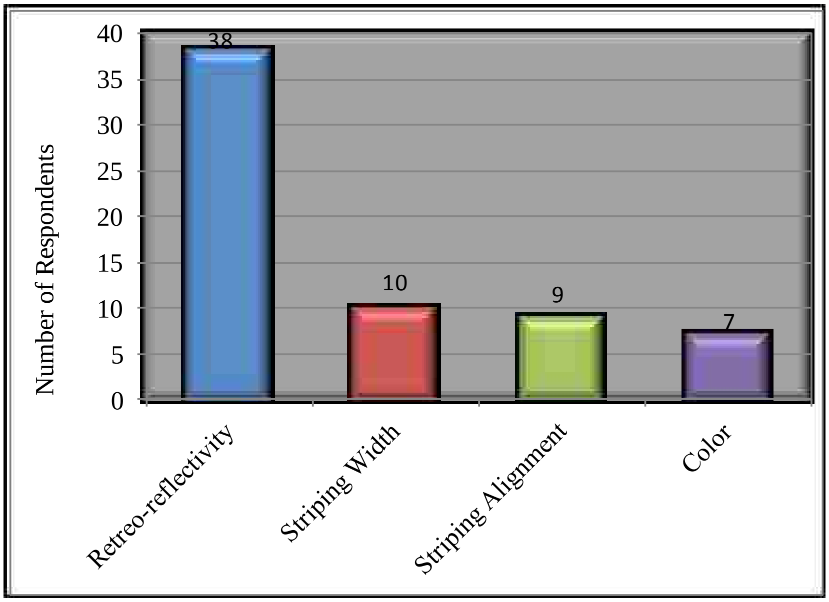


Figure 4.7 Performance Measures of PBC Striping

Then, the respondents were asked whether state DOTs should provide incentive/disincentives to the PBC striping contractor based on their performance. Out of 35, 20 respondents said that the PBC contractors should be provided both incentives/disincentives; six respondents were in the favor of providing only disincentives, and eight were in the favor of providing incentives and disincentives. The respondents who were in the favor of providing incentives and disincentives also stated that the range should be 1-10%. Some respondents stated that disincentives should be more than incentives. The final question of this phase was whether the state-DOT-PBC-team personnel should be trained in the PBC striping before implementing the contract. Forty responses were collected, out of which, 37 stated that they should be trained either In-House by bringing subject experts from other agency or the PBC team should be sent to other agency if state DOT is implementing the PBC striping first time. Three respondents stated no training is required for the PBC team.

4.4.1.2.2 Contract Procurement Phase

Regarding contract procurement phase, three questions were asked to the panel members. The first question was related to the personnel to be included in the PBC striping procurement team. Out of 39 respondents answered, almost all stated that there should be a project manager or contract manager from maintenance division, a construction engineer, a material engineer, a traffic or striping engineer, a district engineer, and a procurement/administration officer. The second question was; how long should be the contract duration of the PBC striping contracts? Although the responses were varied from one to ten years, 20 out of 37 respondents stated that the contract duration should be from three to five years. Figure 4.8 shows the summary of the respondents.

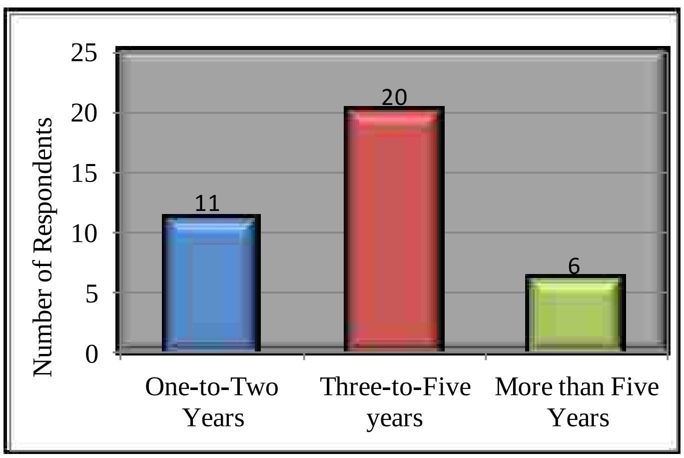


Figure 4.8 The Project Duration of PBC Striping Projects

The final question of this phase was regarding the contractor selection criteria for PBC striping. Out of 36 respondents, 19 stated that contractor should be selected using prequalification-based low bid, 16 stated that the Best-Value procurement method should be used, and one stated just no low bid.

4.4.1.2.3 Contract Implementation Phase

Six questions were asked regarding contract implementation phase. In the first question, the respondents were asked who should be included on the implementation team for PBC striping projects? Out of 39 respondents, almost all of them stated that the implementation team members would be same as the procurement team members with swapping the procurement officer on the procurement team with inspectors. The second question was how should the PBC striping contractor manage the traffic during the maintenance work? Out of 38 respondents answered, 18 stated that it depends on AADT of the road and work volume, and for AADT roads, the contractor may close one lane and detour the traffic with a pilot car; 15 stated that it depends on department plan; and five stated that striping should be done at off-peak period during the day or at night. The third question was how quickly the contractor has to fix the defects of the maintenance work during warranty period? Out 37 respondents answered, 26 stated that one to seven days, eight stated seven to 14 days, and three stated 14 to 30 days. The fourth question was; who should perform the Q/A work? Thirty-nine responses were received for this question, 24 respondents stated that state DOT should perform the Q/A work. Figure 4.9 illustrates the summary of the responses.

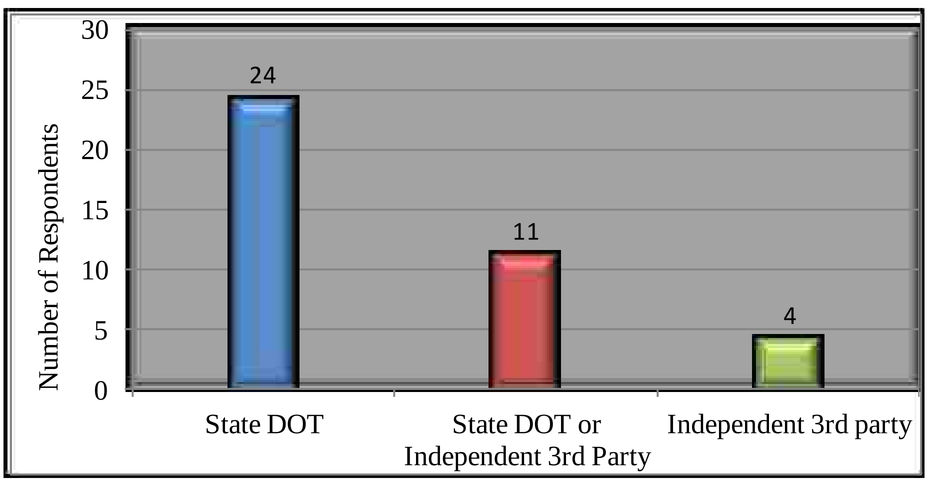


Figure 4.9 Agencies to Conduct Quality Assurance of Striping

Then, the respondents were asked about the monitoring frequency of striping work during the warranty period. Out of 42 respondents provided their opinion, 15 stated that agency should monitor striping work annually, 14 stated semi-annually, nine stated quarterly, and four stated monthly. Finally, the respondents were asked about a payment method to the PBC contractor. Out of 35 respondents answered this question, 24 stated that the PBC striping contractor should be paid in initial acceptance and that amount depends on various factors (project size, cost of material and equipment), one respondent stated that there should be a mobilization item to issue an initial acceptance amount, nine respondents stated that initial acceptance amount should not be issued, and one respondent stated that it should be finalized by negotiation. Then, almost all the respondents stated that the left contract amount should be paid equally on a monthly basis.

4.4.2 Delphi Study Round Two

After the Delphi study round one was completed, the round two was distributed at the start of November 2015 through online survey—Qualtrics. This survey was distributed to that 42 members who completed the first round phone interview, out of which 40 (95% response rate) panel members responded. There were two types of questions in this survey—30 were rating type and one was yes/no type. In this second round, the panel members were asked to rate the questions in a scale of 1 to 5, 5 being 'very important' and 1 being 'very unimportant.' The survey questions are presented in Appendix O. The ratings provided for each of the questions were collected, and then analyzed to see the panel members' consensus was achieved or how close the ratings were. To see the panel consensus, IntraClass Correlation test was conducted in SPSS. The Delphi study round two survey results were presented in the following two sub-sections.

4.4.2.1 Chip Seal

The second round Delphi study of chip seal can be divided into three phases. They are contract document preparation phase, contract procurement phase, and contract implementation phase. The results of each phase are presented in the following three sub-sections.

4.4.2.1.1 Contract Document Preparation Phase

In the contract document preparation phase, there were five questions. The panel members were asked to rate the subjects of each of the questions on a scale of 1 to 5. To test the panel consensus the ICC test was conducted in SPSS. Table 4.25 presents the ICC test results which shows the panel consensus of the responses was achieved (ICC average measure value greater than equal to 0.70) for all of the five questions. Therefore, Table 4.25 also presents the important subjects of the questions based on their average mean rating. The five important subjects affecting for the selection of PBC method for chip seal were result oriented contract, provide longer warranty, transfer risk to the contractor, increase work efficiency, and provide higher road user satisfaction. Similarly, the five important performance measures to evaluate the PBC chip seal were agree retention, bleeding, smoothness, texture, and cracks. The panel members also indicated that the incentives and disincentives should be provided to the PBC contractor in the range of 4% to 5%. Moreover, the PBC chip seal team personnel should be trained in their own DOT with bringing subject experts from other states.

Table 4.25. Results of Contract Document Preparation Phase of Chip Seal

Questions	N	Panel Consensus			Important Subjects (Avg. Rating[2])
		ICC	P-value	Consensus[1]	
Q.1 Please rate the following reasons that the previous phone interview participants had identified for using PBC for chip seal. Please rate on the scale of 1 to 5 (5 being 'very important' and 1 being 'very unimportant').	32	0.90	<0.01*	YES (Almost perfect consensus)	1. Result oriented contract (4.21) 2. Provide longer warranty (3.91) 3. Transfer risk to the contractor (3.88) 4. Increase work efficiency (3.82) 5. Provide higher road user satisfaction (3.76)
Q. 2 What performance measures should be used to evaluate the PBC chip seal contractor's work (after the work is done)?	32	0.92	<0.01*	YES (Almost perfect consensus)	1. Aggregate retention (4.74) 2. Bleeding (4.47) 3. Smoothness (4.29) 4. Texture (3.94) 5. Cracks (3.88)
Q.3 What incentives range should be provided to the PBC chip seal contractors based on their performance.	33	0.88	<0.01*	YES (Strong consensus)	4% to 5% (3.59)
Q. 4 What disincentives range should be provided to the PBC Chip Seal contractors based on their performance.	31	0.79	<0.01*	YES (Moderate consensus)	4% to 5% (3.64)
Q. 5 The participants had stated that the state DOT personnel who will potentially involve in PBC Chip Seal should be trained if they are using the PBC Chip Seal for the first time. Which method of training do you prefer?	34	0.96	<0.01*	YES (Almost perfect consensus)	Use In-House training bringing subject experts from other states (4.36)

[1] IntraClass Correlation Coefficient. More than the ICC value of 0.70 is considered as panel consensus achieved.
[2] Panel members rated the subjects on a scale of 1 to 5. The average rating is the mean rating score of the panel members.

4.4.2.1.2 Contract Procurement Phase

There were three rating questions in contract procurement phase. The panel members provided rating scores for the subjects of each of the questions on the same scale of 1 to 5. Table 4.26 presents the ICC test results that show panel consensus was achieved for all of the three questions. Therefore, Table 4.26 also presents the important subjects of the three questions. The respondents indicated that the five important procurement team members for the PBC chip seal were project/construction manager, state/district pavement engineer, construction engineer, procurement officer, and design engineer. The result also indicated that the most appropriate PBC chip seal contract duration was three-to-five years; in a follow up question, almost all the panel members stated that they considered the snow plough while answering for the contract duration of the chip seal contracts. Moreover, they also indicated that the PBC chip seal contractor should be selected based on 'pre-qualification then low-bid method.'

Table 4.26. Results of Contract Procurement Phase of Chip Seal

Questions	N	Panel Consensus			Important Subjects with Avg. Rating Value
		ICC	P-value	Consensus	
Q.1 From state DOTs, who should be included on the procurement team of PBC Chip Seal? Please rate on the scale of 1 to 5 (5 being 'very appropriate person' and 1 being 'very inappropriate person').	31	0.80	<0.01*	YES (Strong consensus)	1. Project manager or construction manager (4.53) 2. State or district pavement engineer (4.21) 3. Construction engineer (4.00) 4. Procurement Officer (3.94) 5. Design engineer (3.85)
Q. 2 How long should the duration of Performance-Based Chip Seal contract be?	33	0.96	<0.01*	YES (Almost perfect consensus)	Three-to-five years (4.14)
Q.3 How should the PBC Chip Seal contractor be selected?	32	0.77	<0.01*	YES (Moderate consensus)	Pre-qualification then low-bid method (3.70)

[1] IntraClass Correlation Coefficient. More than the ICC value of 0.70 is considered as panel consensus achieved.
[2] Panel members rated the subjects on a scale of 1 to 5. The average rating is the mean rating score of the panel members.

4.4.2.1.3 Contract Implementation Phase

In the contract implementation phase, there were seven questions. The panel members were asked to rate the subjects of each of the questions. Table 4.27 presents the ICC test result that the panel consensus was achieved for six out of seven questions. Therefore, for the six questions, important subjects were identified. The results indicated that five important PBC chip seal implementation team members were project/construction manager, construction engineer, quality assurance team, inspectors, and material engineer. The result also indicated that for minimum traffic disruption during the chip sealing work, the state DOT should get proposal from the contractor and department decides on that. Regarding the response time for the defects on chip seal surface after Q/A team identifies them if the severity of the defect was significant and effecting traffic to drive at posted speed, the result indicated that contractor should fix them in one-to-three days. For another question, if the defects were not significant and effecting traffic to drive at posted speed, the panel consensus was not established; therefore, this question was again asked to the panel members in third round. Moreover, the result indicated that the Q/A work should be conducted by state DOT, and they should conduct the monitoring works semi-annually. Furthermore, regarding the initial payment (mobilization) to the contractor, the result indicated that the initial payment should be a bid item.

Table 4.27. Results of Contract Document Preparation Phase of Chip Seal

Questions	N	Panel Consensus			Important Subjects with Avg. Rating Value
		ICC	P-value	Consensus	
Q.1 From state DOTs, who should be included on the implementation team for PBC Chip Seal. Please rate on the scale of 1 to 5 (5 being 'very appropriate person' and 1 being 'very inappropriate person').	32	0.83	<0.01*	YES (Strong consensus)	1. Project manager or construction manager (4.56) 2. Construction engineer (4.38) 3. Quality assurance team (4.24) 4. Inspectors (4.12) 5. Material engineer (4.06)
Q. 2 Please rate the following clauses for the Performance-Based Chip Seal contract to get minimum traffic disruption during Chip Sealing work. Assuming the road section is two-lane-two-way state route.	33	0.70	<0.01*	YES (Moderate consensus)	Get proposal from contractor and department decides on that (3.66)
Q. 3 After Chip Seal is done, how timely should PBC Chip Seal contractor fix the defects after Q/A team identifies it. **Case 1: If the severity of the defect is significant and effecting traffic to drive at posted speed.**	30	0.97	<0.01*	YES (Almost perfect consensus)	One to three days (4.13)
Q. 4 After Chip Seal is done, how timely should PBC Chip Seal contractor fix the defects after Q/A team identifies it. **Case 2: If the severity of the defect is not significant and not effecting traffic to drive at posted speed.**	31	0.60	<0.01*	NO (Fair consensus)	
Q. 5 Who should perform the Quality Assurance (Q/A) of performance-based Chip Seal contractor's work after the first Chip Sealing is done?	32	0.92	<0.01*	YES (Almost perfect consensus)	State DOT for entire duration (4.33)
Q. 6 What should be the monitoring frequencies for Q/A in the PBC Chip Seal contract after the work is done? If there is no snow plough for almost year round.	29	0.96	<0.01*	YES (Almost perfect consensus)	Semi-annually (4.06)
Q. 7 What should the initial payment method for the PBC Chip Seal contractor be?	29	0.92	<0.01*	YES (Almost perfect consensus)	Mobilization should be a bid item (4.00)

[1] IntraClass Correlation Coefficient. More than the ICC value of 0.70 is considered as panel consensus achieved.
[2] Panel members rated the subjects on a scale of 1 to 5. The average rating is the mean rating score of the panel members.

4.4.2.2 Striping

The second round Delphi study results of striping were presented in three phases—contract document preparation, contract procurement, and contract implementation. The questions and number of subjects were very similar to the chip seal section. The results of each phase are presented in the following three sub-sections.

4.4.2.2.1 Contract Document Preparation Phase

In the contract document preparation phase, there were five questions. The panel members were asked to rate the subjects of each of the questions in the same scale of 1 to 5. Table 4.28 presents the results that panel consensus was achieved for all of the five questions. Therefore, the important subjects for each of the questions were identified based on their average mean rating. The five important subjects affecting the selection of PBC striping were result oriented contract, provide longer warranty, last longer, save life-cycle cost, and transfer risk to the contractor. Similarly, the four important performance measures of the PBC striping were retro-reflectivity, alignment, striping width, and color. The panel members also indicated that the incentives and disincentives should be provided to the contractor in the range of 1%-3% and 4%-5% respectively. Moreover, the PBC striping team personnel should be trained in their own DOT with bringing subjects from other states.

Table 4.28. Results of Contract Document Preparation Phase of Striping

Questions	N	Panel Consensus			Important Subjects with Avg. Rating Value
		ICC	P-value	Consensus	
Q.1 Please rate the following reasons that the previous phone interview participants had identified for using PBC for striping. Please rate on the scale of 1 to 5 (5 being 'very important' and 1 being 'very unimportant').	35	0.86	<0.01*	YES (Strong consensus)	1. Result oriented contract (4.08) 2. Provide longer warranty (4.00) 3. Last Longer (3.92) 4. Save Life-Cycle Cost (3.81) 5. Transfer risk to the contractor (3.72)
Q. 2 What performance measures should be used to evaluate the PBC striping contractor's work (after the work is done)?	35	0.92	<0.01*	YES (Almost perfect consensus)	1. Retro-reflectivity (4.86) 2. Alignment (4.57) 3. Striping width (4.00) 4. Color (3.86)
Q.3 What incentives range should be provided to the PBC striping contractors based on their performance.	33	0.79	<0.01*	YES (Moderate consensus)	1% to 3% (3.29)
Q. 4 What disincentives range should be provided to the PBC striping contractors based on their performance.	33	0.70	<0.01*	YES (Moderate consensus)	4% to 5% (3.45)
Q. 5 The participants had stated that the state DOT personnel who will potentially involve in PBC Chip Seal should be trained if they are using the PBC Chip Seal for the first time. Which method of training do you prefer?	36	0.99	<0.01*	YES (Almost perfect consensus)	Use In-House training bringing subject experts from other states (4.26)

[1] IntraClass Correlation Coefficient. More than the ICC value of 0.70 is considered as panel consensus achieved.
[2] Panel members rated the subjects on a scale of 1 to 5. The average rating is the mean rating score of the panel members.

4.4.2.2.2 Contract Procurement Phase

There were three rating questions in contract procurement phase. The panel members were asked to rate the subjects of each of the questions on the same scale of 1 to 5. Table 4.29 presents the results of the ICC test that the panel consensus was achieved for all of the three questions. Therefore, Table 4.29 presents the important subjects identified for each of the questions. The result also indicated that the five important procurement team members of the PBC striping were project/construction manager, striping/traffic engineer, procurement officer, material engineer, and supervisor. Moreover, the result indicated that the PBC striping contract duration should be three-to-five years; in a follow up question, almost all the panel members indicated that they considered the snow plough while rating the contract duration of the striping contracts. Furthermore, the result indicated that the PBC striping contractor should be selected based on 'pre-qualification then low-bid method.'

Table 4.29. Results of Contract Procurement Phase of Striping

Questions	N	Panel Consensus			Important Subjects with Avg. Rating Value
		ICC	P-value	Consensus	
Q.1 From state DOTs, who should be included on the procurement team of PBC striping? Please rate on the scale of 1 to 5 (5 being 'very appropriate person' and 1 being 'very inappropriate person').	35	0.74	<0.01*	YES (Moderate consensus)	1. Project manager or construction manager (4.36) 2. Striping or traffic engineer (4.11) 3. Procurement Officer (3.92) 4. Material engineer (3.86) 5. Supervisor (3.75)
Q. 2 How long should the duration of Performance-Based striping contract be?	35	0.96	<0.01*	YES (Almost perfect consensus)	Three-to-five years (4.03)
Q.3 How should the PBC striping contractor be selected?	35	0.75	<0.01*	YES (Moderate consensus)	Pre-qualification then low-bid method (3.64)

[1] IntraClass Correlation Coefficient. More than the ICC value of 0.70 is considered as panel consensus achieved.
[2] Panel members rated the subjects on a scale of 1 to 5. The average rating is the mean rating score of the panel members.

4.4.2.1.3 Contract Implementation Phase

In the contract implementation phase, seven questions were asked to the panel members on the same scale of 1 to 5. Table 4.30 presents the ICC test result that the panel consensus was established for six out of seven questions. For those six questions, important subjects were identified. The results indicated that five important PBC striping implementation team members were project/construction manager, Q/A team, striping/traffic engineer, construction engineer, and inspectors. The result also indicated that for minimum traffic disruption during the striping work, the state DOT should get proposal from the contractor and department decides on that. Regarding the response time for the defects on striping lines after Q/A team identifies them if the severity of the defect was significant and effecting traffic to drive at posted speed, the panel members indicated that contractor should fix them in one-to-three days. For another question, if the defects were not significant and effecting traffic to drive at posted speed, the panel consensus was not achieved; therefore, this question was again asked to the panel members in third round. Moreover, the result indicated that the Q/A work should be conducted by state DOT, and they should conduct the monitoring works semi-annually. Furthermore, regarding the initial payment to the contractor, the result indicated that the initial payment should be a bid item.

Table 4.30. Results of Contract Document Preparation Phase of Striping

Questions	N	Panel Consensus			Important Subjects with Avg. Rating Value
		ICC	P-value	Consensus	
Q.1 From state DOTs, who should be included on the implementation team for PBC striping. Please rate on the scale of 1 to 5 (5 being 'very appropriate person' and 1 being 'very inappropriate person').	35	0.84	<0.01*	YES (Strong consensus)	1. Project manager or construction manager (4.47) 2. Q/A team (4.19) 3. Striping or traffic engineer (4.11) 4. Construction engineer (3.94) 5. Inspectors (3.91)
Q. 2 Please rate the following clauses for the Performance-Based striping contract to get minimum traffic disruption during striping work. Assuming the road section is two-lane-two-way state route.	36	0.91	<0.01*	YES (Almost perfect consensus)	Get proposal from contractor and department decides on that (3.84)
Q. 3 After striping is done, how timely should PBC striping contractor fix the defects after Q/A team identifies it. **Case 1: If the severity of the defect is significant and effecting traffic to drive at posted speed.**	32	0.95	<0.01*	YES (Almost perfect consensus)	One to three days (3.91)
Q. 4 After striping is done, how timely should PBC striping contractor fix the defects after Q/A team identifies it. **Case 2: If the severity of the defect is not significant and not effecting traffic to drive at posted speed.**	33	0.05	<0.01*	NO (Fair consensus)	
Q. 5 Who should perform the Quality Assurance (Q/A) of performance-based striping contractor's work after the first Chip Sealing is done?	35	0.89	<0.01*	YES (Strong consensus)	State DOT for entire duration (4.11)
Q. 6 What should be the monitoring frequencies for Q/A in the PBC striping contract after the work is done? If there is no snow plough for almost year round.	32	0.96	<0.01*	YES (Almost perfect consensus)	Semi-annually (4.21)
Q. 7 What should the initial payment method for the PBC striping contractor be?	33	0.84	<0.01*	YES (Strong consensus)	Mobilization should be a bid item (3.62)

[1] IntraClass Correlation Coefficient. More than the ICC value of 0.70 is considered as panel consensus achieved.
[2] Panel members rated the subjects on a scale of 1 to 5. The average rating is the mean rating score of the panel members.

4.4.3 Delphi Study Round Three

4.4.3.1 Chip Seal and Striping

In the previous Delphi study round two survey, panel consensus was not achieved for two questions. Therefore, those two questions were resent to the panel members asking them to rank the subjects in a scale of 1 to 5, 1 being 'very appropriate time period' and 5 being 'very inappropriate time period.' The survey questions are presented in Appendix P. The round three survey was also distributed through online survey—Qualtrics at the start of the January 2016. This survey was distributed to those 40 members who completed the round two survey, out of which 35 (88% response rate) panel members responded. To see the panel consensus, the ICC test was conducted in SPSS.

Table 4.31 presents the ICC test result of the round three survey responses, which showed that a strong panel consensus was achieved for both of the questions. Therefore, the important subjects were identified for both of the questions—the defects on chip seal and striping after Q/A team identifies them if the severity of the defect was not significant and not effecting traffic to drive at posted speed, the results indicated that contractor should fix them in eight-to-fourteen days for chip seals and fifteen-to-twenty days for striping.

Table 4.31. Results of Contract Procurement Phase of Striping

Questions	N	Panel Consensus			Important Subjects with Avg. Rating Value
		ICC	P-value	Consensus	
Q. 1 After chip seal is done, how timely should PBC chip seal contractor fix the defects after Q/A team identifies it. **Case 2: If the severity of the defect is not significant and not effecting traffic to drive at posted speed.**	33	0.89	<0.01*	YES (Strong consensus)	Eight to fourteen days (3.58)
Q. 2 After striping is done, how timely should PBC striping contractor fix the defects after Q/A team identifies it. **Case 2: If the severity of the defect is not significant and not effecting traffic to drive at posted speed.**	32	0.89	<0.01*	YES (Strong consensus)	One to three days (3.63)

[1] IntraClass Correlation Coefficient. More than the ICC value of 0.70 is considered as panel consensus achieved.
[2] Panel members rated the subjects on a scale of 1 to 5. The average rating is the mean rating score of the panel members.

4.4.4 Framework of Performance-Based Chip Seal and Striping Contracts

Based on the findings of the study, the flowcharts and frameworks for PBC chip seal and striping have been prepared and shown in Figure 4.10 and Figure 4.11 (for PBC chip seal) and Figure 4.12 and Figure 4.13 (for PBC striping). The framework can be used by the state DOT and transportation agency maintenance engineers for deciding when and how to do PBC for these road maintenance activities. These frameworks consist of the stepwise process for performing these two types of contracts.

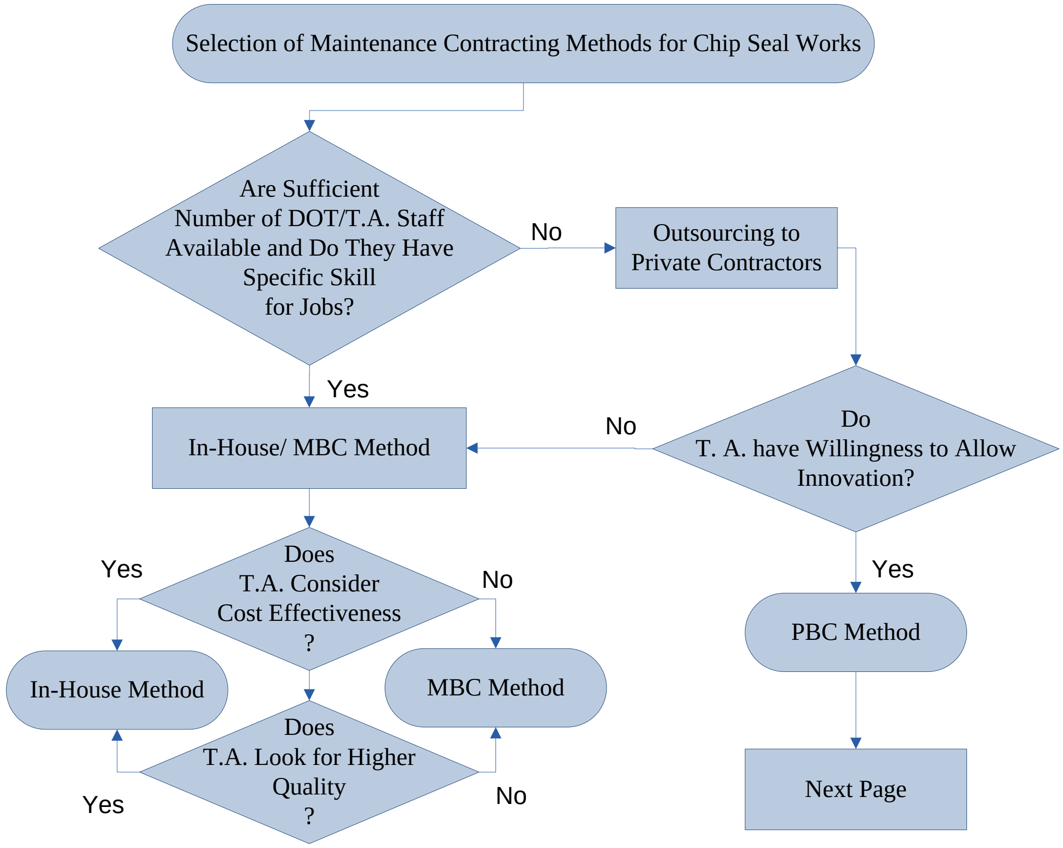


Figure 4.10 Selection of Maintenance Contracting Method for PBC Chip Seal

Figure 4.11 Framework to implement PBC chip seal contracts

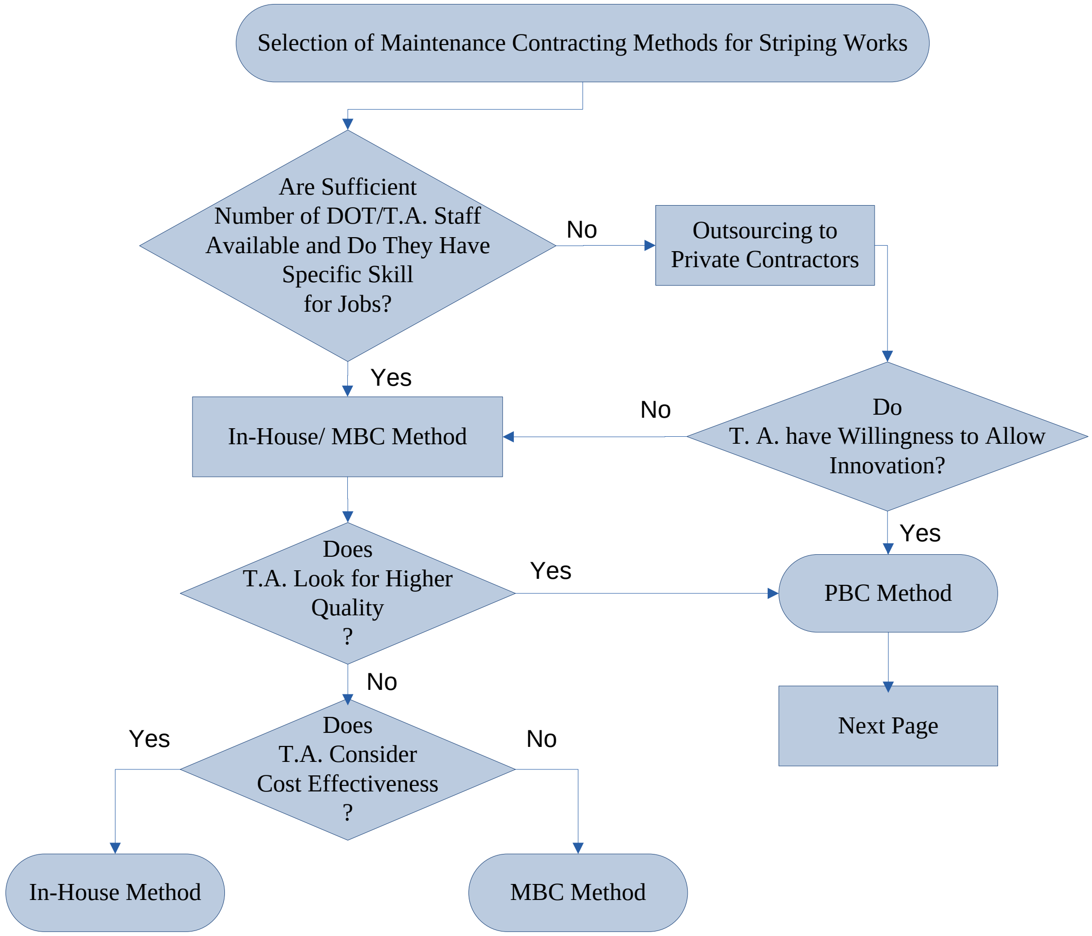


Figure 4.12 Selection of Maintenance Contracting Method for PBC Striping

Figure 4.13 Framework to implement PBC striping contracts

Chapter 5: Conclusions and Recommendations

The primary objective of this dissertation was to develop a framework to perform chip seal and striping using performance-based contract. The framework helps state Department of Transportation (DOT) Transportation Agency (TA) maintenance engineers to identify important factors to select the PBC and also the stepwise process to prepare and execute the performance-based chip seal and striping contracts. To achieve that objective, this study conducted three background studies—1) a national survey with state DOT maintenance engineers to identify the best practices of road maintenance activities and factors affecting the selection of In-house, MBC, and PBC methods, 2) Life-Cycle Maintenance Cost (LCMC) comparison of the chip seal and striping performed by In-house and private contractors to identify the cost-effective road maintenance method, and 3) quality comparison by a site investigation to compare quality of chip seal and striping works performed by In-house and private contractors in Nevada.

The national survey result showed that for road maintenance activities, the first choice of state DOTs was using the In-house work force, followed by Out-Sourcing under Method-Based Contracting (MBC) and Performance-Based Contracting (PBC) methods. The main reasons for Out-Sourcing the maintenance works (MBC method) were unavailability of DOT staff within their department and lack of specific knowledge and skill to perform specific jobs. The PBC method was used in limited states—14 states out of 34 responded states. The states who had used the PBC method revealed that the main three reasons for selecting that method were 1) unavailability of DOT staff within their department, 2) DOT staff do not have specific knowledge and skill to perform specific jobs, and 3) to allow innovation. Moreover, regarding the satisfaction levels based on the benefits (overall experience, schedule advantage, cost advantage, quality delivered, and risk transfer) received from using the three maintenance methods, the state DOTs were significantly more satisfied with the works performed by In-house method than when performed by private contractors; however, the mean difference between the MBC and PBC methods were not significant. Regarding the benefit of quality delivered, the result showed that state

DOTs were least satisfied with the work performed by PBC method than when performed by In-house and MBC methods; this result was clearly counter-intuitive due to the fact that PBC contracts had always predetermined higher performance standards that need to be achieved by the contractor in order to get paid. Regarding the benefit of risk transfer to the contractor, the state DOTs were significantly more satisfied with the works performed by the PBC method than when performed by the MBC method. In the national survey, the respondents also shared their lessons learned from using the maintenance methods. The major lesson learned from using the In-house method was 'the scope of the work should be clearly understood by the state workers', and that when using the Out-Sourcing under MBC method 'DOTs must write very clear and specific contracts and specifications'. The major lessons learned from using the PBC method were 'state DOTs must hold a pre-bid meeting and should have a good baseline survey to determine the conditions of existing roads'; 'the performance measures should be clearly defined in the contracts and an independent third party should be used to verify whether the contractors had fulfilled the performance requirements'; and 'the contractors' performance should be tied to payment'.

To identify the cost-effective method for chip seal and striping, the LCMC analysis was conducted. In Nevada, the chip seal was performed by In-house and private contractors under MBC method. The LCMC analysis result showed that the average unit cost of chip seal per year performed In-House was significantly cheaper than when performed by private contractors. However, when the AADT of the road sections were considered, the average unit cost per year per 1,000 AADT of the chip seal performed by private contractors was slightly lower than that of performed by In-house method; nonetheless, the mean difference was not significant. Regarding the LCMC comparison of chip seals, this study found two issues: 1) the average AADT of the chip sealed road sections performed by In-house staff had relatively lower AADT as compared to that performed by MBC method. It is obvious that higher AADT roads deteriorate much quicker than the lower AADT roads. Therefore, the life-cycle cost of chip seal performed by the private contractors is higher than that of the In-house staff: 2) the cost components included in In-house and private contracts were different. The In-house performed chip seal works included only labor cost, material cost, and equipment cost. In the case of the MBC contractor performed chip seal works, there were three additional costs included in the contracts: traffic control, dust control, and pollution control, which were approximately ten percent of the net chip seal cost. A cost analysis performed by Missouri DOT also showed that the chip seal works performed by contractors were also approximately two times higher than when performed by In-House staff (Broeker 2012).

Regarding the LCMC comparison of striping works, in Nevada, the striping was performed In-house and private contractors under MBC and PBC methods. The LCMC analysis result showed that the average unit cost of striping per year performed by In-house was significantly cheaper than that performed by private contractors under MBC and PBC methods. However it should be noted that under MBC striping, the contractor's cost consisted of three additional costs: traffic control, dust control, and pollution control, which was not included in the work performed by In-house staff. If these three additional costs were not considered, the unit cost of striping performed by the MBC method would reduce by approximately fifty-five percent. The study also found that the LCMC of striping performed by MBC was lower than that performed by PBC method. Some of the reasons for high cost for PBC striping are; the Nevada DOT transferred their risk to the contractor for five years; the PBC had predetermined higher performance requirements compared to In-house and MBC methods.

To compare qualities of the chip seals performed by In-house and private contractors, an on-site quality evaluation was conducted. The on-site evaluation result indicated that the quality of chip seal work performed by In-house method was significantly higher than when performed by private contractors under MBC method. Similarly, the study also found that the quality of striping work performed by the PBC method was significantly higher than that performed by In-house and MBC methods. This may be because the PBC striping contract had predetermined higher performance measures and the contractor had to achieve that target to get paid. The on-site quality results of both the chip seal and the striping surveyed with the local road users validated the findings of the author's on-site evaluation findings. The quality of chip seal and striping was also evaluated by the survey with NDOT maintenance staff and private contractors; however, the results of these surveys were biased because both assessed their work better than their counterparts.

A framework was developed to perform the chip seal and striping using performance-based specification. To develop the framework, a Delphi study was conducted with state DOTs and academicians (panel members). The panel members came into consensus related to various important issues of PBC chip seal and striping. These issues were related to contract document preparation, contract selection process, and contract implementation process. These Delphi findings will help state DOTs and transportation agencies to successfully prepare the guidelines for their PBC contracts of chip seal and striping maintenance works.

In this dissertation, frameworks were developed to use PBC method for chip seal and striping. The frameworks illustrate an overall picture of implementing the PBC chip seal and striping contracts. The author would like to recommend preparing guidelines, which can be used to implement PBC chip seal and striping contracts for a specific state DOT or TA. The guidelines would identify specific factors regarding three phases of the PBC contracts.

Appendix A

National Survey with State DOTs

I would like to thank you in advance for your time and effort involved in your agency's participation in this research. This questionnaire is designed to collect in-depth information related to the procurement process and benefits of In-House and Out-Sourced road maintenance activities in your state. It is divided into five sections:

1. General Information
2. Road Maintenance Specifications Methods and Satisfaction Level
3. Performance Assessment of In-House, MBC, and PBC methods
4. Cost Analysis (In-House versus Out-Sourcing)
5. Performance Based Contract

If not enough space is provided to answer questions, please feel free to attach extra sheets. In the questions, we ask you to indicate how the road maintenance activities are performed in your state. Please provide this information as fully as possible. Your detailed responses will help us in a study of Performance-Based Road Maintenance Contracting funded by the Nevada Department of Transportation (NDOT).

The confidentiality of this questionnaire will be maintained. The questionnaire data will not be placed in any permanent record and will be destroyed when no longer needed by the researcher. The identity of respondents who provided all this information will remain anonymous. The data obtained during this questionnaire will not be linked in any way to the participants' names. The results of the current survey will assist us to select the best methods for maintaining the roads in Nevada.

I greatly appreciate your assistance. Please return this questionnaire by email, fax, or mail to the following address:

Pramen P. Shrestha, Ph.D., P.E.
Associate Professor
Department of Civil and Environmental Engineering and Construction
Howard R. Hughes College of Engineering
University of Nevada, Las Vegas
4505 S. Maryland Pkwy.
Las Vegas, NV 89154

Phone: 702-895-3841
Email: pramen.shrestha@unlv.edu
Fax Number: 702-895-3936

General Information

Name of your Agency: ______________________
Name of your State: ______________________
Name of the maintenance engineer (respondent): ______________________
Respondent's phone number: ______________________
Respondent's E-mail address: ______________________

Road Maintenance Specifications Methods and Satisfaction Level

From our literature review, most DOTs maintained roads using prescriptive specifications. While out-sourcing maintenance works to private contractors, DOTs choose the prescriptive specification or the performance specification. Please check the appropriate box (es) for the listed maintenance activity, performed by In-House staff and/or Out-Sourced contracts. Select the specifications method that is used, Method-Based (traditional prescriptive specifications), Performance-Based or other methods.

Maintenance Activities	In-House Methods	Out-Sourcing Methods			N/A
	Method-Based	Method - Based	Performance-Based	Other methods	
a) Road Pavement	☐	☐	☐	☐	☐
b) Shoulder	☐	☐	☐	☐	☐
c) Drainage System	☐	☐	☐	☐	☐
d) Side Slopes and Median	☐	☐	☐	☐	☐
e) Right of Way and Fencing	☐	☐	☐	☐	☐
f) Snow and Ice Removal	☐	☐	☐	☐	☐
g) Side Walk and Curb	☐	☐	☐	☐	☐
h) Traffic Safety-Road Signs and markings, Traffic Attenuators, Guard Rails, Barriers, and Street Lights	☐	☐	☐	☐	☐

If your DOT maintains any road activities by <u>in-house</u> staff using performance based specifications criteria, write the name of the maintenance activities and performance targets below (or attach any documents you would like to share.)

Name of the maintenance activities **Performance Targets**

1.
2.
3.
4.
5.

Which specification methods did you use in your DOT last year for the majority of road maintenance activities?

☐ In-House
☐ Out-Sourcing with Method-Based Contracts (MBC)

☐ Out-Sourcing with Performance-Based Contracts (PBC)
☐ Out-Sourcing with other methods

Please estimate the percentage of your maintenance budget that is allocated to the following type of methods for your DOT maintenance activities in last year.

In-House	……%
Out-Sourcing with MBC	……%
Out-Sourcing with PBC	……%
Other Out-Sourcing methods	……%
Total	**100 %**

Please rate (1-5 scale, 5 being "very important" and 1 being "least important") for the selection criteria of In-House and Out-Sourced methods for maintenance work in your DOT:

In-House Method Selection Criteria	Out-Sourcing Method Selection Criteria
____ Availability of DOT staff to accomplish additional works	____ Lack of DOT staff to accomplish additional works
____To complete the task on schedule	____ To complete the task on schedule
____ To complete the task on budget or to save money	____ To complete the task on budget or to save money
____ DOT have specific knowledge/skill for the job	____ DOT does not have specific knowledge/skill for a particular job
____ Budget constraint	____ Long-term budget availability
____ Time constraint	____ Time constraint
____ Quality of work	____ Quality of work

Based on your experience, rate on a scale of 1 to 5, 5 being "very satisfied" and 1 being "very unsatisfied", the benefits received for the following methods.

Maintenance methods	**Rating**
In-House work	_______
MBC	_______
PBC	_______
Other Contracting Method; please specify ……………	_______

Please rate (1-5) the benefits of In-House maintenance work.

Cost effective	_______
Schedule advantage	_______
Quick response for emergency activities	_______
Quality	_______

Flexibility _______
Others, please specify …………………………………………………….. _______

Please rate (1-5) the benefits of Out-Sourced maintenance work.

Cost effective _______
Schedule advantage _______
Quality _______
Flexibility _______
Easy to call and give contracts _______

Rank 1 to 3 (3 as highest ranking) the maintenance methods that is best suitable for emergency work, like snow removal.

In-House _______
MBC _______
PBC _______

Identify lessons learned from the In-House contracting processes for maintenance work.

a) …………………………………………………………………………………….
b) …………………………………………………………………………………….
c) …………………………………………………………………………………….

Identify lessons learned from the Out-Sourced contracting methods for maintenance work.

a) ……………………………………………………………………………………..
b) ……………………………………………………………………………………..
c) ……………………………………………………………………………………..

Performance Assessment of In-House, MBC, and PBC (If your DOT has not used the listed method, please leave the column blank.)

Rate the satisfaction level for the overall experience of In-House, MBC, and PBC methods for road maintenance activities.

	In-House work	MBC	PBC
Highly Satisfied	☐	☐	☐
Satisfied	☐	☐	☐
Neutral	☐	☐	☐
Unsatisfied	☐	☐	☐
Highly Unsatisfied	☐	☐	☐

Rate the satisfaction level for the cost effectiveness of In-House, MBC, and PBC methods for road maintenance activities.

	In-House work	MBC	PBC
Highly Satisfied	☐	☐	☐
Satisfied	☐	☐	☐
Neutral	☐	☐	☐
Unsatisfied	☐	☐	☐
Highly Unsatisfied	☐	☐	☐

Rate the satisfaction level for the schedule advantage of In-House, MBC, and PBC methods for road maintenance activities.

	In-House work	MBC	PBC
Highly Satisfied	☐	☐	☐
Satisfied	☐	☐	☐
Neutral	☐	☐	☐
Unsatisfied	☐	☐	☐
Highly Unsatisfied	☐	☐	☐

Rate the satisfaction level for the quality delivered of In-House, MBC, and PBC methods for road maintenance activities.

	In-House work	MBC	PBC
Highly Satisfied	☐	☐	☐
Satisfied	☐	☐	☐
Neutral	☐	☐	☐
Unsatisfied	☐	☐	☐
Highly Unsatisfied	☐	☐	☐

Rate the satisfaction level for the risk transfer to the MBC and PBC contractor.

	MBC	PBC
Highly Satisfied	☐	☐
Satisfied	☐	☐
Neutral	☐	☐
Unsatisfied	☐	☐
Highly Unsatisfied	☐	☐

Cost Analysis (In-House versus Out-Sourcing)

Please rate on a scale of 1-5, 5 being "very important" and 1 being "least important", the following cost items that should be included while analyzing the cost of In-House and Out-Sourced maintenance work.

In-House Maintenance Work	Out-Sourced Maintenance Work
____ Labor, Material, and Equipment cost	____ Labor, Material, and Equipment cost
____ DOT Headquarter Office administration cost	____ DOT Headquarter Office administration cost
____ District Office administration cost	____ District Office administration cost
____ Accounting, agreement services and legal staff cost	____ Accounting, agreement services and legal staff cost
____ Inspection and monitoring team cost	____ Inspection and monitoring team cost
____ Others, please specify ……………..	____ Others, please specify ……………..

Did your DOT perform a cost analysis to compare In-House versus Out-Sourced maintenance work?

☐ Yes (If yes, please provide the report or if it available online, please provide the web link)
____

☐ No (Go to **Q. No. 4.4**)

If the cost analysis was performed, what were the findings?

☐ In-House method is more cost effective than other Out-Sourced methods
☐ In-House method is not as cost effective as other Out-Sourced methods
☐ Neutral
☐ Difficult to compare
☐ Do not know

In your opinion, should the quality of work be considered while comparing the cost effectiveness of In-House and Out-Sourced methods of maintenance work?

☐ Yes
☐ No
☐ Not Sure

Performance-Based Contracts (PLEASE STOP, if your DOT had not used PBC)

Please list the most important lessons learned from PBC method for road maintenance in the following phases that might be useful for other states.

Contract Procurement Phase

a. ………………………………………………………………………………….
b. ………………………………………………………………………………….
c. ………………………………………………………………………………….
d. ………………………………………………………………………………….

Initial Baseline Measurement Phase

a. ………………………………………………………………………………….
b. …………………………………………………………………………………..
c. …………………………………………………………………………………..
d. ……………………………………………………………………………………

Performance Measurement Phase

a. …………………………………………………………………………………
b. …………………………………………………………………………………
c. …………………………………………………………………………………
d. …………………………………………………………………………………

Payment Phase

a. …………………………………………………………………………………
b. ………………………………………………………………………………….
c. ………………………………………………………………………………….
d. ………………………………………………………………………………….

If your DOT has <u>not</u> used Performance-Based contracts for maintenance work, please check the reasons that apply

a) We are satisfied with current Out-Sourced methods. ☐
b) There is a leadership resistance, as it measures the performance ☐
of both the contractor and the DOT. ☐
c) There is fear PBC will lay-off many workers. ☐
Union is not in the favor of PBC. ☐
d) Our DOT has enough expertise, skilled workers, and equipment. ☐
e) Our DOT tried and moved back from PBC, please explain the reasons ☐
…………………………………………………………………………………
f) Other, please specify …………………………………………………… ☐

Please rate (1-5) the following factors affecting your DOT's decision to use PBC method for road maintenance.

Name of factors	**Rating**
Availability of staffs in DOT	_______
Degree of schedule complexity of the work	_______
Requirement of specific knowledge/skill	_______
To save money (with life-cycle cost consideration)	_______
To save time	_______
Contractors' capability to perform works	_______
Permission from state statute	_______
Types of maintenance activities	_______
Guaranteed funding availability for a long period of time	_______
Innovation	_______

Does your DOT prepare Performance-Based road maintenance specifications?

☐ Yes. (If yes, please provide a copy or if it is available in web, please provide the web link) ___________________________

☐ No

THANK YOU FOR YOUR HELP AND COOPERATION

Appendix B

On-site Quality Evaluation of Chip Seal

Name of the Road:

Please rate (1-5 scale, 5 being “very satisfied” and 1 being “very unsatisfied”) for the following activities:

	Road maintenance activities	Very Satisfied	Satisfied	Neutral	Dissatisfied	Very Dissatisfied
A.	**Chip Seal**					
A. 1	**Presence of Pot holes** • 5 for < 2#-64 sq. in.x 1 in. deep potholes per 0.1 lane mile • 4 for 2 to 3#-64 sq. in.x 1 in. deep potholes per 0.1 lane mile • 3 for 4 to 5#-64 sq. in.x 1 in. deep potholes per 0.1 lane mile • 2 for 6 to 7#-64 sq. in.x 1 in. deep potholes per 0.1 lane mile • 1 for > 8#-64 sq. in.x 1 in. deep potholes per 0.1 lane mile	5	4	3	2	1
A. 2	**Loss of aggregate** • 5 for < 10% aggregate loss • 4 for 10-20% aggregate loss • 3 for 20-30% aggregate loss • 2 for 30-40% aggregate loss • 1 for > 40% aggregate loss	5	4	3	2	1
A. 3	**Presence of cracks on the surface** • 5 for presence of cracks of width < 1/7 in. • 4 for insignificant amount of bleeding and cracks width < 1/6 - 1/7 in. • 3 for insignificant amount of bleeding and cracks width < 1/5-1/6 in. • 2 for significant amount of bleeding and cracks width < 1/4-1/5 in. • 1 for significant amount of bleeding and cracks width > ¼ in.	5	4	3	2	1
A. 4	**Presence of rutting** • 5 for < 7/8 in • 4 for 7/8-6/8 in. • 3 for 6/8-5/8 in. • 2 for 5/8-1/2 in. • 1 for > ½ in	5	4	3	2	1
A. 5	**Uniform distribution of aggregate on the surface** • 5 for 90-100% aggregate are uniformly distributed • 4 for 80-90% aggregate are uniformly distributed • 3 for 70-80% aggregate are uniformly distributed • 2 for 60-70% aggregate are uniformly distributed • 1 for <60% aggregate are uniformly distributed	5	4	3	2	1
B.	**Striping**					

B. 1	Ensuring road striping is visible during the DAY	5	4	3	2	1
B. 2	Ensuring road striping is visible during NIGHTS	5	4	3	2	1
B. 3	Ensuring road striping is straight and continuous	5	4	3	2	1

Appendix C

Surveying users of Selected Road Sections for Chip Seal and Striping

Name of the Road:
Please rate (1-5 scale, 5 being "very satisfied" and 1 being "very unsatisfied") for the following activities:

1. Road Maintenance activities		Very Satisfied	Satisfied	Neutral	Dissatisfied	Very Dissatisfied
1.	**CHIP SEAL**					
A.	Keeping the surface of roads smooth and free of potholes	5	4	3	2	1
B.	Ensuring riding quality of road is comfortable at posted speed	5	4	3	2	1
C.	Keeping the road diversion is safe and easy during maintenance	5	4	3	2	1
2.	**STRIPING**					
A.	Ensuring road striping is visible during the DAY	5	4	3	2	1
B.	Ensuring road striping is visible during WET weather and NIGHTS	5	4	3	2	1
C.	Keeping the road diversion is safe and easy during maintenance	5	4	3	2	1

Appendix D

Quality Satisfaction Rating Survey with NDOT Personnel for Chip Seal and Striping

Name and Title of the Evaluator: ……………………………………………………..
District: ……………………………………………………..
Name of the Road: ……………………………………………………..

1. Are you involved in overseeing CHIP SEAL done by NDOT In-House workers?
   ☐ YES
   ☐ NO

   If yes, please rate (1-5 scale, 5 being "very satisfied" and 1 being "very unsatisfied") your satisfaction level with NDOT's work performance for CHIP SEAL:

1. Chip seal performed by NDOT		Very Satisfied	Satisfied	Neutral	Dissatisfied	Very Dissatisfied
A.	Keeping the surface of roads smooth and free of potholes	5	4	3	2	1
B.	Ensuring riding quality of road is comfortable at posted speed	5	4	3	2	1
C.	Keeping the road diversion safe and without obstruction during maintenance	5	4	3	2	1
D.	Ensuring material quality of chip seal	5	4	3	2	1
E.	Ensuring workmanship during chip seal	5	4	3	2	1
F.	Ensuring equipment used during chip seal	5	4	3	2	1

2. Are you involved in overseeing CHIP SEAL conducted by private contractor?
   ☐ YES
   ☐ NO

   If yes, please rate your satisfaction level with Private contractor's work performance for CHIP SEAL:

2. Chip seal performed by Private contractor		Very Satisfied	Satisfied	Neutral	Dissatisfied	Very Dissatisfied
A.	Keeping the surface of roads smooth and free of potholes	5	4	3	2	1
B.	Ensuring riding quality of road is comfortable at posted speed	5	4	3	2	1
C.	Keeping the road diversion safe and without obstruction during maintenance	5	4	3	2	1
D.	Ensuring material quality of chip seal	5	4	3	2	1
E.	Ensuring workmanship during chip seal	5	4	3	2	1
F.	Ensuring equipment used during chip seal	5	4	3	2	1

3. Are you involved in overseeing STRIPING done by NDOT In-House workers?
   - ☐ YES
   - ☐ NO

   If yes, please rate (1-5 scale, 5 being "very satisfied" and 1 being "very unsatisfied") your satisfaction level with NDOT's work performance for STRIPING:

3. Striping performed by NDOT		Very Satisfied	Satisfied	Neutral	Dissatisfied	Very Dissatisfied
A.	Ensuring road striping is visible during the DAY	5	4	3	2	1
B.	Ensuring road striping is visible during WET weather and NIGHTS	5	4	3	2	1
C.	Keeping the road diversion safe and without obstruction during striping	5	4	3	2	1
D.	Ensuring material quality used by private contractor	5	4	3	2	1
E.	Ensuring workmanship used by private contractor	5	4	3	2	1
F.	Ensuring sophisticated equipment and its quality used by contractor	5	4	3	2	1
G.	Others, please specify, ……………………………………………..	5	4	3	2	1

4. Are you involved in overseeing STRIPING conducted by private contractor?
   - ☐ YES
   - ☐ NO

   If yes, please rate your satisfaction level with Private contractor's work performance for STRIPING:

4. Striping performed by Personnel		Very Satisfied	Satisfied	Neutral	Dissatisfied	Very Dissatisfied
A.	Ensuring road striping is visible during the DAY	5	4	3	2	1
B.	Ensuring road striping is visible during WET weather and NIGHTS	5	4	3	2	1
C.	Keeping the road diversion safe and without obstruction during striping	5	4	3	2	1
D.	Ensuring material quality used by private contractor	5	4	3	2	1
E.	Ensuring workmanship used by private contractor	5	4	3	2	1
F.	Ensuring sophisticated equipment and its quality used by contractor	5	4	3	2	1
G.	Others, please specify, ……………………………………………..	5	4	3	2	1

Appendix E

Quality Satisfaction Rating Survey with Private Contractors for Chip Seal and Striping

Name and Title of the Evaluator: ……………………………………………….

Name of the firm: ……………………………………………….

1. Are you involved in overseeing CHIP SEAL done by NDOT In-House workers?
   ☐ YES
   ☐ NO

   If yes, please rate (1-5 scale, 5 being "very satisfied" and 1 being "very unsatisfied") your satisfaction level with NDOT's work performance for CHIP SEAL:

	1. Chip seal performed by NDOT	Very Satisfied	Satisfied	Neutral	Dissatisfied	Very Dissatisfied
A.	Keeping the surface of roads smooth and free of potholes	5	4	3	2	1
B.	Ensuring riding quality of road is comfortable at posted speed	5	4	3	2	1
C.	Keeping the road diversion safe and without obstruction during maintenance	5	4	3	2	1
D.	Ensuring material quality of chip seal	5	4	3	2	1
E.	Ensuring workmanship during chip seal	5	4	3	2	1
F.	Ensuring equipment used during chip seal	5	4	3	2	1

2. Are you involved in overseeing CHIP SEAL done by your firm?
   ☐ YES
   ☐ NO

   If yes, please rate your satisfaction level with your firm maintained work performance for CHIP SEAL:

	2. Chip seal performed by private contractor	Very Satisfied	Satisfied	Neutral	Dissatisfied	Very Dissatisfied
A.	Keeping the surface of roads smooth and free of potholes	5	4	3	2	1
B.	Ensuring riding quality of road is comfortable at posted speed	5	4	3	2	1
C.	Keeping the road diversion safe and without obstruction during maintenance	5	4	3	2	1
D.	Ensuring material quality of chip seal	5	4	3	2	1
E.	Ensuring workmanship during chip seal	5	4	3	2	1
F.	Ensuring equipment used during chip seal	5	4	3	2	1

3. Are you involved in overseeing STRIPING done by NDOT In-House workers?
☐ YES
☐ NO

If yes, please rate (1-5 scale, 5 being "very satisfied" and 1 being "very unsatisfied") your satisfaction level with NDOT's work performance for STRIPING:

	3. Striping performed by NDOT	Very Satisfied	Satisfied	Neutral	Dissatisfied	Very Dissatisfied
A.	Ensuring road striping is visible during the DAY	5	4	3	2	1
B.	Ensuring road striping is visible during WET weather and NIGHTS	5	4	3	2	1
C.	Keeping the road diversion safe and without obstruction during striping	5	4	3	2	1
D.	Ensuring material quality used by private contractor	5	4	3	2	1
E.	Ensuring workmanship used by private contractor	5	4	3	2	1
F.	Ensuring sophisticated equipment and its quality used by contractor	5	4	3	2	1
G.	Others, please specify, ………………………………………………..	5	4	3	2	1

4. Are you involved in overseeing STRIPING conducted by private contractor?
☐ YES
☐ NO

If yes, please rate your satisfaction level with your firm maintained work performance for STRIPING:

	4. Striping performed by private contractor	Very Satisfied	Satisfied	Neutral	Dissatisfied	Very Dissatisfied
A.	Ensuring road striping is visible during the DAY	5	4	3	2	1
B.	Ensuring road striping is visible during WET weather and NIGHTS	5	4	3	2	1
C.	Keeping the road diversion safe and without obstruction during striping	5	4	3	2	1
D.	Ensuring material quality used by private contractor	5	4	3	2	1
E.	Ensuring workmanship used by private contractor	5	4	3	2	1
F.	Ensuring sophisticated equipment and its quality used by contractor	5	4	3	2	1
G.	Others, please specify, ………………………………………………..	5	4	3	2	1

Appendix F

Delphi Study Round One Survey

Section 1: Background Information:

1. Your Name:
2. Name of your Organization:
3. Current Position:
4. Total Years of Experience in Transportation Area:
5. Please identify your experience with the following methods for construction and maintenance:

Name of Methods	Approximate Years of Experience
a. State Force	……………….
b. Method Based Contracting	……………….
c. Performance Based Contracting	……………….
d. Other	………………..

6. Please identify your Areas of Expertise from the following
   - a. Contract procurement
   - b. Design
   - c. New construction
   - d. Maintenance/Operations
   - e. Project Management
   - f. Performance Based Construction/Maintenance
   - g. Monitoring/Inspection
   - h. Other

Section 2: Chip Seal

Section 2A: Factors Affecting the Selection of Performance Based Road Maintenance Method

1. Tell us about the factors that influence in transitioning from the use of traditional outsourcing method to PBC for chip seal.

……………………………………………………………………………………………………..

Section 2B: Contract Document for PBC chip seal

1. List the performance measures for PBC chip seal.

   ………………………………………………………………………………………………

2. Should the state DOTs provide incentives/disincentives to the PBC chip seal contractors based on their performance? If yes, please state the percentage range.

   ………………………………………………………………………………………………

3. Do you think the state-DOT-PBC-team personnel should be trained in the PBC chip seal method before implementing the method? If yes, how should the team be trained?

……………………………………………………………………………………………………..

Section 2C: Procurement Phase for PBC chip seal

1. List the position titles of the state DOT personnel to be included on the procurement team for PBC chip seal.

   ………………………………………………………………………………………………

2. Some DOTs have already completed the PBC method in maintenance projects; all the PBC contracts were more than two years in duration. In your opinion, what should be the contract duration of PBC chip seal projects?

   ………………………………………………………………………………………………

3. Based on your experience, what should be the contractor selection criteria for PBC chip seal?
……

Section 2D: PBC Implementation for chip seal

1. List the position titles of the state DOT personnel to be included on the implementation team for PBC chip seal projects.
……
2. How should the PBC chip seal contractor perform their work so that there is minimum traffic disruption during the work?
……
3. When PBC chip seal maintenance (for example pot hole sealing) is required, what is the required timeliness or duration (in days) should the contractor get to complete the maintenance work?
……
4. Who should perform the Quality Assurance (QA) work?
……
5. Estimate appropriate monitoring frequencies for the PBC chip seal work.
……
6. How should the PBC chip seal contractor be paid in initial acceptance and warranty/maintenance years?
………

<u>Section 3: Striping</u>

Section 3A: Factors Affecting the Selection of Performance Based Road Maintenance Method

1. Tell us about the factors that influence in transitioning from the use of traditional outsourcing method to PBC for striping?
……

Section 3B: Contract Document for PBC striping

1. List the performance measures for PBC striping.
……
2. Should the state DOTs provide incentives/disincentives to the PBC striping contractor based on their performance? If yes, please state the percentage range.
……
3. Do you think the state DOT PBC team personnel should be trained in the PBC striping method before implementing the method? If yes, how should the team be trained?
………

Section 3C: Procurement Phase for PBC striping

1. List the position titles of the state DOT personnel to be included in the procurement team for striping?
……
2. Some DOTs have already completed the PBC method in maintenance projects; all the PBC contracts were more than two years in duration. In your opinion, what should be the contract duration of PBC striping projects?

………..
3. Based on your experience, what should be the contractor selection criteria for PBC striping?
……

Section 3D: PBC Implementation for striping

1. List the position titles of the state DOT personnel to be included on the implementation team for PBC

striping projects.

………

2. How should the PBC striping contractor perform their work so that there is minimum traffic disruption during the work?

………

3. When PBC striping maintenance (for example repainting for a segment) is required, what should be the required timeliness or duration (in days) should the contractor get to complete the maintenance work?

………

4. Who should perform the Quality Assurance (QA) work?

………

5. Estimate appropriate monitoring frequencies for PBC striping work.

………

6. How should the PBC striping contractor be paid in initial acceptance and warranty/maintenance years?

………

***** Thank you *****

Appendix G

Delphi Study Round Two Survey

Thank you once again for your time for the phone interview in the first round of Delphi Study. In this second round, you will be rating the answers of each question.

1. Please rate the following reasons that the participants had identified for using Performance-Based Contract (PBC) for chip seal. The rating should be on a scale of 1 to 5 (5 being very important and 1 being very unimportant.)
    a. Create innovation
    b. Consider quality of the contractors
    c. Due to political decision or state statute
    d. Easy to manage
    e. Increased work efficiency
    f. Increase level of service (LOS)
    g. Outcome-based contract
    h. Overcome lack of skilled workers within state DOTs
    i. Provide higher customer satisfaction
    j. Receive warranty or liability of the work done by the contractor
    k. Save life-cycle Cost
    l. Transfer risk to the contractor

2. Please rate the following reasons that the participants had identified for using Performance-Based Contract (PBC) for striping. The rating should be on a scale of 1 to 5 (5 being very important and 1 being very unimportant.)
    a. Create innovation
    b. Consider quality of the contractors
    c. Due to political decision or state statute
    d. Easy to manage
    e. Increase level of service (LOS)
    f. Increase work efficiency
    g. Last longer
    h. Outcome-based contract or result-oriented contract
    i. Provide higher customer satisfaction
    j. Provide longer warranty or insurance for the work done by contractor
    k. Save life-cycle Cost
    l. Statutes law
    m. To assure long-term funding
    n. To overcome lack of skilled worker within state DOTs
    o. Transfer risk to the contractor

3. What performance measures should be used in performance-based chip seal contract? Rate on the scale of 1 to 5 (5 being very important measure and 1 being very unimportant measure).
    a. Aggregate retention or loss of aggregate
    b. Bleeding
    c. Cracks
    d. Oxidation
    e. Smoothness or friction test

4. What performance measures should be used in performance-based striping contract? Rate on the scale of 1 to 5 (5 being very important measure and 1 being very unimportant measure).
    a. Color
    b. Retro-reflectivity
    c. Striping alignment
    d. Striping width

5. What incentives should be provided to the performance-based chip seal contractors based on their performance. Please rate on the scale of 1 to 5 (5 being very likely incentive and 1 being very unlikely incentive)

    Incentives:
    a. More than 10%
    b. 6% to 10%
    c. 4% to 5%
    d. 1% to 3%
    e. No Incentives
6. What disincentives should be provided to the performance-based chip seal contractors based on their performance. Please rate on the scale of 1 to 5 (5 being very likely disincentive and 1 being very unlikely disincentive)

    Disincentives:
    a. More than 10%
    b. 6% to 10%
    c. 4% to 5%
    d. 1% to 3%
    e. No Disincentives
7. What incentives should be provided to the performance-based striping contractors based on their performance. Please rate on the scale of 1 to 5 (5 being very likely incentive and 1 being very unlikely incentive)

    Incentives:
    a. More than 10%
    b. 6% to 10%
    c. 4% to 5%
    d. 1% to 3%
    e. No Incentives
8. What disincentives should be provided to the performance-based striping contractors based on their performance. Please rate on the scale of 1 to 5 (5 being very likely disincentive and 1 being very unlikely disincentive)

    Disincentives:
    a. More than 10%
    b. 6% to 10%
    c. 4% to 5%
    d. 1% to 3%
    e. No Disincentives

9. The participants had stated that the state DOT personnel involved in performance-based maintenance contract should be trained. Which method of training does you prefer? Please rate on the scale of 1 to 5 (5 being very appropriate method and 1 being very inappropriate method).
    a. In-House training
    b. Out-source the training to the experience third party
    c. Use In-House as well as experience third party trainers

10. The participants had stated that the state DOT personnel involved in performance-based maintenance contract should be trained. Which method of training does you prefer? Please rate on the scale of 1 to 5 (5 being very appropriate method and 1 being very inappropriate method).
    a. In-House training
    b. Out-source the training to the experience third party
    c. Use In-House as well as experience third party trainers

11. From state DOTs, who should be included on the procurement team of performance-based chip seal contract? Please rate on the scale of 1 to 5 (5 being very appropriate person and 1 being very inappropriate person).
    a. Administrative or Procurement Officer
    b. Construction Engineer
    c. Maintenance Contract Manager
    d. Material Engineer
    e. Project Manager
    f. State or district Pavement Engineer
    g. State Maintenance Engineer

12. From state DOTs, who should be included on the procurement team of performance-based striping contract? Please rate on the scale of 1 to 5 (5 being very appropriate person and 1 being very inappropriate person).
    a. Administrative or Procurement Officer
    b. Construction Engineer
    c. Maintenance Contract Manager
    d. Material Engineer
    e. Project Manager
    f. State or district Pavement Engineer
    g. State Maintenance Engineer

13. How long should be the duration of performance-based chip seal contract? Please rate on the scale of 1 to 5. (5 being very reasonable period and 1 being very unreasonable period)
    a. 1 to 2 years
    b. 3 to 5 years
    c. 6 to 7 years
    d. 8 years or more
14. How long should be the duration of performance-based striping contract? Please rate on the scale of 1 to 5. (5 being very reasonable period and 1 being very unreasonable period)
    a. 1 to 2 years
    b. 3 to 5 years
    c. 6 to 7 years
    d. 8 years or more
15. Did you consider the snow plowing while selecting the contract duration in the previous two questions?
    a. Yes
    b. No

16. How should the performance-based chip seal contractor be selected? Please rate on the scale of 1 to 5 (5 being very appropriate method and 1 being very inappropriate method).
    a. Prequalification then low bid selection method

b. Prequalification then best value selection method (qualification 50% and financial 50%)
c. Prequalification then best value selection method (qualification 60% and financial 40%)
d. Prequalification then best value selection method (qualification 70% and financial 30%)
e. Prequalification then best value selection method (qualification 80% and financial 20%)

17. How should the performance-based striping contractor be selected? Please rate on the scale of 1 to 5 (5 being very appropriate method and 1 being very inappropriate method).
    a. Prequalification then low bid selection method
    b. Prequalification then best value selection method (qualification 50% and financial 50%)
    c. Prequalification then best value selection method (qualification 60% and financial 40%)
    d. Prequalification then best value selection method (qualification 70% and financial 30%)
    e. Prequalification then best value selection method (qualification 80% and financial 20%)

18. From state DOTs, who should be included in the implementation team for performance-based chip seal contract. Please rate on the scale of 1 to 5 (5 being very appropriate person and 1 being very inappropriate person).
    a. Construction Engineer
    b. Design Engineer
    c. District Resident Engineer
    d. Inspectors
    e. Maintenance Contract Manager
    f. Material Engineer and Q/A team
    g. Project Manager
    h. State Maintenance Engineer

19. From state DOTs, who should be included in the implementation team for performance-based striping contract. Please rate on the scale of 1 to 5 (5 being very appropriate person and 1 being very inappropriate person).
    a. Contract Manager or Project Manager
    b. Construction Engineer
    c. Design Engineer
    d. District Resident Engineer
    e. Inspectors
    f. Maintenance Engineer
    g. Material Engineer
    h. Quality Assurance (QA) Team
    i. Traffic or Striping Engineer

20. Which following clause should be included in performance-based chip seal contract to get minimum traffic disruption during construction phase? Rate on the scale of 1 to 5. (5 being most appropriate clause and 1 being most inappropriate clause)
    a. One lane closure for not more than 30 minutes with using a pilot car

b. Entire road closure with lane-off fee charge to the contractor and divert traffic to secondary route
c. The lane closure plan should be included in the contractors' proposal so that state DOT can take a final decision

21. Which following clause should be included in performance-based striping contract to get minimum traffic disruption during construction phase? Rate on the scale of 1 to 5. (5 being most appropriate clause and 1 being most inappropriate clause)
    a. One lane closure for not more than 30 minutes with using a pilot car
    b. Entire road closure with lane-off fee charge to the contractor and divert traffic to secondary route
    c. The lane closure plan should be included in the contractors' proposal so that state DOT can take a final decision

22. How timely performance-based chip seal contractor should fix the defects after state DOT identifies it. Please rate the following time period on the scale of 1 to 5 (5 being most appropriate time period and 1 being most inappropriate time period).
    a. 1 to 3 days
    b. 4 to 7 days
    c. 8 to 14 days
    d. 15 to 21 days
    e. 22 to 30 days

23. How timely performance-based striping contractor should fix the defects after state DOT identifies it. Please rate the following time period on the scale of 1 to 5 (5 being most appropriate time period and 1 being most inappropriate time period).
    a. 1 to 3 days
    b. 4 to 7 days
    c. 8 to 14 days
    d. 15 to 21 days
    e. 22 to 30 days

24. Who should perform the Quality Assurance (QA) of performance-based chip seal contractors' work? Rate on the scale of 1 to 5 (5 being the most appropriate party and 1 being the most inappropriate party)
    a. State DOT for entire contract duration
    b. Independent third party for entire contract duration
    c. Independent third party for the first year then state DOT

25. Who should perform the Quality Assurance (QA) of performance-based striping contractors' work? Rate on the scale of 1 to 5 (5 being the most appropriate party and 1 being the most inappropriate party)
    a. State DOT for entire contract duration
    b. Independent third party for entire contract duration
    c. Independent third party for the first year then state DOT

26. What should be the monitoring frequencies for QA in performance-based chip seal contract? Please rate on the scale of 1 to 5 (5 being most reasonable frequency and 1 being most unreasonable frequency)
    a. Weekly
    b. Monthly
    c. Quarterly
    d. Semi-annually
    e. Annually

27. What should be the monitoring frequencies for QA in performance-based striping contract? Please rate on the scale of 1 to 5 (5 being most reasonable frequency and 1 being most unreasonable frequency)
    a. Weekly
    b. Monthly
    c. Quarterly
    d. Semi-annually
    e. Annually

28. What should be the payment method for the PBC chip seal contract? Please rate on the scale of 1 to 5 (5 being most appropriate payment method and 1 being most inappropriate method)
    a. Provide 5% of total contract cost as mobilization then make payment linearly every month.
    b. Provide 10% of total contract cost as mobilization then make payment linearly every month.
    c. Provide 15% of total contract cost as mobilization then make payment linearly every month.
    d. Provide 20% of total contract cost as mobilization then make payment linearly every month.
    e. Provide mobilization for resources only then make payment linearly every month.

29. What should be the payment method for the PBC striping contract? Please rate on the scale of 1 to 5 (5 being most appropriate payment method and 1 being most inappropriate method)
    a. Provide 5% of total contract cost as mobilization then make payment linearly every month.
    b. Provide 10% of total contract cost as mobilization then make payment linearly every month.
    c. Provide 15% of total contract cost as mobilization then make payment linearly every month.
    d. Provide 20% of total contract cost as mobilization then make payment linearly every month.
    e. Provide mobilization for resources only then make payment linearly every month.

Appendix H

Delphi Study Round Three Survey

Q. 1 After Chip Seal is done, how timely should PBC Chip Seal contractor fix the defects after QA team identifies it.

Case 2: If the severity of the defect is not significant and not effecting traffic to drive at posted speed.

a. 22 to 30 days
b. 15 to 21 days
c. 8 to 14 days
d. 4 to 7 days
e. 1 to 3 days

Q. 1 After Striping is done, how timely should PBC Striping contractor fix the defects after QA team identifies it.

Case 2: If the severity of the defect is not significant and not effecting traffic to drive at posted speed.

a. 22 to 30 days
b. 15 to 21 days
c. 8 to 14 days
d. 4 to 7 days
e. 1 to 3 days

Appendix I

Sample Calculation of Determining Average Frequency of Maintenance Performed by In-House and MBC Method

Maintenance Frequency for road US XX in county XX of district X																	
Years	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1990																	
1991	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1992																	
1993																	
1994	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1
1995																	
1996																	
1997																	
1998																	
1999																	
2000																	
2001																	
2002																	
2003																	
2004	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2005	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0
2006																	
2007	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2008	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2009																	
2010	C	C	C	C	C	C	C	0	0	0	0	0	0	0	0	0	0
2011	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2012	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
2013																	
2014				C	C	C	C	C	C	C	C	C	C	C	C	C	C
Initial Year	2005	2005	2005	2005	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008	###	###
Final Year	2010	2010	2010	2010	2010	2010	2010	2014	2014	2014	2014	2014	2014	2014	2014	###	###
Period of Mtnc	5	5	5	5	2	2	2	6	6	6	6	6	6	6	6	6	6
Frequency of maintenance	5	5	5	5.0				6	6	6	6	6	6	6	6	6	6
Contractor's																	
Initial Year	2010	2010	2010	2010	2010	2010	2010										
Final Year	2012	2012	2012	2014	2014	2014	2014										
Period of Mtnc	2	2	2	4	4	4	4										
Frequency of maintenance				4	4	4	4	**4.00**									

Appendix J

Sample Calculation of Determining Average Unit Cost of Chip Seal Performed by In-House Method

Chip Seals on US XX Performed by In-House Method							
Year	HW Cost Index Factor	Direct Cost		Indirect Cost (%)	Indirect cost	Quantity (SY)	Unit Rate
		Cost	Adjusted Cost				
1990	1.43	134310.66	192708.65	17.06%	32876.10	257570.00	0.88
1991	1.38	167906.63	232096.66	17.06%	39595.69	275692.00	0.99
1992	1.43	65907.49	94039.84	17.06%	16043.20	114359.00	0.96
1993	1.35						
1994	1.28						
1995	1.24	115936.19	143228.31	17.06%	24434.75	185383.00	0.90
1996	1.29			17.06%			
1997	1.22			17.06%			
1998	1.41			17.06%			
1999	1.12	196622.60	219542.51	17.06%	37453.95	213122.00	1.21
2000	1.03			17.06%			
2001	1.04	9119.21	9481.34	17.06%	1617.52	22823.00	0.49
2002	1.06	258663.77	274502.60	17.06%	46830.14	335400.00	0.96
2003	1.11	556100.65	616251.10	17.06%	105132.44	569398.00	1.27
2004	1.04						
2005	0.94						
2006	0.82	40450.89	33327.31	17.06%	5685.64	95791.00	0.41
2007	0.86	766747.88	660762.03	17.06%	112726.00	685516.00	1.13
2008	0.86	60646.63	52065.80	17.06%	8882.42	39775.00	1.53
2009	1.01	126683.79	128369.83	17.06%	21899.89	44670.00	3.36
2010	1.05						
2011	1.04	935742.07	969585.09	17.06%	165411.22	645642.00	1.76
2012	0.99						
	1.008					Average Rate=	1.22

Unit Costs of 49 Road Sections Performed by In-House Method

SN	Name of Roads	Average Unit Costs	Average Unit Costs/YR	AADT	Average Unit Costs/YR/1,000 AADT
1	SR XXX CH	1.49	0.28	2965	0.09
2	SR XXX HU	1.06	0.20	370	0.53
3	SR XXX CL	0.84	0.16	1050	0.15
4	SR XXX CL	1.00	0.19	2340	0.08
5	SR XXX EL	1.00	0.19	175	1.07
6	SR XXX EL	1.25	0.23	13125	0.02
7	SR XXX EL	1.46	0.27	137	1.98
8	SR XXX EL	0.92	0.17	160	1.07
9	SR XXX ES	1.00	0.19	50	3.71
10	SR XXX NY	0.81	0.15	50	3.00
11	SR XXX EU	1.17	0.22	700	0.31
12	SR XXX LA	1.05	0.20	1650	0.12
13	SR XXX LN	1.17	0.22	1600	0.14
14	SR XXX NY	1.13	0.21	1200	0.17
15	SR XXX WP	0.64	0.12	1300	0.09
16	SR XXX LY	1.81	0.34	617	0.55
17	SR XXX MI	1.84	0.34	1083	0.32
18	SR XXX MI	1.33	0.25	100	2.47
19	SR XXX NY	1.47	0.27	275	1.00
20	SR XXX NY	0.55	0.10	350	0.29
21	SR XXX LN	0.99	0.18	250	0.74
22	SR XXX NY	1.00	0.19	200	0.93
23	SR XXX NY	1.25	0.23	150	1.55
24	SR XXX PE	0.75	0.14	250	0.56
25	SR XXX WA	0.95	0.18	20775	0.01
26	SR XXX WA	1.87	0.35	933	0.37
27	SR XXX EL	1.09	0.20	5600	0.04
28	SR XXX CL	0.89	0.17	15000	0.01
29	SR XXX CH	1.10	0.21	430	0.48
30	SR XXX DO	1.68	0.31	6067	0.05
31	SR XXX EU	1.13	0.21	265	0.80
32	SR XXX LY	1.29	0.24	400	0.60
33	SR XXX LY	1.79	0.33	150	2.22
34	SR XXX LY	1.57	0.29	350	0.83
35	SR XXX PE	2.65	0.49	700	0.70
36	SR XXX WP	1.12	0.21	90	2.32
37	USXX NY	1.22	0.23	450	0.50
38	US XX ES	0.88	0.16	625	0.26
39	US XX MI	1.38	0.26	675	0.38
40	USXX CH	1.42	0.26	6709	0.04
41	US XX EU	0.82	0.15	950	0.16
42	US XX LA	0.81	0.15	1017	0.15
43	US XX LY	1.00	0.19	10922	0.02
44	US XX WP	0.92	0.17	4383	0.04
45	US XX EL	1.18	0.22	1450	0.15
46	US XX LN	0.95	0.18	1650	0.11
47	US XX WP	1.23	0.23	3758	0.06
48	US XX HU	1.54	0.29	3175	0.09
49	US XX WA	1.21	0.22	17589	0.01
	Average Cost	1.20	0.22	2740	0.64

Appendix K

Determination of Striping Cost Percentage

SN	Description	Total Estimated cost	Striping Cost	Striping Cost (%)	Road Sections	Total Contract Cost
1	Contract 1-D1	2,005,607.00	209,480.67	10.44%	SR 147 CL (34.61-41.79). US 93 CL(52.09-68), LN (109.79-132.03)	1811007
2	Contract 2-D3	8,492,533.56	1,093,700.78	12.88%	SR 225 EL(68.89-94.37), US 93 EL(11.80-44), SR 305 LA (69.35-97), SR 140 HU(0-14.94, 34-56), SR 893 WP (0-39.75)	6695007
3	Contract 3-D2	1,627,747.31	219,666.66	13.50%	SR 341 LY(0-4.9), US 95 LY(0-2.67, CH 0-15.75, MI83.16-92.56)	1139007
			Average Striping	12.3%		

Appendix L

Photographs of Chip Seal Works

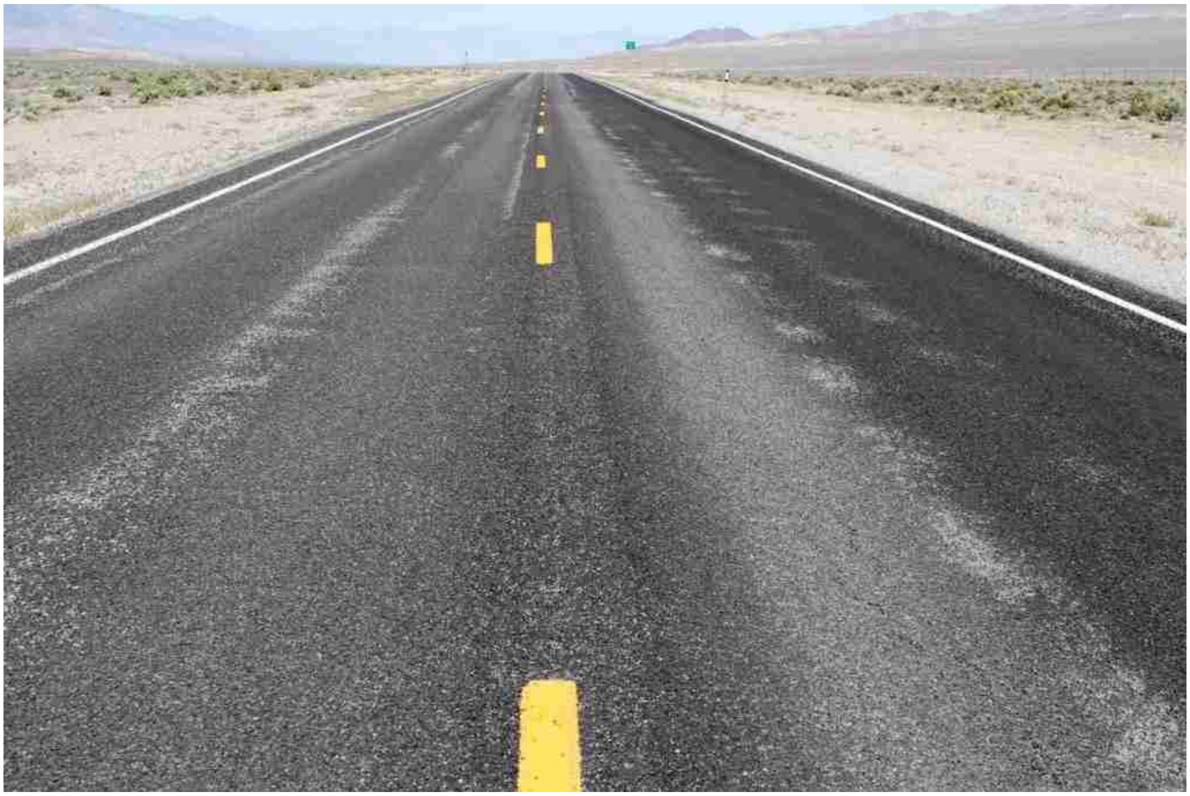
Chip Seal, State Force, US 93 LN County 2012

Chip Seal, State Force, SR 266 ES County 2012

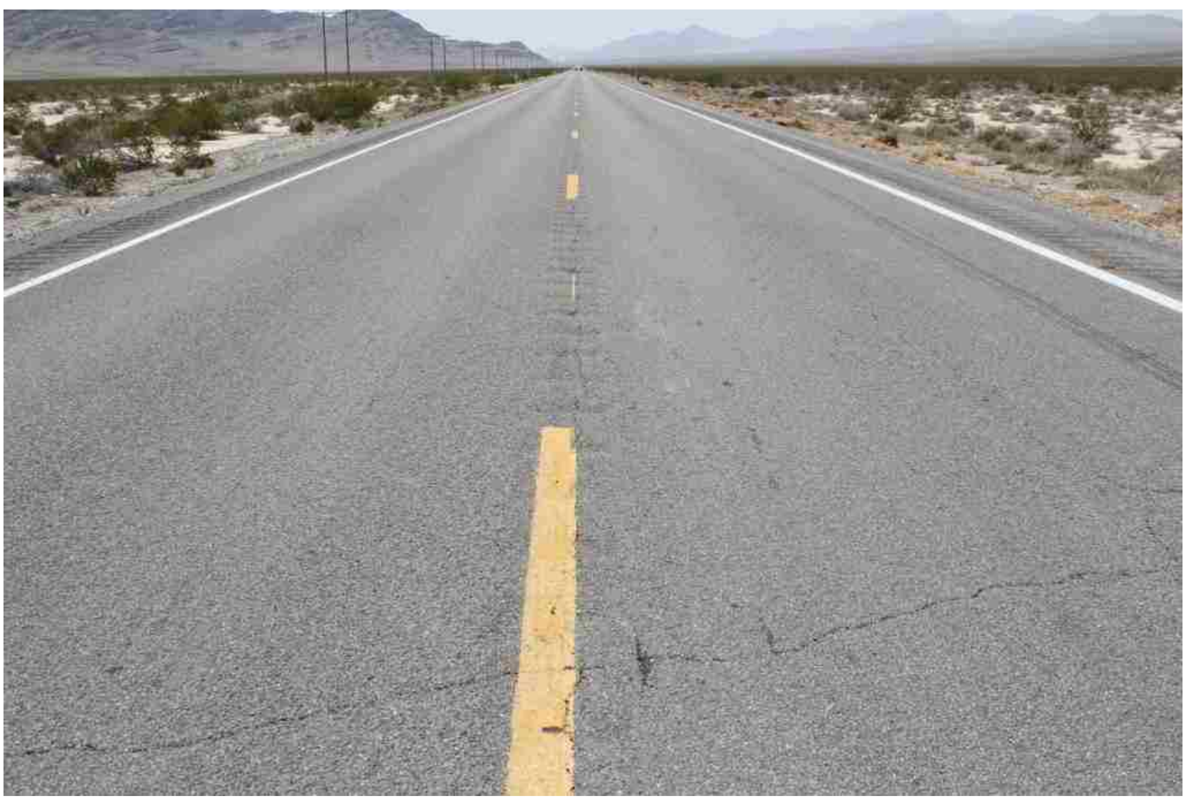
Chip Seal, State Force, US 93 EL County 2011

Chip Seal, State Force, US 6 NY County 2011

Chip Seal, Private Contract Work, SR 121 CH County 2014



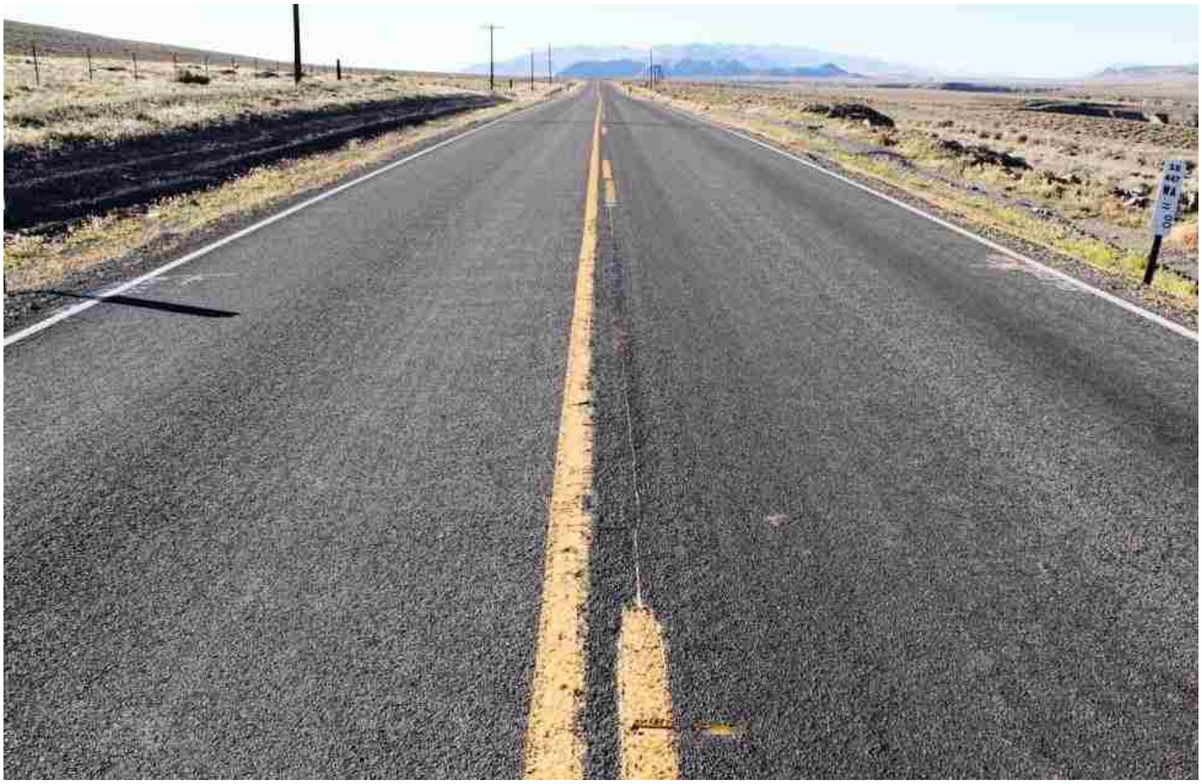
Chip Seal, Private Contract Work, US 93 CL County 2012



Chip Seal, Private Contract Work, US 93 LN County 2012

Chip Seal, Private Contract Work, SR 305 LA County 2012

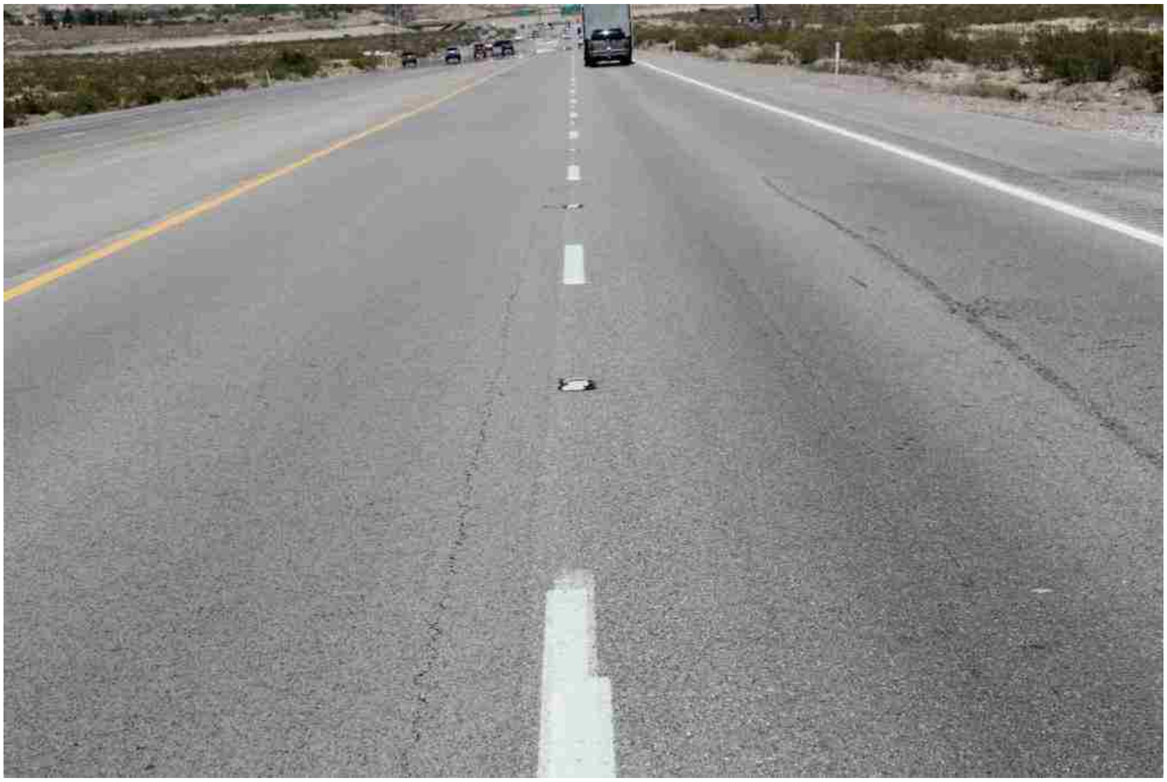
Chip Seal, Private Contract Work, SR 447 WA County 2013



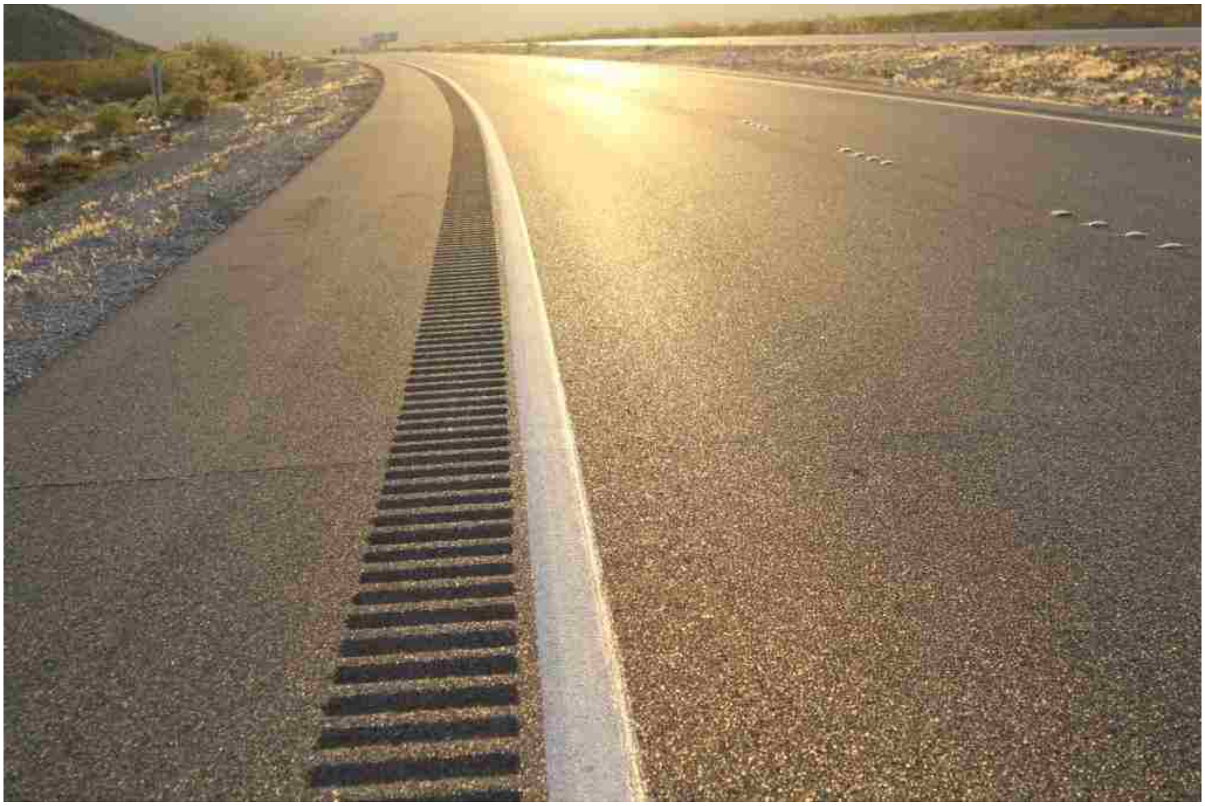
Chip Seal, Private Contract Work, SR 225 EL County 2014

Appendix M

Photographs of Striping Works
Striping, State Force Work, US 95 CL County 2012



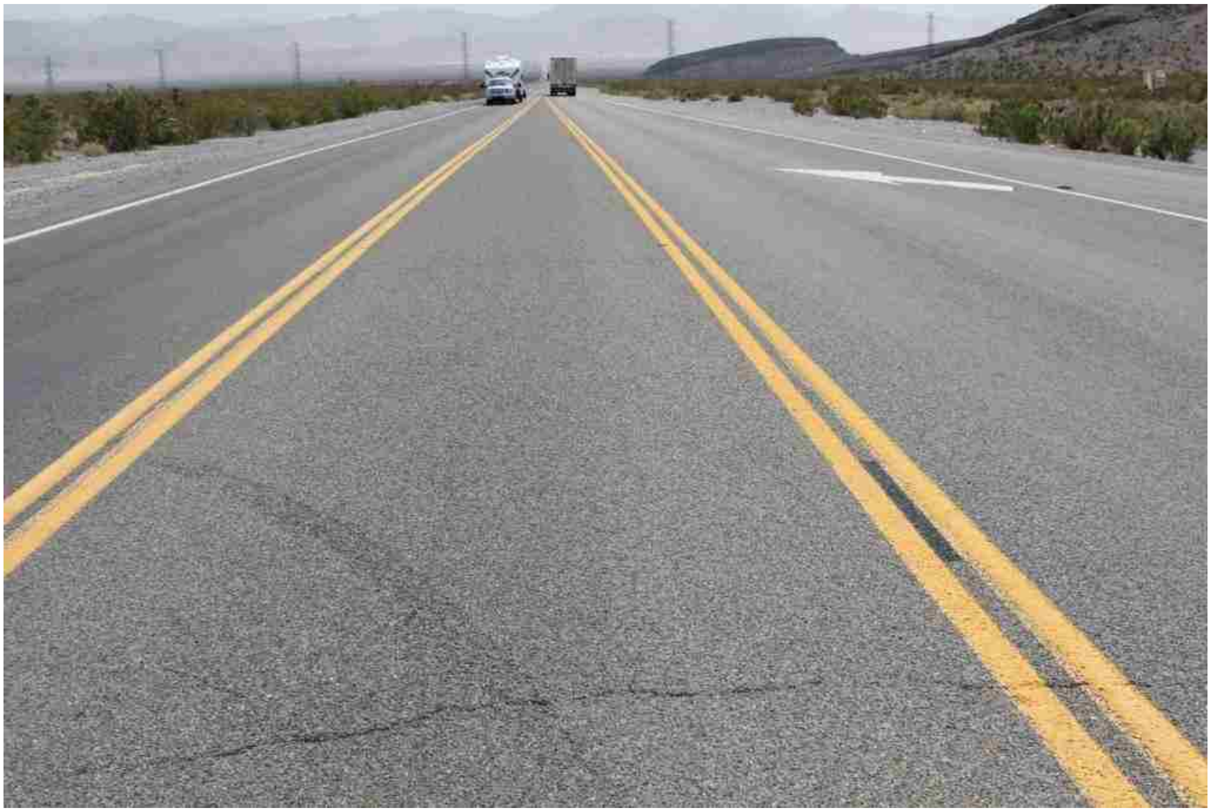
Striping, State Force Work, SR 163 CL County 2012



Striping, State Force Work, SR 160 CL County 2013

Striping, State Force Work, US 95 CL County 2013

Striping, Private Contractor Work, US 93 CL County 2011



Striping, Private Contractor Work, US 95 CH County 2011


US
95
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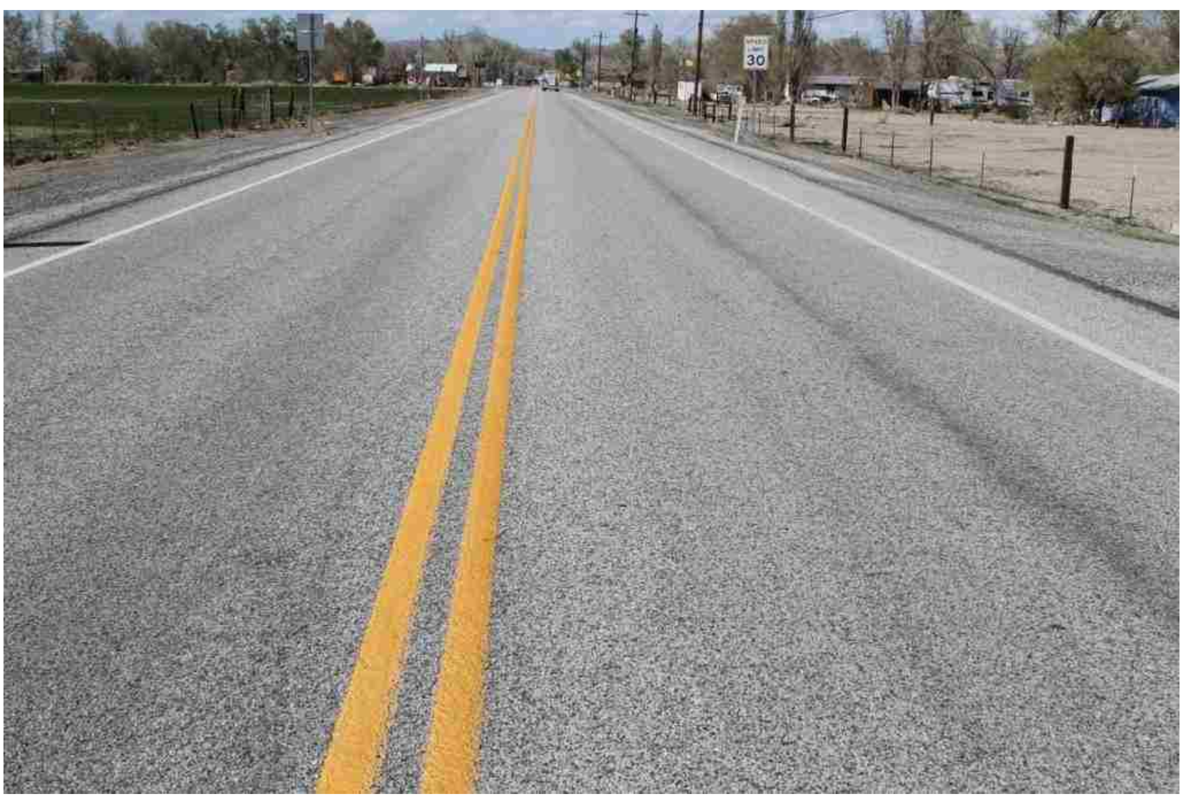
00

Striping, Private Contractor Work, US 93 LN County 2011

Striping, Private Contractor Work, US 95 MI County 2011



Striping, PBC Contractor Work, US 95 CL County 2012-2017

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Curriculum Vitae

Date: April 2016

Kishor Shrestha, Ph.D.

4441 Escondido Street

University of Nevada, Las Vegas

Las Vegas, NV, 89119

Office Phone: (702) 895-3808

E-mail address: kishor.shrestha@unlv.edu

yeskishor@hotmail.com

Education:

University of Nevada, Las Vegas

Ph.D., Civil and Environmental Engineering, May 2016

M.S., Construction Management, May 2012

Ph. D. Dissertation Committee:

Pramen P. Shrestha, Ph.D., P.E.

Aly Said, Ph.D., P.E.

David R. Shields, Ph.D., P.E.

Hualiang Teng, Ph.D., P.E.

Neil Opfer, MBA, P.D.

Ashok Singh, Ph.D.

Tribhuvan University

B.E., Civil Engineering, November 2006